A NATION CALLS FOR EDUCATION REFORM

"If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war."

"What was unimaginable a generation ago has begun to occur – others are matching and surpassing our educational attainment"

A Nation at Risk
National Commission on Excellence in Education
U.S. Department of Education

Over a quarter of a century ago, the Department of Education's report "*A Nation at Risk*" called upon the education community to substantially strengthen education in the United States.[1] This 1983 report was followed in 1986 by a National Science Board report, known as the "*Neal Report,*" that called for strengthening collegiate science education and encouraged the pursuit of excellence in the next generation of U.S. leadership in science and technology.[2] A strong undergraduate sector was cited as critical to "keep new ideas flowing through research; to have the best technically trained, most inventive and adaptable workforce of any nation; and to have a citizenry able to make intelligent judgments about technically-based issues."

In 1998 and 2002, the two Boyer Commission reports *"Reinventing Undergraduate Education: A Blue print for America's Research Universities,"*[3] and *"Reinventing Undergraduate Education: Three Years after the Boyer Report"*[4] called upon the research community to make "research-based learning the standard." Quoting the eminent psychologist and education reformer, John Dewey, from almost a century before, the Boyer Commission emphasized that "learning is based on discovery guided by mentoring rather than on the transmission of information."

In the early 2000s, the National Science Board, in its report titled, *"The Science and Engineering Workforce – Realizing America's Potential,"* urged the science community to take action to ensure U.S. science and engineering capacity in an increasingly competitive and changing global labor market and strongly advised the Federal Government "to lead the Nation in a coordinated response to meet our long-term needs for science and engineering skills in the US workforce.[5] In that same period, *Greater Expectations – A New Vision for Learning as a Nation Goes to College*, published by the Association of American Colleges and Universities, called for a teaching-learning paradigm shift that would ensure active, empowered, informed, and responsible learners.[6]

More recently, the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies report titled "*Rising Above the Gathering Storm – Energizing and Employing America for a Brighter Economic*

Future,"[7] called yet again for improvements in U.S. education and STEM education to help ensure the nation's competitiveness in a rapidly changing global economy.

The most recent call for a significant improvement in STEM education came from President Obama in his speech to the National Academies of Science. While directing his attention to energy research, his call for additional funds for undergraduate research emphasized its importance in motivating and preparing tomorrow's scientists.[8]

> *"…the Department of Energy and the National Science Foundation will be launching a joint initiative to inspire tens of thousands of American students to pursue careers in science, engineering and entrepreneurship related to clean energy. It will support an educational campaign to capture the imagination of young people who can help us meet the energy challenge. It will create research opportunities for undergraduates and education opportunities for women and minorities who too often have been underrepresented in scientific and technological fields – but are no less capable of inventing the solutions that will help us grow our economy and save our planet."*

The continuing flood of reports and statements that make similar and repeated calls for educational change is disconcerting. The obvious question must be asked, "If the desired educational change has occurred, why have the reports and statements not stopped?" The answer, unfortunately, is that the desired change - at the level needed - has not occurred.

THE STATE OF PHYSICS IN THE UNITED STATES

For physics, it is sobering to note that the proportion of bachelor's degrees in physics to total degrees awarded was twice as high the year before Sputnik, deemed a time of dangerous educational neglect, than it was in 2004.[9]

When this low level of production of new physics talent is linked to data on the average age of the physics workforce and the current percentage of the physics workforce that is foreign born, a disturbing picture evolves.[10] While across all degree levels and fields the Science and Engineering Indicators report that 26.4% of the labor force with science and engineering degrees is older than age 50, the percentage of the workforce with their highest degree in physics that is older than age 50 is 38%, the highest percentage in any STEM discipline. A review of the percentage of physicists and astronomers who are foreign born in the U.S. workforce finds that 26.6%, 34.4% and 40.1% of the bachelors, master's and doctorate physics/astronomy workforce are foreign born, respectively. The combination of a low production of new physicists, an aging workforce, and a workforce that is heavily populated by a foreign-born talent paints a particularly troubling picture.

For decades, the U.S. has relied on foreign talent to compensate for the lack of U.S.-born STEM talent. As can be seen in the above percentages, this is clearly the case in physics. With increasing STEM employment opportunities globally,[11] the strategy to simply "import" the needed talent may no longer be viable. Significant new employment opportunities are appearing in countries like China, India, the European Union, Canada, Japan and the Middle East. We should probably even ask whether or not the United States will be able to retain U.S.-born STEM talent when attractive job opportunities are beginning to appear in other countries. As the world's highest-energy accelerator is now located at CERN in Switzerland, this question might already be asked by those in the high energy physics community. The situation the U.S. physics community finds itself in is as dire, if not more dire, as it is in any STEM discipline.

ADDRESSING PHYSIC'S CHALLENGE

Maintaining the "status quo" where a students' primary exposure to the discipline is in the classroom or in course-based laboratories is no longer a viable option for the physics community. While physics has been a leader in education research and more departments are introducing active-learning into their classrooms and course-based laboratories, the numbers argue that more needs to be done. Continuing to under-produce U.S.-born physics talent not only places U.S. physics at considerable jeopardy, given the centrality of physics to other science disciplines, it places all U.S. science at risk.

While a larger comprehensive reform is needed, one action that can be taken by the physics community at this time is to provide all undergraduate physics and astronomy majors with the opportunity to become "practicing scientists" by providing them with the opportunity to engage in research while they are undergraduates. A research experience exposes undergraduate students to the nature of scientific investigation while permitting them to gain skill in project design, to use appropriate instruments and techniques, to engage in data analysis, and to communicate complex ideas. Every student can benefit from such an experience and it is difficult to achieve some of these educational benefits through traditional classes and course laboratories.

Studies of the involvement of undergraduates in significant research experiences have shown increases in:

- students' understanding of science,
- retention,
- the likelihood of participation in their discipline,
- student motivation to study science,
- intellectual ability,
- student confidence in their ability to do research,
- student awareness of Ph.D. training,
- student interest in obtaining a Ph.D., and
- continued involvement in research 5 to 10 years after graduation.[12 - 23]

The physics community continues to rely on lecture and laboratories associated with courses as the principal mode of physics instruction. While certainly being introduced to physics concepts, the primary student activity is memorizing and manipulating equations. In the preface to his textbook, Richard Feynman commented on the shortcomings of this approach[24]:

> "*I think, however, that there isn't any solution to this problem of education other than to realize that the best teaching can be done only when there is a direct individual relationship between a student and a good teacher – a situation in which the student discusses the ideas, thinks about the things, and talks about the things. It's impossible to learn very much by simply sitting in a lecture, or even by simply doing problems that are assigned.*"

In the mid-1990s, the American Association of Physics Teachers, American Institute of Physics, and American Physical Society initiated a study of 21 "thriving" undergraduate physics programs that kept these departments in the top 10% or so of departments with large numbers of majors.[25] While the study, titled *"Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP),"* certainly found a variety of practices employed by these departments that created a nurturing and supportive environment for their undergraduate majors, an element that was common to all of the programs was an undergraduate research program. As stated in the SPIN-UP report,

> "*All of the site visit departments had thriving undergraduate research programs. About half of them **required** participation in undergraduate research for the major. In addition to on-campus research with their own faculty, many students take advantage of off-campus opportunities, for example, in the Research Experiences for Undergraduate programs sponsored by the National Science Foundation and some of the national laboratories. In many departments, students are encouraged to participate in research even after their first and second years, just to see what research is like and to experience working on a research team."*

The report went on to say that

> "*Undergraduate research participation benefits both the students and the department in many ways that go beyond just the completion of the research. Students gain experience working in teams and communicating their results, both orally and in written reports. The shared research experience gives the students a deserved sense of being part of the scientific community, not just passive consumers of science through their courses. Most departments recognize the importance of undergraduate research in building a sense of community within the department."*

In its booklet, *"Guidelines for Self-Study and External Evaluation of Undergraduate Physics Programs,"* the American Association of Physics Teachers, with an endorsement from the Committee on Education of the American Physical Society, observes[26],

> *"There is a general consensus that undergraduate research both introduces students to the excitement of physics and prepares them for graduate research or for immediate entry into the job market. Many departments either require undergraduate research participation or strongly encourage it."*[25]

The guide goes on to state,

> *"Undergraduate research experiences frequently convince students to pursue a physics major. Anecdotal evidence strongly suggests that they are an attractive component of a strong physics major. Research experience is clearly valuable for students who are pursuing a career in science, but they also provide an understanding of how science is done that may prove particularly valuable to students who pursue careers outside of physics research, for example in clinical medicine, business or law."*

These positive attributes of engaging undergraduates in meaningful research experiences and the community's need to increase the number of students who pursue an undergraduate degree in physics and astronomy strongly argue that all physics and astronomy departments should strive to provide all physics and astronomy majors with the opportunity to engage in research as part of their undergraduate experience.

IMPLEMENTATION

The implementation challenge may not be as daunting as it might first appear. According to the AIP's survey of graduating physics majors, over 70% of graduating seniors have participated in one or more undergraduate research experiences.[27] As the physics community and departments work to increase the percentage of undergraduates engaged in research, a variety of strategies can and should be used to accomplish this end. A variety of models for recruiting, implementing and evaluating undergraduate research experiences exist.[28,29] Students can be directed to on-campus faculty-mentored projects, to research opportunities at NSF REU sites, to national and corporate laboratories, and to other federal agencies and private foundations. Where larger numbers of students need to be accommodated, an upper division course that emphasizes the nature and process of research might also be used to provide this learning experience. A variety of research on student learning in undergraduate laboratories and research experiences in physics exists and can be considered in the design, implementation, and evaluation of a course that emphasizes research.[28,31,32] In such a course, students would be expected to develop research questions, design experiments, collect, analyze, and synthesize data, perform error analyses, develop an understanding of limitations, inferences, and conclusions from their results, and present their results in an appropriate forum. In short, if all the possible ways to make research opportunities available to students are considered, a combination that is both effective and practical and based upon local circumstances can then be chosen.

EPILOGUE

The rest of the world is not waiting for the next report to call for the U.S. STEM community to develop a new cadre of physicists and astronomers. The world community is developing the talent it will need today. The U.S. can either take action now or cede its scientific leadership to the rest of the world just as it has done in the manufacture and production of electronics, steel, automobiles, textiles and now, possibly, high energy physics. As a robust and vital physics program is the responsibility of the physics community, we urge that the physics community take this important first step in what will ultimately be a larger reform and call for all physics departments to provide all their majors a learning experience that has been shown to retain them in the discipline, to encourage them to pursue advanced degrees, and to enhance their skill level.

REFERENCES

[1] The National Commission on Excellence in Education, D. P. Gardner (Chair), *"A Nation at Risk: The Imperative for Educational Reform,"* **1983**, Report to the Secretary of Education, US Department of Education (www.ed.gov/pubs/NatAtRisk/title.html)

[2] National Science Board (Neal Report), 1986 (NSB-86-100)

[3] Boyer Commission on Educating Undergraduates in the Research University, S.S. Kenny (chair) *"Reinventing Undergraduate Education: A Blueprint for America's Research Universities"*, **1998**, State University of New York at Stony Brook

[4] Boyer Commission on Educating Undergraduates in the Research University, S.S. Kenny (chair) *"Reinventing Undergraduate Education: Three Years after the Boyer Report"*, **2002**, State University of New York at Stony Brook

[5] National Science Board, Washington, W.M. (chair) *"The Science and Engineering Workforce – Realizing America's Potential,"* **2003** (NSB 03-69)

[6] National Panel Report, Ramaley, J. (chair), "*Greater Expectations: A New Vision for Learning as a Nation Goes to College,"* **2002**, Association of American Colleges and Universities (ISBN 0-911696-92-x).

[7] Committee on Science, Engineering and Public Policy, N.R. Augustine (Chair), National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies report titled "*Rising Above the Gathering Storm – Energizing and Employing America for a Brighter Economic Future,* **2007**, National Academies Press (ISBN: 978-0-309-65442-5).

[8] President Barack Obama, Address to the U.S. National Academy of Science, April 27, 2009

[9] American Physical Society, **2007**, APS News. August/September

[10] Science and Engineering Indicators (S&EI), National Science Board, **2008**, pages 3:44 and 3:51).

[11] Science and Engineering Indicators (S&EI), National Science Board, **2008**, 3:46-57

[12] Bauer, K.W.; Bennett, J.S. Alumni Perceptions Used to Assess Undergraduate Research Experiences, *Journal of Higher Education* **2003**, 74, 210-230.

[13] Seymour, E.; Hunter, A.B.; Laursen, S.L.; Deantoni,T. Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-year Study. *Science Education* **2004**, 88, 493-534.

[14] Rauckhorst, W.H., Czaia, J.A. and Baxter Magolda, M , Measuring the Impact of the Undergraduate Research Experience on Student Intellectual Development. (2001, July) Paper presented at Project Kaleidoscope Summer Institute, Snowbird, UT.

[15] Hunter, A.B.; Laursen, S.L.: Seymour E. Becoming a Scientist: The Role of Undergraduate Research in Students' Congnitive, Personal, and Professional Development, *Science Education* **2007**, 91, 36-74

[16] Russell, S.J.; Hancock, M.P. and McCullough, J. Benefits of Undergraduate Research Experiences, *Science Education* **2007**, 316, 548- 549

[17] Nagda, B.A.: Gregerman, S.R.; Jonides, J.; von Hippel, W.; and Lerner, J.S. Undergraduate student-faculty Research Partnerships Affect Student Retention, *The Review of Higher Education* **1998**, 22, 55-72.

[18] Gregerman, S. Improving the Academic Success of Diverse Students through Undergraduate Research, *Council on Undergraduate Research Quarterly* **1999**, 2, 52-59.

[19] Hutchinson, A.R., and Atwood, D.A. Research with First- and Second-year Undergraduates: A Model for Undergraduate Inquiry at Research Universities, *J. Chem. Education* **2002**, 79, 125-12

[20] Hathaway, R.S., Nagda, B.A. and Gregerman, S.R.,The Relationship of Undergraduate Research Participation to Graduate and Professional Education Pursuit: An Empirical Study. *Journal of College Student Development* **2002**, 43, 614-631.

[21] Karukstis, K. The Impact of Undergraduate Research on America's Global Competitiveness, *Journal of Chemical Ed*ucation **2007**, 84, 912, and references therein.

[22] Lindsay, H.A.; McIntosh, M.C. Early Exposure of Undergraduates to the Chemistry Research Environment; A new Model for Research Universities, *Journal of Chemical Education* **2000**, 77, 1174.

[23] Hurtado, S., Eagan, M.K., Cabrera, N.L., Monica, H.L., Park, J., and Lopez, M. Training Future Scientists: Predicting First-year Minority Student Participation in Health Science, *Research in Higher Education* **2008,** 49, 126-152.

[24] Feynman, R.P., *"Six Easy Pieces: Essentials of Physics Explained by its Most Brilliant Teacher" Perseus Books (ISBN: 0-201-40955-0).*

[25] Hilborn, R.C., Howes, R.H., Krane, K.S. Strategic Programs for Innovations in Undergraduate Physics: Project Report (SPIN-UP), **2003**, American Association of Physics Teachers.

[26] *"Guidelines for Self-Study and External Evaluation of Undergraduate Physics Programs,"* American Association of Physics Teachers **2005,** p. 10 – 11

[27] "*Survey of Physics Seniors*," Physics Trends, Statistical Research Center, American Institute of Physics (Spring 2005)

[28] http://www.spsnational.org/programs/research/

[29] http://www.nsf.ogv/crssprgm/reu/reu_search.cfm

[30] Anna Karelina and Eugenia Etkina, "Acting Like a Physicist: Student Approach Study to Experimental Design," Phys. Rev. ST Phys. Educ. Res. 3, 020106 (**2007**)

[31] T. S. Volkwyn, S. Allie, A. Buffler, and Fred Lubben, "Impact of a Conventional Introductory Laboratory Course on the Understanding of Measurement," Phys. Rev. ST Phys. Educ. Res. 4, 010108 (**2008**)