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Communication with Teachers and Students

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53.1 Introduction

Particle physics is building on a rich history of long-term, collaborative, international experiments. These continue to seek answers to some of the most profound questions in science.

The technology used to make the measurements is often revolutionary, the computers and data storage techniques are cutting-edge, and the data analysis techniques are novel and untried. Like all basic research, particle physics constructs new knowledge for the field and develops technologies that can benefit society.

Scientifically literate societies support investment in science research. A June 2013 survey of American attitudes toward science [1] indicates that 74% of respondents answered strongly agree (32%) or somewhat agree (42%) to the question:

> "Even if it brings no immediate benefits, basic scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government."

The survey indicates broad support of the idea of federal support for basic research. The field must seek ways to turn this support of the idea of federal support into increased support.

The particle physics community is in a strong position to contribute to improvement of education and development of a technological workforce. The science is compelling and draws students and the public. The nature of the community is one of collaboration, rigor, and work on an international scale. And the particle physics community has a good start due to its efforts over the past decade. By inviting students, teachers, and the public into its community, particle physics can make a positive and enduring difference.

Working with learners of all ages, from school children to interested seniors, increases their excitement and interest in science, and leads to better appreciation of the societal value of basic research, gaining advocates for our field. It also helps develop knowledge and critical thinking to help them make informed decisions in their daily lives on technological issues that affect society as a whole.

Another important resource for a healthy particle physics community is a talented and diverse workforce. Whether a students career path leads them to graduate school and research or into another STEM-related field, particle physics provides a fertile training ground.

The three overarching goals for the CE&O Working Group articulate all of these elements. One way to realize these goals is an increased presence of particle physics concepts everywhere students learn: in school, at home, in the community and on the Web. Educators and students should learn directly from research scientists about their exciting work, using tools that are grounded in education research. There should be

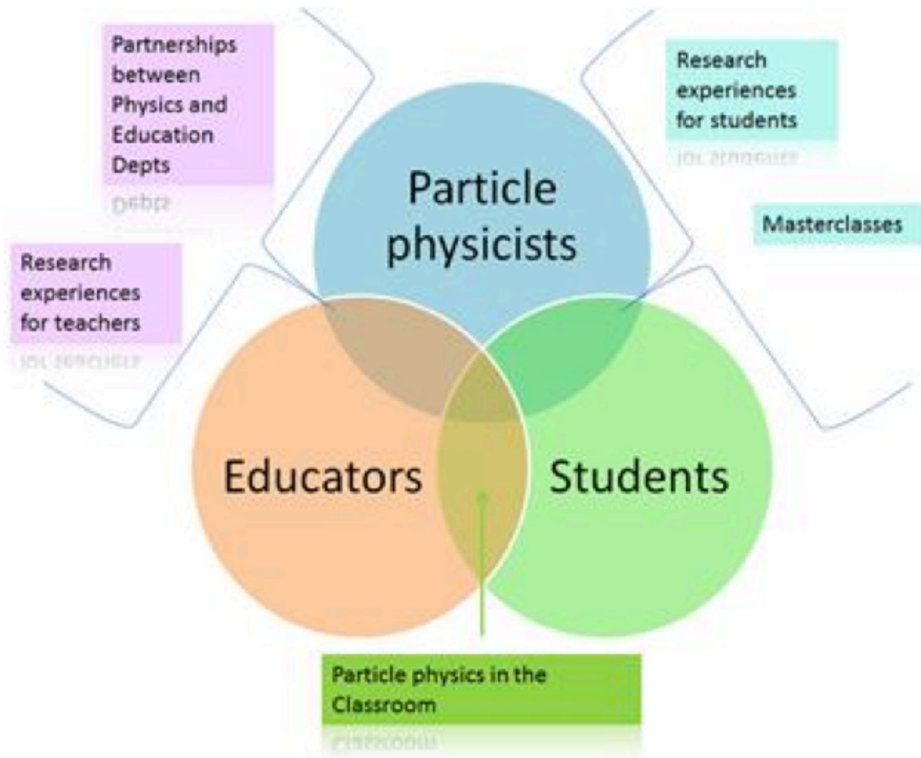

Figure 53-1. *A vision for inviting student and educators into the particle physics community.*

vertical integration of opportunities for students to be exposed to particle physics, in line with the vertical integration of the Next Generation Science Standards (NGSS) [2], from elementary school through high school. These opportunities should continue through the undergraduate level, with particle physics hooks in introductory, education and other non-major courses, and research opportunities not only for future physicists but for future and current teachers.

The Teachers and Students Subgroup of the CE&O Working Group embarked on a several month process of fact finding and pulse taking of particle physicists, educators and education specialists as laid out in Appendix B. We recommend that educators and students need to be invited into the particle physics community at all levels. Fig. 55-1 articulates our vision for the future. In order for this to happen, resources need to be provided, for example:

- Ways to facilitate particle physicistsincorporation of best practices from education research when the work with students and educators;
- Particle physics resources for teachers aligned with the NGSS standards at all grades.
- Professional development courses for elementary and middle school teachers incorporating particle physics concepts

We recommend that the particle physics community devote resources to implement a website to implement these steps will enable the best use of precious resources and facilitate communication among all parties.

53.2 Educating a new generation

53.2.1 Overview

The particle physics community has an important role in workforce development. There has been considerable progress in the past ten years. Student enrollment in physics at all levels has been increasing and opportunities for students to learn about science by doing science have blossomed. Particle physics-related programs such as QuarkNet [3] have been at the forefront.

Appendix A presents details of the physics workforce and pipeline in the United States from American Institute of Physics reports [4, 5, 6]. For particle physics specifically, PhD numbers have been tracked in the National Science Foundation Survey of Earned Doctorates [7]. Other data comes from a High Energy Physics Advisory Panel (HEPAP) subcommittee which looked at the workforce most recently in 2011 [8].

Training the next generation of particle physics — as well as a technologically knowledgeable workforce meeting other national needs — begins in the context of general science education in elementary school. As a student progresses through middle school into high school, she solidifies her science and engineering practices and knowledge. Whether taken in high school or as undergraduate, Introductory physics courses should engage and challenge her, and introduce her to physics research, if not through a research experience then by including access to authentic scientific data in the classroom. Whether she continues into graduate school or enters the workforce, she will have a strong background in problem-solving and understands and appreciates what physics brings to society.

53.2.2 Achievements since the last decadal plan

Elementary particle physics had many triumphs during the last decade, many of which have received national and international press coverage and inspired educators and a new generation of students. In 2012, the discovery of the Higgs Boson was chosen as the breakthrough of the year by Physics World magazine [9]. Included in the runner-up list was the BaBar experiment, for its direct observation of time-reversal violation, and a collaboration from North Carolina State, the MINERvA Experiment at Fermilab, and NASA, for being the first to demonstrate communication using neutrinos. In 2011, neutrino oscillation measurements at T2K and a calculation of the condensation temperature of the early universe made the list of top ten breakthroughs [10]. Also in 2011, Astrophysicist Saul Perlmutter won the Nobel prize in physics for the discovery of the accelerating expansion of the universe through observations of distant supernovae [11]. In 2013, The Daya Bay Reactor Neutrino Experiment reported evidence that electron neutrinos change into muon neutrinos; the effect was large enough that it increases the probability that researchers will be able to see the differences between matter and antimatter in future experiments [12].

The number of students entering graduate school in particle physics has remained at a healthy levelin spite of the fact that many of the experiments highlighted above took place outside of the U.S. Approximately 1/3 of the 200 students a year earning a PhD in particle physics remain in the field as postdocs; the remainder enter the workforce in various capacities. The Young Physicists group formed for the Community Planning Process conducted a survey and presented the results at the Snowmass on the Mississippi meeting [13]. 956 respondents were identified as being in the early stages of their careers. Of these, the most were still pursuing careers in particle physics; only 74 respondents were among the 2/3 whom left the field after receiving their degrees. Of that small sampling, the most common careers were in consulting, finance and data analysis, and the skills that respondents stated were most useful were programming, data analysis, and statistical analysis followed by oral communication.

While the number of graduate students in particle physics has increased slightly, the total number of students entering graduate school in physics has seen a more dramatic increase, 22% between 2006 and 2011.This is consistent with the number of physics majors at the undergraduate level, which has shown a sharp increase in the last decade, from a historic low of less than 4000 bachelors degrees awarded in 1999 to over 6200 in 2011. The number of physics majors in colleges increased to the point that "Physics Department Chairs are scrambling to meet the demand" [14].

The demand for physics high school teachers is enormous. Of all sciences taught at the secondary level, physics has the greatest shortage of qualified teachers: fewer than half of the 27,000 high school physics teachers in the U.S. have completed a major or minor in physics or physics education [15]. Programs such as the Physics Teacher Education Coalition (PhysTEC), a joint project of the American Physical Society (APS) and the American Association of Physics Teachers (AAPT) are working with university Physics Departments to help meet that demand [16].

In the last decade, science and engineering education has received much attention. Numerous studies, many commissioned by the National Academies, produced comprehensive reports on the needs for training more students for Science, Technology, Engineering and Mathematics (STEM) careers, for training more science teachers, and for best practices, including evaluation, in teaching science from K-8 to college. Some of the reports relevant to science and physics education include:

- Rising Above the Gathering Storm, 2005 — the pivotal report [17]
- Americas Lab Report, 2005 — investigations in high school science [18]
- Ready, Set, SCIENCE!, 2007 [19]
- Taking Science to School: Learning and Teaching Science in Grades K-8, 2007 [20]
- Learning Science in Informal Environments, 2009 [21]
- Rising Above the Gathering Storm, Revisited, 2010 [22]
- Preparing Teachers, 2010 [23]
- Gender Differences at Critical Transitions in the Careers of Science, Engineering and Mathematics Faculty, 2010 [24]
- Expanding Underrepresented Minority Participation, 2011 [25]
- Successful K-12 STEM Education, 2011 [26]
- Monitoring Progress towards Successful K-12 Science Education, 2012 [27]
- Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering, 2012 [28]
- A Framework for K-12 Science Education, 2012 [29]
- Engage to Excel: Producing One Million New College Graduates with Degrees in Science, Technology, Engineering and Mathematics, 2012 [30]
- Adapting to a Changing World – Challenges and Opportunities in Undergraduate Physics Education, 2013 [31]

- Next Generation Science Standards: For States, By States, 2013 [2]
- Transforming the Preparation of Physics Teachers: A Call to Action, A report by the Task Force on Teacher Education in Physics, 2013 [32]

Research on science education produced recommendations at all levels, recognizing e.g., higher than previously assumed ability of abstract thinking of K-8 children [20]. Active learning was recommended at all stages [33, 34]. Experts generally agree on the "Research Based Instructional Strategies" (RBIS), and some physics departments have reformed their teaching accordingly [34]. This includes education of future physicists as well as future science teachers [35, 36]. Evaluation has become an important part of all work, from undergraduate education research through informal education programs.

The physics education community and the particle physics community have stepped forward to improve K-12 education in impressive ways. Much of the work has centered on professional development for teachers; while much remains to be done, there has been real progress. Some examples of efforts in K-12 Education follow. As in the previous decadal report [37], a comprehensive listing of the many excellent programs is beyond the scope of this effort.

> The American Association of Physics Teachers has worked with the NSF to offer workshops facilitated by specially-trained **Physics Teaching Resource Agents** (PTRAs), who have worked with teachers in underserved urban and rural communities to build teacher capacity and give teachers tools so that their students can have meaningful, hands-on, and inquiry-based experiences [38]. The result is that a cadre of master teacher-facilitators has been created and teachers who had insufficient resources and limited training were enabled to develop more of what they need to teach physics effectively at the high school level [39]. Among the honors the program team was given is the Excellence in Physics Teaching Award in 2011 by the APS Forum on Education [40]. The PTRA program has given at least one week of professional development to 1904 teachers since 2005 and in the past twenty years has touched 6120 participants.
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> **QuarkNet** [3] is a high school teacher development program(funded by NSF and DOE) initiated and developed by the particle physics community. Started in 1999, QuarkNet has more than spanned the time since the last Snowmass meeting (and, indeed, was present at it). QuarkNet brings data and methods from particle physics to the high school physics classroom. The aim is to bring particle physics and reform from educational best practices into the classroom through teacher development and engagement with students. The program is comprised of 54 QuarkNet centers.These are designed to be learning communities; teachers work together with local particle physicists as mentors. Each center operates differently in detail but the overall structure includes:
>
> - two mentors
> - two lead teachers who started QuarkNet with summer research experiences and a one-week intensive particle physics boot camp at Fermilab
> - approximately ten associate teachers.
>
> The center has some similarities to a particle physics research group: connection to large particle physics experiment, specified areas of inquiry, and international collaboration. The centers and their teachers and mentors are knit together by a small national staff; each center is associated with a staff member who helps them accomplish their goals. While some teachers leave a center after a year or two and others join after the center is established, the goal and reality are long-term involvement. Research shows that reform in educational practices occurs with such long term involvement.

The QuarkNet program was in its growth phase from 1999 through 2004, starting with 25 new lead teachers. From 2004 to 2011 the program averaged 526 teachers each year. The integrated number of teacher-years is 5710. Given that each teacher can reach more than 100 students in a given year, the program has worked with the teachers of over half a million students.

QuarkNet has afforded critical opportunities to teachers and students. Each year 20-30 teachers have had the opportunity to attend a week-longBoot Camp at Fermilab; attend the High School Teachers program at CERN through a University of Michigan RET award [41]. Teachers and students have been able to create in-school research groups centered around cosmic ray detectors and a cosmic ray e-Lab, both made available by QuarkNet. The number of these student research groups is now well over 2000. Additionally, over 2000 students have participated in International Particle Physics Masterclasses [42] through QuarkNet since 2006. Data indicate that this has increased interest in and knowledge of particle physics.

QuarkNet has modeled the international nature of particle physics research by giving students and teachers opportunities to work with international colleagues in masterclass videoconferences and cosmic ray collaboration. It has also been a collaborator in international particle physics education and outreach, responsible for the design of a highly successful cosmic ray detector system used worldwide as well as the for the design and implementation of the CMS masterclass that is the CMS contribution to International Masterclasses.

These two examples (PTRA and QuarkNet) are not nearly exhaustive but represent two poles: a major program to improve general physics education and a unique, major contribution by the particle physics community.

Some examples of programs directed at undergraduate physics education follow:

The **Physics Teacher Education Coalition (PhysTEC)** [16], a partnership between the APS and the AAPT, funded primarily by the National Science Foundation, is an example of a project participating in, and driving the reform of physics teacher education. PhysTEC funds 29 participating universities to develop physics teacher preparation programs into national models. The companion organization PTEC, comprises 287 institutions dedicated to improving and promoting physics and physical science teacher education.An example of their work is the recently released report, Transforming the Preparation of Physics Teachers: A Call to Action [32]. Model programs include, for example,Pedagogical Content Knowledge (from Rutgers), Learning Assistant Program (from Boulder, Colorado; Minneapolis, Minnesota, and others, see below), UTeach teachers preparation program (Austin, Texas) [43].

The **University of Colorado at Boulder Learning Assistants (LA) Program** [44, 45] was created in 2003 and is now a model for many schools throughout the nation. The transformation of large-enrollment courses involves creating environments in which students can interact with one another, engage in collaborative problem solving, and articulate and defend their ideas. To accomplish this, undergraduate LAs are hired to facilitate small-group interaction in large-enrollment courses. The program hires dozens of undergraduate LAs each semester. LAs who decide to pursue a K-12 teaching license are eligible for scholarships. By employing undergraduate students as LAs, the program aims to both improve introductory math and science classes and recruit and train future K-12 science and math teachers.

The **University of Illinois Introductory Physics Sequence**; approximately 6500students each year take the calculus based introductory physics sequence, their gateway to engineering. A team of Physics faculty members has focused on improving and modernizing the sequence, looking to research in physics education for guidance, and applying particle physics analysis techniques to test improvements at each step. The current version of the course [46] includes pre-lecture tutorials and assessments, with feedback before, during and after lecture. It redefines the interaction between students, instructors, and course content - inside and outside of lecture. Students are better prepared, and instructors can access powerful data to understand their students' strengths and weaknesses. The three leaders of this reform received the APS 2013 Excellence in Physics Education Award *"For the creative application of physics education research results with components of modern technology to create a new pedagogy for an introductory physics curriculum that substantially changes the roles of the instructors and students and, as measured through research, provides significant and nationally recognized learning benefits."* [47].

There are many opportunities for dissemination of successful programs and important findings. American Association of Physics Teachers (AAPT) with its state affiliates, and Physics Education sessions of the American Physics Association (APS) meetings offer a platform for exchanging information, in addition to the dedicated section of the Physical Review Special Topics – Physics Education Research. Starting in 2006, the APS has established the Excellence in Physics Education award to recognize and honor a sustained commitment to excellence in physics education.

53.2.3 Particle physics as a training ground for a STEM workforce

53.2.3.1 Undergraduate level

In 1999, the Boyer Commission on Educating Undergraduates released the report, 'Reinventing Undergraduate Education: A Blueprint for Nations Research Universities' [48]. One of the reports major recommendations was to involve more undergraduates in the research mission of the university. Many universities embraced this recommendation, and the number of undergraduate opportunities to participate in research has increased in the last decade.Many research groups offer research opportunities to undergraduate and high school students in the belief that these opportunities draw students to considering research careers, and foster their interest. Additionally, there has been recognition of the value of students presenting the results of their research at science meetings [49]. As working physicists, we know many examples of students who discovered through doing that they like research and that they are good at it.

The National Science Foundation and the Department of Energy Office of Science both recognize the value of undergraduate research and fund such internships through, in the case of NSF, the Research Experience for Undergraduates (REU) grants to university departments and, in the case of DOE, the Science Undergraduate Laboratory Internship (SULI) program.

In 2011, the DOE SULI program funded 592 students from four-year colleges and universities and an additional 18 students from two-year colleges at 13 national laboratories for either semester or summer research opportunities [50, 51]. These numbers cover all areas of research conducted at the national laboratories and numbers are not available forparticle physics in particular.

NSF currently supports REU programs in physics at 63 institutions, of which 32 of these include research topics with the key words 'particle', 'high energy' or 'astrophysics' [52]. Some of the grants are for international travel, for example, the University of Michiganruns a CERN Summer Research Experiences for Undergraduates program which gave 18 students in 2012 an opportunity to work with research groups at CERN. [41] The University of Michigan has followed up the alumni of their program, who are recruited from a diversity of universities, including historically black colleges and universities (HBCU). In 2003, an extensive survey shows that the proportion of students being very likely to apply to graduate school went from 78% in pre-surveys to 100% in post-surveys [53]. Students also indicated that the REU program helped them clarify and refine their science plans. Of the 12 REU 2010–2012 participants who completed their undergraduate programs, only one has left the STEM fields, two are pursuing internships, while 9 are in graduate programs (civil engineering, astronomy, physics, applied physics, mathematics, medical physics) [54].

The Presidents Council of Advisors on Science and Technology [30] recommended that resources be put in place to address the issue of retention in STEM majors in the first two years of college. Across all STEM fields, more than 40% of students who declare STEM majors upon entering college abandon them before their junior year [55]. The report pointed out that improving this number would go a long way towards meeting the needs of the nation for a STEM-trained workforce in the future.

Improving the climate for physics majors during their first two years helps make them feel part of a community and encourages them in their studies. Organizations such as the Society of Physics Students (SPS) [56] provide a conduit for this endeavor. For female students and others who may feel like a minority within a department, targeted undergraduate conference experiences such as the regional Conferences for Undergraduate Women in Physics (CUWIP) [57] — funded by the NSF and the DOE Office of Science — provide an opportunity to network with other female undergraduates and role models. The program has grown from three sites in 2010 to eight planned for 2014.

Most research internships target students in their last two years of college. Programs for freshmen and sophomores that introduce students to the nature of physics research and what a research scientist actually does, can serve to motivate them to get through their introductory courses. In South Dakota, the Sanford Underground Research Facility (SURF) has partnered with the state of South Dakota - with funding from the 3M Corporation and the NASA Space Grant Consortium - to offer an expense-paid summer enrichment program for rising freshmen and sophomores declaring STEM majors [58]. The participants learn modern physics and hear from scientists and graduate students working on cutting edge research at SURF. They then spend two weeks traveling to science laboratories in Europe and the United States for lectures and tours. In the five years of the program, groups of students have visited CERN, Gran Sasso and Frascati laboratories in Europe, and Princeton, Brookhaven, Fermilab, Argonne, University of Chicago and University of Notre Dame in the U.S. In the summer of 2013, students encountered alumni of the program interning at SURF, Argonne (with the ATLAS group) and Notre Dame. The program has served 89 students since its inception, three of whom are now in graduate school in physics and numerous others in graduate schools and professional schools across the STEM disciplines.

53.2.3.2 High School Level

In order to attract the best and brightest into particle physics, students need to be inspired to consider physics, and in particular particle physics, as a career. Unfortunately, particle physics is not part of a typical high school physics curriculum; even AP classes focus on classical Newtonian mechanics and some electromagnetism. This can leave students with the impression that advances in physics ended with the discovery of radioactivity and the modern model of the atom.

The particle physics community is in a strong position to contribute to improvement of education and development of a technological workforce. The science is compelling and draws students and the public. The nature of the community is one of collaboration, rigor, and work on an international scale. And the particle physics community has a good start due to its efforts over the past decade. By inviting students, teachers, and the public into its community, particle physics can make a positive and enduring difference.

Research opportunities can attract and motivate students still in high school. A survey of 15,000 undergraduate students, and faculty mentors in 2002-2003 by SRI International concluded that [59]

> The large number and variety of students surveyed represented a variety of colleges and universities. Many types of undergraduate research experience fuel interest in STEM careers and higher degrees. No formulaic combination of activities optimizes the URO, nor should providers structure their programs differently for unique racial/ethnic minorities or women. Rather, it seems that the inculcation of enthusiasm is the key elementand the earlier the better. Thus, greater attention should be given to fostering STEM interests of elementary and high school students and providing UROs for college freshmen and sophomores.

While research opportunities for high school students are much less abundant than those for undergraduates and often are limited to students within commute distance of a campus or laboratory many programs exist at universities and national laboratories. Summer programs reach hundreds of students in communities around Argonne, Brookhaven, LBNL, Fermilab and other sites. Opportunities span the breadth of research taking place at each laboratory, including particle physics. Some universities also include high school internships as a small component of REU programs, using the undergraduates as mentors for the high school students. QuarkNet includes a high school research summer componentin some of its centers, with QuarkNet teachers acting as mentors. An estimated 200 high school students took part in this program in 2013 [60].

A comprehensive listing of high school internship opportunities in physics and/or particle physics does not currently exist and is beyond the scope of this document. However, such programs reach into the local community and generate interest and goodwill among parents and educators. They also create loyalty among students who see themselves as possibly returning to the laboratory or campus in the future as a researcher [61].

Enrichment courses offered within university physics departments can be used to introduce students to particle physics outside the classroom. Since 1990, the Physics Department at University of Maryland, for example, has offered a two-week course for high school girls; rising 9th graders study classical physics, while rising juniors and seniors study modern physics [62]. Physics of Atomic Nuclei, a program that has recruited teachers and high school students from around the country to Michigan State University each summer since 1986 [63], has a small component of particle physics included in a course that focuses on nuclear physics and astrophysics.

Motivated teachers can increase the inclusion of particle physics in a high school physics class.This motivation can come from exposureto the topic, perhaps through a local QuarkNet center or a research experience at a national laboratory. Additionally, the DOE Office of Science awards Albert Einstein Fellowships for teachers to spend a year at DOE [64]. NSF sponsors Research Experience for Teachers programs at university departments.

Additionally, online resources make it much easier for high school teachers to introduce particle physics into the standard high school curriculum. Some recent examples include:

- The **Cassiopeia Project** [65] — The Cassiopeia Project is an effort to make high-definition science education videos available to anyone who wants them. For example, the video on the standard model can be viewed in its entirety (15 minutes), or there are short videos on the individual particles, with a five-minute video on the Higgs.
- **Physics for the 21st Century** [66] — Annenberg Learners multimedia resources help teachers increase their expertise in their fields and assist them in improving their teaching methods. Many programs are also intended for students in the classroom and viewers at home. Physics for the 21st Century is an 11-unit online course that explores dark matter, string theory, particle accelerators and other big topics in modern physics, produced by the Harvard-Smithsonian Center for Astrophysics Science Media Group in association with the Harvard University Department of Physics.

Activity	Data used	Fundamental concepts
Top Quark	D-Zero	Momemtum and mass-energy conservation, vector sums
Mass Calculation: Z	CMS, ATLAS	Momentum and mass-energy conservation, vector sums
Plotting LHC Discovery	CMS	mass plots, histograms
Investigating Accelerators	Tevatron	Relativistic energy and momentum, Lorentz force, accelerator design
What happens when things go near the speed of light?	Fermilab E687	Special relativity
Seeing Particles	CERN 2m bubble chamber	Particle and process ID
Identifying interesting particles at LEP	OPAL	Particle ID, conservation of momentum
Cartoon Muon Solenoid	CMS	Particle ID, conservation of momentum and energy, how detectors work

Table 53-1. *Sample activities using particle physics*

- The **Perimeter Institute for Theoretical Physics** [67] — Perimeter Institute shares ideas with students, teachers, and like-minded people through programs and resources that communicate the power, joy, and mystery of science. They have developed units on dark matter and the subatomic world that include videos, games and lesson plans. DVDs are free to Canadian teachers.
- The **Particle Adventure** [68] — This award-winning website aimed at high school students introduces the Standard Model. In the form of an interactive tutorial, the site was developed by the Contemporary Physics Education Project [69] to go along with their particle physics wallchart.

Useful sets of links for particle physics lesson plans and online resources have been compiled by QuarkNet [70] and by ComPADRE [71], the national digital library for physics resources. The more those resources can tie into the NGSS standards the more useful they will become.

53.2.4 Using data from HEP experiments to teach fundamental concepts

QuarkNet is constructing a so-called "Data Portfolio." This includes multiple pathways for students to learn physics through particle physics data. The learning experiences in the portfolio range from those that use just a few datum (activites) to those that use many thousands (masterclasses) and longer-term projects that investigate larger data sets (e-Labs).

53.2.4.1 Activities

There are a number of activities [70] that have been developed that use LHC and other particle physics data so that students can apply basic physics to elementary particles — or, rather, use elementary particle physics as a way for students to learn basic physics in an exciting, data-based approach. Some examples are included in Table 53-1.

53.2.4.2 Masterclasses

Masterclasses [43, 72, 73] enable high school students to be "particle physicists for a day". They spend a day at a masterclass institute where, under the mentorship of particle physicists, they learn about an experiment and analyze the data, discussing their conclusions at the end. This is followed by a videoconference with 2–4 other masterclass institutes which have done the same analysis and moderators at CERN or Fermilab.

International Masterclasses started in Europe in 2005 [43] but were soon picked up by the United States. At that time, students analyzed LEP data to examine the branching ratios of the Z boson. In 2011, the International Masterclasses switched to LHC data with measurements from ALICE, ATLAS, and CMS. TOTEM and LHCb are also currently developing masterclass measurements. In 2013 there were 161 recognized international masterclasses; 29 were connected with Fermilab.

Evaluation has shown that students learn particle physics content from masterclasses and enjoy the chance to see and work with data as physicists do. There are also many stories of the masterclass being the crucial element that convinced a student to study physics in university. There are already some masterclass alumni in graduate school for particle physics.

53.2.4.3 e-Labs

The CMS e-Lab [74] is an online platform in which students can create plots of real data from the 7 and 8 TeV runs of the LHC. CMS-released datasets thatinclude Z decays, J/ψ decays, and 100,000 dimuon events between 0 and 100 GeV. It will also soon include W decays and 100,000 dielectron events from 0 to 100 GeV. Students can make a variety of histograms based on quantities such as mass, transverse momentum, and pseudorapidity. Students can make cuts on the data, change bin size, and other manipulations and then see the effects. The CMS e-Lab provides scaffolding to enable students to use the tools and learn about what they are studying.

The CMS e-Lab works best when teachers have professional development that helps them become users so that they can facilitate the work of the students [75]. Using the e-Lab themselves and then working with students, teachers can see what can be done and how and when to guide students.

QuarkNet based the CMS e-Lab on the successful Cosmic Ray citerefseventysix and LIGO [77] e-Labs. These all have a similar look and feel and all run from a web browser.Data, analyses, and student posters are stored on the QuarkNet servers at ANL. Thus the e-Labs are accessible to almost any school in the U.S, and any with internet access [78].

53.2.4.4 Online CSV files

QuarkNet and CMS hav makee collaborated to make a large amount of CMS data available to the public. The files are in the form of four-vectors from decays of Z, W, J/, top, etc. This has been used in various venues, from Science Hack Days [79] to the QuarkNet Boot Camp to student summer research at Notre Dame. This growing data repository makes it possible for students to explore CMS and particle physics in open inquiry.

53.2.5 Particle physics in the non-major curriculum

Scientific literacy of the general public increasingly affects decisions that people must make about everything, from their response to different national energy policies, to their understanding of information technology, and national spending on science or space programs. They must evaluate scientific and technology news that affect them, such as medical advances. Physicists are driven to know how things work, and they love to share what they learn with everyone else. An increasing awareness of the need for scientific literacy, and physicists' love of learning and teaching have led many physics departments to offer courses for undergraduates not majoring in physics that familiarize students with modern physics and cosmology.

Most universities with strong physics and astronomy research programs have such courses. For example, the University of Minnesota offers modern physics in their Freshmen Seminars, e.g., "What is Everything Made of?", "Quantum Physics for Everyone", and "Exploring the Universe". Cornell has "Why the Sky Is Blue: Aspects of the Physical World". The University of Chicago has sequences of "Foundations of Modern Physics", "Everyday Physics" and "Stellar Astronomy and Astrophysics", "The Origin of the Universe and How We Know" for students who don't plan to major on physical sciences. Johns Hopkins University offers several successful survey courses for non-majors, including "Subatomic World", and "Stars and the Universe: Cosmic Evolution". The University of Notre Dame offers a course on "Modern Physics from Quarks to Quasars" for freshmen. Rich Muller of the University of California at Berkeley developed "Physics for Future Presidents", with an accompanying textbook [80]. The University of Illinois in Urbana-Champaign offers non-majors a course "Space, Time, and Matter" that reviews the origins of modern physics. University of Massachusetts (Amherst) introduces non-science majors to modern physics in the "Conceptual Physics" and in "Big Bang to Black Holes". The "Explore Courses" at Stanford have several courses on modern physics and cosmology, e.g., "Frontiers in Theoretical Physics and Cosmology" and "Symmetries of Nature: Inner to Outer Space".

Many four year colleges also offer such courses, e.g., Grinnell has "The Universe and its Structure", Carleton College offers "Revolutions in Physics", and Cal State at San Luis Obispo has "Contemporary Physics for Nonscientists". However, smaller schools often do not have sufficient physics faculty to be able to offer physics for non-majors in addition to teaching physics majors. In today's interconnected world there are opportunities to use technology so small colleges can create non-majors physics courses using access to online data, good videos, and videoconferences. There is also an opportunity for particle physicists — perhaps through DPF and AAPT — to help create content for such courses.

To our knowledge, while such courses are often very popular with the students, no studies exist on the impact of such courses on the students. Developing measures and evaluating these courses would be desirable.

53.2.6 Particle physics as a training ground for K-12 teachers

Every child starts out curious. Formal science education can develop or destroy this curiosity. Science education of K-12 teachers plays a crucial role in this process. Schools of Education teach methods, but their students often lack knowledge about the content of physical sciences. Many physics departments collaborate with Education faculty to develop courses that address this problem. Collaboration between Physics and Education is crucial to success in this endeavor. Here we describe several examples of successful physics courses for future elementary education teachers:

> The **School of Physics and Astronomy of the University of Minnesota** is well known for its contributions to physics education [81]. It has developed a special undergraduate major

emphasis, "Physics with a Teaching Emphasis for students interested in teaching secondary school physics. Working with faculty in the College of Education, the School developed a laboratory-based, active learning physics course for pre-service elementary education majors, taught by physics faculty, and based on the Constructing Physics Education (CPU) modules.

At the **University of Wisconsin at La Crosse** [82, 83] scientists and K-12 teachers collaborate on preparing future science teachers. They conducted workshops to prepare for the Next Generation Science Standards. Assistant Professor Jennifer Docktor, a researcher in Physics Education, teaches a physics course for Elementary Education majors. For this and many other improvements, the Department received the APS Award for Improving Undergraduate Physics Education in 2013 [84].

At the **University of Illinois in Urbana**, working with the School of Education Physics Professor Mats Selen developed a "Physics Made Easy" course for Elementary Education Majors [85]. High on Selen's list was making future teachers believe that even when they don't know answers, they can find out. The course is taught using active learning, and provides the students with simple inexpensive experiments that they can take straight to their classrooms. The course has trained 1000 students in 10 years. If all became teachers, over 100,000 school children would already have been taught by a Physics 123 alumnus. Thats the power of the multiplier effect of training teachers!

Institutional support is essential to bring more physicists to work on outreach or improving education. A case history is helpful in illustrating this point. At the University of Illinois, Urbana-Champaign (UIUC) in mid-1990s, the department head David Campbell convinced his colleagues to start several outreach efforts and to work on modifying their large-lecture traditional approach to introductory physics [86, 87]. Given the support from the top, the Department committed substantial resources towards reforming teaching, and developed a thriving multifaceted outreach program led by physicists, including participation by everyone from graduate students, to National Academy Members, to Nobel Prize winners.

53.3 Fostering Diversity

Despite many efforts through the years, particle physics is still very much a white male enterprise. Table 53-2 gives the latest data on the percentage of women and minorities studying physics at various points in the Education to Career pipeline. Physics has the lowest percentage of women among all scientific disciplines. There are many diverse reasons why students of any gender or color choose not to go into physics and other STEM disciplines. These include:

- Cultural biases often lead to feelings of inadequacy. This 'stereotype threat' has been documented in many studies.
- Students who are in the first generation of their family to attend college are often pressured to become doctors, lawyers or other such professionals that they perceive as successful.
- Some students are looking for careers that they consider relevant to their lives or as helpful to society.

A national network of organizations working to encourage girls to enter STEM disciplines is making inroads through a series of programs grounded in research on how girls learn. A set of seven strategies [90] include open-ended investigations, finding personal relevance, instilling self-confidence and teaching collaboration, among others.

Level	Year	Total	Women	Asian Amer.	Hispanic Amer.	African Amer.
High School Physics (all courses)	2009	1,351,000	635,000 (47%)			
High School Physics (AP B)	2009	N/A	N/A (36%)			
High School Physics (AP C)	2009	N/A	N/A (27%)			
Bachelor's degrees	2010[b]	5899	1238 (21%)	310 (5%)	221 (4%)	157 (3%)
Master's degrees (exiting)	2008	790	167 (21%)	25 (3%)	25 (3%)	25 (3%)
PhD degrees	2008	1499	291 (19%)	32 (2%)	16 (1%)	15 (1%)

Table 53-2. *Gender and underrepresented minorities in high school and college physics. The sources of the data are: High School [88] (no data available for the last three columns); Bachelor's (3-year average 2008–2010) [5]; Master's and PhD (2 year average 2007–2008) [89].*

Resources of this network include:

- The bf National Girls Collaborative [91] and their regional subgroups — A networking group of organizations provide professional development to program leads working in their communities; the Collaborative also supports a national directory of programs.
- **SciGirls$^{\mathbf{TM}}$** [92] — What began as a TV program produced at Twin Cities Public Television has become a multifaceted resource for girls and providers including activities, games, videos and a website for girls.
- **FabFems** [93] — This website connects girls and role models.

For undergraduates, the Committee on the Status of Women in Physics (CSWP), through the APS, runs the CUWIP conferences for undergraduate women described earlier [57]. The Society of Black Physicists [94], the Society of Hispanic Physicists [95], the Society for the Advancement of Chicanos and Native Americans in Science [96], and the American Indian Science and Engineering Society [97] are all organizations whose mission is to provide role models and support for students and professionals in various minority groups. Students play an important role at their regional and national conferences.

53.4 International Perspective

There are a number of ways that particle physicists outside the U.S. community contribute to education and outreach. Some of these are influenced by what the U.S. particle physics does, some are potential or actual collaborators, and others provide useful examples for emulation or adaptation. The European Strategy for Particle Physics is a good starting point. In that document, education and outreach are specifically addressed [98]:

> Sharing the excitement of scientific discoveries with the public is part of our duty as researchers. Many groups work enthusiastically in public engagement. They are assisted by a network of communication professionals (EPPCN) and an international outreach group (IPPOG). For example, they helped attract tremendous public attention and interest around the world at the start of the LHC and the discovery of the Higgs boson. Outreach and communication in particle physics should receive adequate funding and be recognised as a central component of the scientific activity. EPPCN and IPPOG should both report regularly to the Council. [Emphasis in original.]

It goes on:

> Particle physics research requires a wide range of skills and knowledge. Many youngphysicists, engineers and teachers are trained at CERN, in national laboratories and universities. They subsequently transfer their expertise to society and industry. Education and training in key technologies are also crucial for the needs of the field. CERN, togetherwith national funding agencies, institutes, laboratories and universities, should continuesupporting and further develop coordinated programmes for education and training. [Emphasis in original.]

The document specifically mentions IPPOG, the International Particle Physics Outreach Group [72]. This group began as the EPPOG, with E for European. The name change occurred in 2011 to recognize that the group was expanding and opening up beyond Europe. There already was a U.S. representative; one of the current co-Chairs is from the U.S. In addition, Mexico will likely join in 2013. IPPOG is the main sponsor of International Masterclasses [73] and is a forum to share ideas and strategies in education and outreach. The IPPOG database is being developed as an international resource. The U.S. particle physics community plays an important collaborative role with IPPOG as well as in Masterclasses.

An example of programs outside the U.S. that draw inspiration from U.S. models is Netzwerk Teilchenwelt in Germany [99]. Similar to QuarkNet, it is a network of teachers and physicist working to bring particle physics into high school classrooms. Rather than create smaller learning communities as QuarkNet does, however, there is a single large network in which physicists make direct classroom visits and teachers are organized for professional development, including workshops at CERN. Netzwerk Teilchenwelt makes extensive use of masterclasses in schools, which QuarkNet is investigating for U.S. students.

Education and Outreach efforts worldwide have varying levels of organization, just as in the U.S. Several programs are built on cosmic ray detectors, such a GELATICA in Georgia [100] and QuarkNet-TW [101] in Taiwan. HiSPARC [102] is such a program in Holland that has operated since 2004 and is one of the models for this sort of effort. There are or have been similar efforts in Poland, Slovakia, Canada, Israel, Portugal, and other countries. Some of these use the QuarkNet-designed cosmic ray detector while others have "home" versions. QuarkNet has distributed detectors through the International Linear Collider collaboration to Japan, India, Poland, Germany, South Korea, and Ecuador.

53.5 What our colleagues outside of particle physics are doing

53.5.1 Physics professional societies

The mission statement of the American Physical Society (APS)[103] is:

> The American Physical Society strives to:
>
> - Be the leading voice for physics and an authoritative source of physics information for the advancement of physics and the benefit of humanity;
> - Provide effective programs in support of the physics community and the conduct of physics;
> - Collaborate with national scientific societies for the advancement of science, science education and the science community;
> - Cooperate with international physics societies to promote physics, to support physicists worldwide and to foster international collaboration;
> - Promote an active, engaged and diverse membership, and support the activities of its units and members.

To accomplish these goals, the APS has major efforts in education, outreach and diversity, with Education and Public Outreach Departments, and standing committees for Education, Public Outreach, Women in Physics, and Minorities in Physics. The Committee on Education's Policy Working Group advises the APS staff and leadership on matters of education policy, including diversity issues related to education. In addition, members of the APS have established Forums for Education, Outreach and Engaging the Public, and Physics and Society, and as of 2013, a newly formed Topical Group in Physics Education Research.

The APS Education Department [104] partners with the American Association of Physics Teachers (AAPT) as principal investigators of the PhysTec program, a project to improve and promote the education of future physics and physical science teachers. Other undergraduate programs include a wide variety of resources for improving undergraduate physics education; they also administer an award for Excellence in Undergraduate Education. At the high school level, they sponsor Physics and Instructional Resources (PAIR), a pilot project in physics teacher professional development designed to support physics teachers in need of content and/or material resources.

The APS Public Outreach Department [105] annually awards several grants up to $10,000 to help APS members develop new physics outreach activities. The awards are for innovative projects for engaging the public, and in some cases K-12 students.

The vision of the AAPT is to be the leader in physics education [106]. They are committed to providing the most current resources and up-to-date research needed to enhance a physics educator's professional development. The results are not only a deeper appreciation of the teaching profession, but most importantly, more enthusiastic involvement from their students.

The Association has identified four critical issues to guide their future activities:

1. Increase AAPT's outreach to and impact on physics teachers
2. Increase the diversity and numbers of physics teachers and students
3. Improve the pedagogical skills and physics knowledge of teachers at all levels

4. Increase the understanding of physics learning and of ways to improve teaching effectiveness

The AAPT has eighteen area committees [107], organized by interest, for example, Graduate Education, Undergraduate Education, Science Education for the Public, etc. Particle physicists who are interested in teaching can and do play a role in these committees. The APS and AAPT both have regional sections. Often the regional sections from the two organizations have a combined meeting. This is an excellent way to bring teachers together with scientists in their geographic area. Periodically, the APS and AAPT have a combined national meeting. The American Institute of Physics (AIP) is a federation of ten professional societies, including the APS and AAPT. The Statistical Research Center tracks trends in education and employment in physics, astronomy and associated fields. They also manage the national organization for the Society of Physics Students (SPS) and Sigma Pi Sigma, the honor society for physics students.

53.6 Issues and Concerns

Funding: The direct support of outreach efforts of particle physicist have been threatened in the 2014 budget by recent federal language to consolidate support for K-12, undergraduate, and informal education programs into three agencies with very broad agendas. If this decision stands, it will threaten QuarkNet and other programs that connect scientists directly with students and teachers.

Technology: The omnipresence of digital devices requires the particle physics community to explore the effective use of technology to deliver its message. In addition to 1990's era webpages, the community must consider utilizing social media, mobile applications, data portals, video conferencing and other, not-yet realized tools as ways to carry-out its outreach efforts. Particle physics was at the vanguard of the web in the early 1990's; the field must retain its leadership role.

Recognition for outreach efforts: Young, university faculty members face many pressures in order to attain tenure. These pressures often crowd out the important work of outreach. Physicists at other stages of their careers face different pressures. The particle physics community must change its culture and work to change the university culture to lower barriers — both real and perceived — to engagement in outreach efforts. Physics Education. The number of students enrolled in a high school physics course tripled from 1990-2005. If enrollment trends continue, the nation will need more people teaching physics. A recent survey of physics teachers asks what "Resources [they] use to find answers about physics content." The top three resources were: college physics textbooks, the World Wide Web, and high school physics textbooks. The item "Asking research scientist acquaintances" was down by an order of magnitude from these three.

It is clear that improving physics instruction starts with helping teachers comprehend more about the field. This help can come from workshops and programs that build capacity and learning communities that enable teachers to learn from local scientists and from each other.

Diversity: In spite of numerous efforts to increase diversity in physics, progress has been slow. While women now comprise approximately 23% of younger particle physicists (according to the Young Physicists Group Survey), that number is still well below 50%, and overall the number of women in the field is still 14%. While there are many more girls taking high school physics, there are numerous reasons that they do not choose to pursue physics majors in college. Working with girls in middle school and high school to introduce them to the range of careers available with a physics degree, and to women role models in physics, will aid in increasing the numbers entering the field.

The number of students from underrepresented minorities in the field is still too low for meaningful statistics. Clearly, there is work to be done in bringing more of these students into STEM fields. In order to attract more students from underrepresented minorities it is critical to work with the students in elementary school to strengthen their mathematics skills, and to interest students in pursuing math and science courses and careers in STEM. We should continue to provide opportunities for the students to engage science in an authentic, meaningful, and exciting way.

53.7 Strategies

We encourage the direct engagement of physicists with students and educators. Particle physicists should invite educators and students into their unique community. Particle physicists should be involved in and support local, national and world-wide efforts that:

> Offer longterm professional development and training opportunities for educators (including pre-service educators), aligned with current and appropriate standards and enabling educators to explore best-practice teaching methods. Local schools of education should collaborate as possible.
>
> Create learning opportunities for students of all ages, including classroom, out-of-school and on-line activities that allow students to explore particle physics to construct their own understanding and develop the skills and habits of mind necessary to perform research.

53.7.1 Implementation

The strategies address all three goals of the Communication, Education and Outreach Group through scientific literacy for all students (Goals 1 and 2) and through inspiring and exciting the next generation of students entering particle physics and other STEM careers (Goals 1 and 3). They call for direct engagement of particle physicists with educators at all levels (elementary through undergraduate) in a variety of programs. Such programs might require commitments from physicists ranging from 15-minutes to a summer mentorship with a high school or college student to a multi-year relationship with a local teacher. All such commitments are equally valued, and should be made as seamless as possible for the physicist. In order to fully realize these strategies, we call for the following implementation elements:

Programs:

- extending existing educator networks (e.g., QuarkNet, Modeling, PTRA) and creating additional professional development opportunities to educators (including pre-service educators) who present science at all grade levels, especially those who teach physics. QuarkNet is an excellent example of a program that fosters the connections between particle physicists and physics teachers, and through the teachers, with students. It is successful in large part because it provides an infrastructure and framework that (i) is the seed to begin to foster local learning communities of scientists and teachers doing science together, and (ii) brings teachers and students to an early understanding of the international nature of contemporary physics research. New programs will be piloted to expand professional development opportunities for teachers, reach more students, extend these opportunities to middle and elementary school teachers, and to work with education departments to provide girls, and IPPOG masterclasses that introduce students to analyzing LHC data. Research skills workshops and research experiences for teachers, high school students and undergraduates are also important.
- creating programs that use examples from particle physics and experimental data to allow educators and students to develop skills, concepts and scientific habits of mind. Examples of such programs are

University of Marylands modern physics summer course for high school girls, and IPPOG masterclasses that introduce students to analyzing LHC data. Research skills workshops and research experiences for teachers, high school students and undergraduates are also important.

- aligning and collaborating with national efforts to improve diversity in STEM fields in order to broaden their reach in physics. In order to have a healthy particle physics workforce in the future that more closely represents the diversity of the general public, students from groups traditionally underrepresented in physics need to be engaged and encouraged in elementary school. We propose to partner with national and regional programs, for example SciGirls and GEAR-UP, to include more physics content in their programs and materials, and to make those resources and programs known and available to interested members in the particle physics community.

Resources:

- producing learning materials that support the programs above, and materials for scientists that assist them in reaching a variety of audiences. Groups such as the Contemporary Physics Education Project have produced particle physics posters and wall charts (including the latest on the Higgs discovery) and award-winning websites, such as the Particle Adventure, primarily through the effort of a few dedicated scientists and educators in their spare time. This effort should be greatly extended to produce a variety of material for a range of audiences, made available to scientists who wish to do outreach in their local communities. In addition, material should be made available to educators at both the K-12 and college levels that facilitate bringing best practices in physics education research to physics courses at all levels.

Training:

- creating workshops for scientists who want to engage educators and students. A variety of workshops should be made available to scientists who want to do outreach to schools or work with teachers, in order to keep them updated on education research and best practices, communication skills, etc. These could be coordinated in partnership with the APS and other professional organizations.

53.7.2 Resources

The implementation of these strategies requires a national infrastructure that would provide an organizational structure and resources for scientists wishing to engage students and teachers as well as the general public. We call for the establishment of such an organization within the particle physics community. A national outreach office with a staff of 2–3 could serve as a liaison office and resource center for particle physicists wishing to reach a variety of audiences. With the help of IT and graphic artists, either in-house or outsourced, they would, for example, develop material that scientists could use for public lectures or school visits, offer training to scientists and partner with other organizations to develop diversity. Collaborations with universities, national laboratories, and professional and international organizations would be facilitated to apply for funding for longer term programs such as professional development and student enrichment programs.

53.8 Appendix A: The particle physics workforce and pipeline

Since 1998, demographic data on the particle physics workforce has been collected by Lawrence Berkeley National Laboratory (LBNL). HEPAP formed a Demography Committee in 2002. In 2006-2007, a grant from

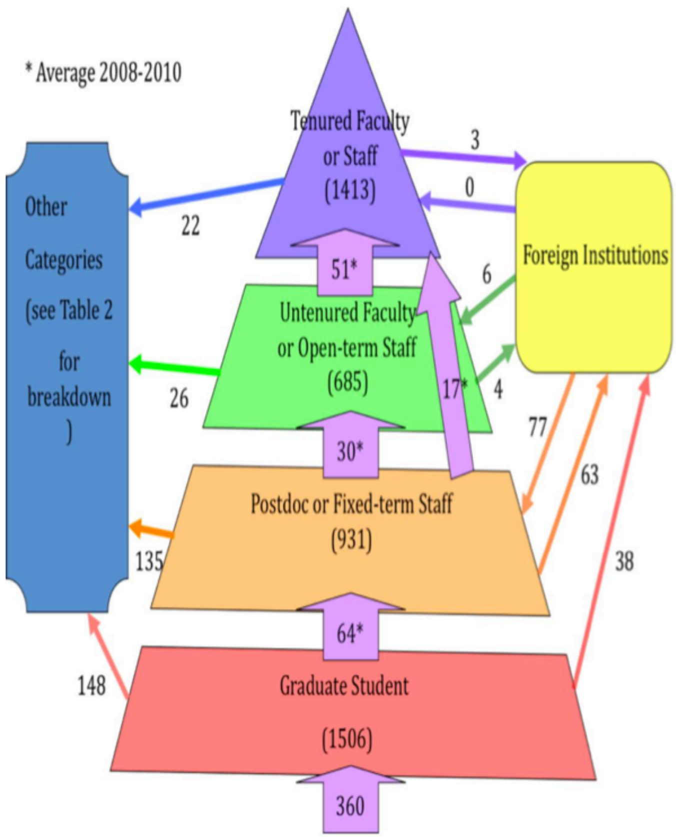

Figure 53-2. *Census of the field of particle physics in 2010, the last year in which data is available [8].*

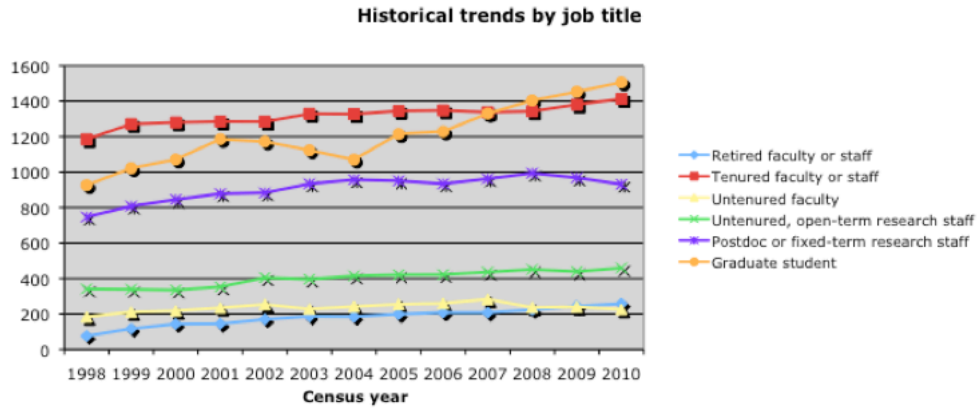

Figure 53-3. *Historic trends in particle physics by job title [8].*

the Department of Energy enabled a database to be set up at LBNL, and data was verified with extensive cross-checks by University of Iowa. The cross-check results were fed back into the database program. Since funding ended in 2007, the database has been in a steady-state with minor technical upgrades. The database is filled out each spring by one P.I. from each institution.

The 2010 census of the community is shown in Fig. 55-2.

Historic trends are shown in Fig. 55-3. The most dramatic trend is in the number of graduate students entering the field, which has risen steadily between 2004-2010, from a low of approximately 1050 to a value of nearly 1500 in 2010. Likely factors that contribute to this include the excitement of results from the LHC as well as the expansion of particle physics into new areas.

Departure data out of particle physics is not very well tracked. It is known that approximately 60% of transitioning graduate students and 55% of transitioning postdocs leave particle physics. A survey of the workforce 5-10 years after the PhD could provide data that would be very useful in demonstrating the impact of particle physics on society, and was recommended by the HEPAP Demography Committee in 2011. It would take some effort and money to mount such a survey. A proposal for such a survey was made to DOE and NSF in 2011 but did not receive funding.

Figure 55-4, from the NSF Survey of Earned Doctorates, gives historic trends — as reported to the NSF between 2001-2011 — for the total number of PhDs in physics as well as the number in particle physics. The total number of PhDs in physics has also been rising steadily in recent years, and the number of PhDs granted in particle physics has remained a relatively constant percentage of 12-13% since 2007.

Further down the pipeline, the AIP monitors long term trends in undergraduate physics degrees, shown in Fig. 55-5. The academic year 2010-11 produced all-time highs for physics Bachelors degrees conferred in the U.S. The 6,296 physics Bachelors degrees earned in the class of 2011 represent a 73% increase from a historic low of less than 4000 in 1999.

The AIP also monitors enrollments in high school physics. The total numbers have been increasing steadily since 1990 at all levels, as shown in Fig. 55-6. The percentage of girls taking regular physics has been steady at 47% since 1997. The percentage of girls taking AP Physics C is 32%.

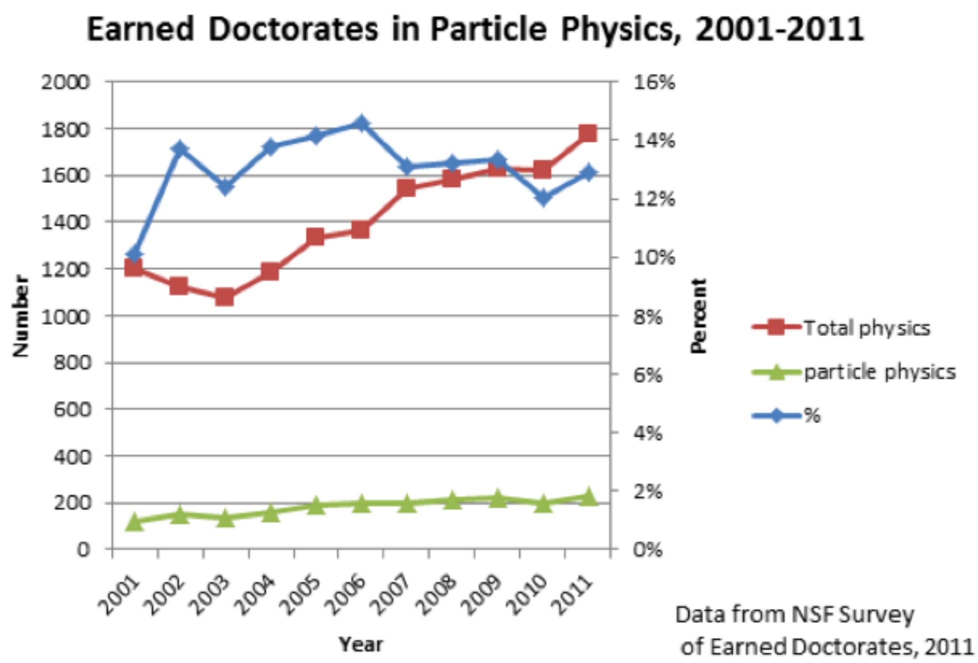

Figure 53-4. *Earned doctorates in particle physics, 2001–2011 [7].*

53.9 Appendix B: Activities of the subgroup on teachers and students

Members of the subgroup attended the first Community Planning Meeting held at Fermilab in October 2012. At that meeting they met with the full CE&O Working Group in an initial planning meeting.

Subsequently, members of the subgroup participated in biweekly telephone conferences of the full CE&O Working Group, and held subgroup phone conferences approximately once per month. The subgroup planned two information gathering sessions, associated with the two major APS meetings.

53.9.1 March 2013

Preceding the APS March Meeting in Baltimore — and concurrent with the PhysTec annual meeting — a session was planned for K-12 teachers. Teachers were recruited through area Quarknet centers and other contacts in the Baltimore area. Teachers attending the PhysTec meeting also took part. Teachers attended the opening plenary talk for the PhysTec meeting and had a special lunch talk about the Higgs Boson discovery. Before and after lunch there were two focus sessions, in which teachers were asked the following questions:

Before lunch (focus on teaching):

- How can we help with your classroom implementation of NGSS?

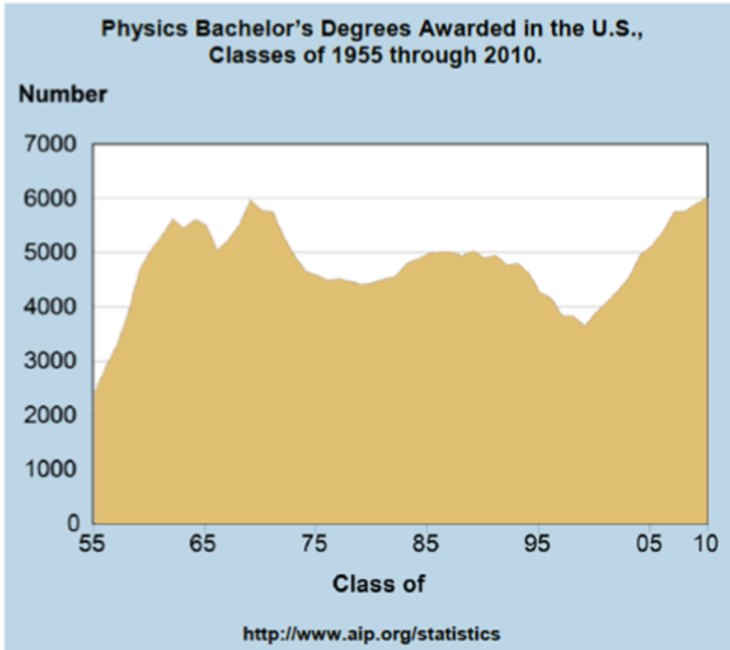

Figure 53-5. *Bachelors degrees in physics, 1955–2010 [5].*

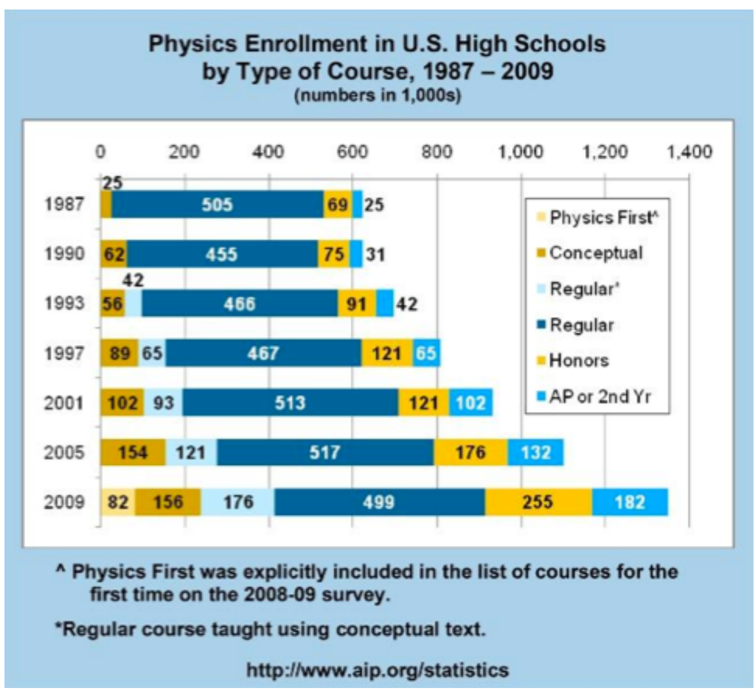

Figure 53-6. *Physics enrollment in U.S. high schools by type of course, 1987–2009 [4].*

- What does a good professional development (PD) experience look like? Points made by teachers in response:
- need for NGSS and other content workshops and courses for teachers, with grad credit or continuing education certification;
- need for a feedback process and for continued support after one-day PD courses.
- Teachers want practical examples in the PD that they can "use in their classroom tomorrow", not generalities.
- Communities of teachers are good source of mutual support.
- We want to help provide examples from modern physics that fit the curriculum.

After lunch (focus on students):

- How can we inspire, support and prepare the next generation of scientists — especially physicists? How can we develop an appreciation of and support for scientific research — especially physics?

Points made by teachers in response:

- improving science starting in elementary school;
- the coolness factor;
- research, competitions in MS, HS;
- hands-on activities, especially construction.
- Reducing the anxiety about being "wrong" is important in building confidence.
- Discussing events featured in the media is a good tool for making science relevant to students, e.g., Felix Baumgartens jump or the "Big Bang" effect.
- Meetings between students and scientists show science and role models: visits to schools, students visiting labs and universities.
- We need to inform HS students that physics graduate students are paid.

Teachers requested that both teachers and students have access to reliable look-up sites. An existing example is Physics Central by the APS [95].

Subgroup members also held discussions in Baltimore with APS and AAPT staff / officers. An important topic of discussion was about the role of physicists in helping teachers implement the NGSS with its content changes. The Engineering standards especially will require help.

Subgroup members also held discussions in Baltimore with physics faculty about the role of universities. Some comments and suggestions were:

- participate in QuarkNet;
- introduce modern physics in physics courses for non-majors;
- offer research opportunities to HS and undergraduate students;
- offer TA opportunities to physics majors;
- do not use introductory physics courses to "weed out" students;

- Physics Fairs and traveling Physics Shows.
- When there is lack of departmental support (e.g., tenure not helped by outreach), it creates a barrier to outreach participation.
- NSF, NASA and some physics departments are very supportive.

53.9.2 April 2013

At the April 2013 APS meeting, the subgroup organized a brown bag town meeting for members of the particle physics community to give input. Only one scientist attended; his interest was in Science Hack Days, a public outreach type of event. His input was passed on to the Subgroup on Public Outreach.

53.9.3 May 2013

The subgroup participated in planning for the survey of the particle physics community. Survey questions related to teachers and students and results were:

12. Are you engaged in any education or outreach activities that reach K-12 teachers or students?

# answered	# skipped	# yes (percent)	# no (percent)
567	130	276 (48.7%)	291 (51.3%)

13. What type of outreach to K-12 teachers have you engaged in that brings particle physics into their classrooms (top 6 responses)?

research mentor	workshop presenter	Quarknet mentor	developer of materials for teachers	other Quarknet volunteer	participate in inservice at local school district
72 (38.9%)	72 (38.9%)	52 (28.1%)	44 (23.8%)	40 (21.6%)	38 (20.5%)

14. In your experience, what was effective in helping teachers develop better teaching practices?

15. What type of outreach to K-12 students have you engaged in? Do they attract students from underrepresented groups?

tours at my university or lab	classroom presentations	involvement in science fair or competition	research mentor	developed material for students	Quarknet mentor
152 (96.8%)	143 (98.6%)	99 (94.3%)	85 (97.7%)	62 (96.9%)	51 (92.7%)
64 (40.8%)	57 (39.3%)	35 (33.3%)	31 (35.6%)	20 (31.3%)	19 (34.5%)

The second line gives the numbers for students from underrepresented groups.

16. How supportive is your department, university or laboratory of outreach efforts to K-12 teachers and students?

	1 (not supportive	2	3 (moderately supportive)	4	5 (very supportive)
K-12 Teachers	3.4% (8)	10.9% (26)	27.3% (65)	20.6% (49)	37.8% (90)
K-12 Students	2.5% (6)	10.0% (24)	27.5% (66)	20.8% (50)	39.2% (94)

21. Are you engaged in any education or outreach activities other than course work that reach undergraduate students?

# answered	# skipped	# yes (percent)	# no (percent)
549	148	284 (51.7%)	265 (48.3%)

22. If you mentor undergraduate researchers, do you do so for:

# answered	# skipped	the summer?	the academic year?
234	463	198 (84.6%)	171 (3.1%)

24. Do you work with School/College of Education and participate in preservice teacher education?

# answered	# skipped	# yes (percent)	# no (percent)
270	427	27 (10.0%)	243 (90.0%)

There were also open-ended questions asking about effective practices in teacher development and diversity. Those are not included here and will be followed up on separately.

53.9.4 July 2013

During the Snowmass on the Mississippi meeting, the CE&O Working Group held lunch meetings to give members of the particle physics community an opportunity to give input. The Teachers and Students Subgroup lunch was on Wednesday, July 31. More than 30 participants attended and four break out groups were presented with the following questions to discuss:

1. What are the barriers to using Research Based Instruction Strategies (RBIS) in undergrad physics classes?
2. How can we bring particle physics into Intro physics courses?
3. How do we attract best students into physics?
4. How do we help teachers and students at all grade levels become more comfortable with physics?

This is the summary of the discussion of these questions:

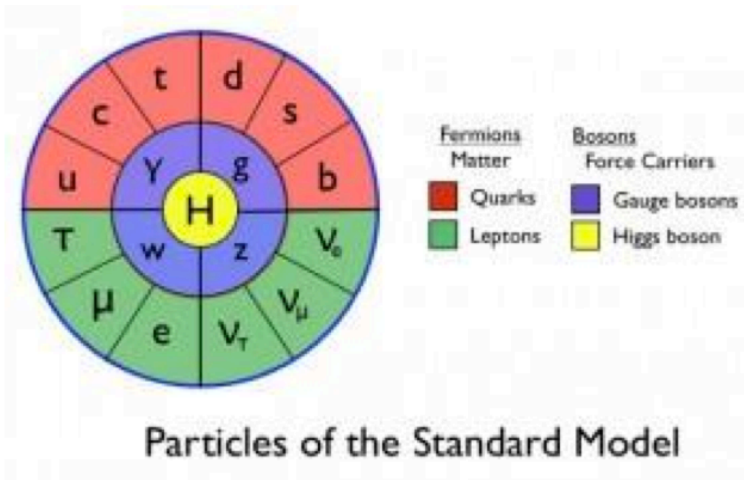

Figure 53-7. *Proposal for a circular presentation of the Standard Model [108].*

53.9.4.1 Barriers to using Research Based Instruction Strategies in undergrad physics classes

Faculty have personnel, time and money concerns about introducing new methods. They have some anxiety about adopting unfamiliar techniques. They need more information about the methods, their applicability and effectiveness. Suggestions included:

- Contact undergrad teaching committee or dept heads to bring Physics Education Research (PER) people for a physics colloquium.
- AAPT offers training for faculty in RBIS.
- Mentoring and peer coaching would be very useful during implementation.
- Interactive learning should be used at all levels, some administrators think it is only for introductory physics.
- Need to gather information on implementation from the teaching community and make it available (via APS?).

Comment: Very comprehensive information is available, in, e.g., the book by E.Redich "Teaching Physics with the Physics Suite", but people do not know of it.

53.9.4.2 How can we bring particle physics into Intro physics courses?

Observations and suggestions: most books do not have modern physics examples, we need books that have them. Some people spent a little extra time to introduce invariant mass, and used data to plot and see Higgs mass bump. Special relativity seems exciting to students.

Outside intro physics sequence there are many physics courses for non-scientists that include concepts of modern physics.

Kyle Cranmer showed a new circular Standard Model Chart (see Fig. 55-7.)

53.9.4.3 How do we attract best students into physics ?

All levels: train teachers in teaching physics, improve instruction from elementary to college level, build teachers confidence. Outreach programs, science festivals. Use Skype for areas far away from resources.

Early childhood through middle school: physics programs and books about physics for families and women

High school: introduce students to modern physics in school, and via physics outreach programs; Physics Days for students admitted to college; give teachers good and attractive tools for teaching physics; research opportunities;

Undergraduates: improve formal instruction; research opportunities;

Funding: PI grants should include outreach;

Get statistics what students do who leave the field after getting a physics degree.

53.9.4.4 How do we help teachers and students at all grade levels become more comfortable with physics?

Physics training for in-service and for pre-service teachers. In-service: e.g., through programs like UTeach at U of Texas, Austin. Pre-service: physics departments should get involved in pre-service training, e.g., Physics Made Easy for Elementary Ed at the U of Illinois

Teachers use popular culture: many teachers use Big Bang Theory to interest students in physics concepts. Physicists should visit schools, classrooms and PTA meetings, and other places where people are to help personalize physics.

Physicists can make use of social media to talk in appropriate way about interesting physics developments. Important: to train in talking to the public.

National labs have a role to help.

53.9.5 August 2013

Friday, August 2nd was an open brown bag forum for additional discussion by the community on any of the CE&O topics. A group of five gathered at one table to discuss undergraduate education and K-12 outreach. The conversation mostly centered around active learning; how to build into upper-level courses and how to manage time. There was also discussion of a Quark Matter card game designed by middle school students and other variations on it [109].

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