A Critical Role for Physicists in K-12 Science Education Reform

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A robust mechanism to drive sustained K-12 science education reform can be supplied by university physics departments through graduate programs tailored to meet the professional development needs of inservice teachers.

For more than two decades, blue ribbon reports have warned that *K-12 science education is in dire disrepair, if not in a desperate crisis* [1]. This has led to proposals for sweeping K-12 science education reform as a priority in *national science policy* [2], with emphasis on strengthening the

- *Technology pathway*: To educate scientists and engineers for sustaining economic growth,
- *Workplace readiness*: To provide the technical foundation for an effective workforce,
- *Informed citizens*: To produce science literate citizens and consumers.

Concomitantly, with broad input from the science and education communities, the National Research Council has achieved a consensus on *National Science Education Standards* (NSES) to guide K-12 science education reform [3]. In a similar way the *National Council of Teachers of Mathematics* (NCTM) has created standards for mathematics education [4]. These documents have strongly influenced standards for science and mathematics education in individual states. For physics education in particular, reforms are needed along three main lines:

- **Pedagogical reform** to meet or exceed recommendations of the NSES. New evaluation instruments have documented serious deficiencies in conventional physics teaching methods as well as considerable improvements from research-based instructional designs [5]. However, these advances have not yet been widely diffused or deeply assimilated by most physics teachers. Deeper reforms in curriculum and instruction are continually emerging from educational research, but adequate mechanisms to move them into the classroom are still lacking.
- **Curriculum reform** incorporating contemporary science. The main accomplishment of 20th century physics is arguably: unraveling the atomic structure of matter. This unifies physics and chemistry into a common science of the structure of matter and its properties. It also provides the foundation for nanotechnology, molecular biology and astrophysics. Little of this astounding science has penetrated the K-12 curriculum except in occasional "gee-whiz" tidbits. More is not to be expected without participation of research scientists in the professional development of teachers and curriculum reform. As a gateway to the wonders of 21st century science, it is essential to establish an integrated science curriculum that initiates students into physics of the atomic world in high school.
- **Technology infusion.** Electronic technology is rapidly becoming an integral part of modern society. It is already essential to modern science, engineering, manufacturing and many businesses. Therefore, it is imperative to incorporate technology into science curricula at all grade levels. Educational research has established that computers do little to enhance student learning without carefully designed adjustments to the curriculum implemented by a well-trained teacher. This is particularly true in physics courses, where students need to learn how to use the computer as a scientific tool for data acquisition, analysis and problem solving. The computer can enhance pedagogy, but not replace it. Therefore *infusion of computers into*

science classrooms must be coupled to reform in science pedagogy and teacher professional development.

It should not be surprising that, despite all the fanfare, the impact of the NSES on science teaching in the schools has been slight. Our education system is not geared for change. Besides, schools and school districts are ill-equipped to implement reform on their own; they lack the necessary *expertise* in science and technology as well as the *resources* to keep up-to-date with advances in science curriculum materials and pedagogy. Those resources reside primarily in the nation's universities, especially in the science and mathematics faculties, as well as in engineering and education. *Without participation of research scientists, science education reform is doomed to mediocrity*, for research is the life-blood of science.

Consequently, *we must look to the nation's universities to supply the missing mechanism needed to drive science education reform in the schools*. Our mission in this article is to explain that *a robust mechanism to drive sustained and rapid reform is easy to create, cost effective and sure to work*. The remaining problem is to organize the political will and leadership to put the mechanism in place.

Engaging the Physics Community: What is the problem?

The need for science education reform is well articulated in several AIP/APS policy statements. [6] Most recently, at least 240 US physics departments have endorsed the Joint APS/AIP/AAPT *Statement on the Education of Future Teachers* [7]. This is a welcome expression of *broad recognition in the physics community of its responsibility for improving K-12 physics education*. As APS Executive Officer Judy Franz observed, "This has been an amazing outpouring of support."

Fig. 1: WHAT'S WRONG WITH THIS STATEMENT?

Excerpt from the Joint APS/AIP/AAPT
Statement on the Education of Future Teachers:

"The scientific societies listed below urge the physics community, specifically physical science and engineering departments and their faculty members, to take an active role in improving the *pre-service training* of K-12 physics/science teachers. . . . *Strengthening the science education of future teachers addresses the pressing national need for improving K-12 physics education*."

However, APS News goes on to report that "despite their commitment to K-12 education, some schools are *wary of increasing faculty responsibilities*." As one department chair remarked, "Good K-12 training requires a large investment in time and money. . . and we just don't have that here currently." Thus, there is little reason to expect that current APS policy on K-12 science education will do much to stimulate needed pre-service reforms.

But that's not the worst of it. The statement on teacher education [Fig. 1], though well intentioned, is seriously misleading, for, as one department chair observed, "The statement suggests a *mechanism* for improving the science education of K-12 teachers." The problem is: that mechanism cannot work! *There is no realistic possibility, within even a decade, of significantly impacting K-12 science education by improving pre-service teacher training*.

Just look at the numbers for physics teachers in Fig. 2. The annual graduation rate of 400 teachers with degrees in physics or physics education is only half the replacement rate for in-service teachers [9]. Even if these new teachers were prepared to implement the needed reforms (though most are surely not), and considering the typical 40% attrition rate for new teachers, the replacement would be less than 10% in a decade. Moreover, few principals see any need to upgrade the qualifications of their physics teachers. Indeed, the loss of a physics teacher is usually addressed by asking an unqualified teacher already on the staff to teach physics. That is why the replacement rate for physics teachers in Fig. 2 is so much larger than the production rate.

Fig. 2. **High School Physics Teacher Profile** [8]

Pipeline: (~21,000 teachers in the U.S.)
Graduation (400/y), Attrition (1,000/y), Replacement (600-800/y)

Background (Degree):
Phys (33%), Math/eng (29%), Chem (25%), Biology (22%), Other (14%)

Teaching Assignment:
All physics (23%), Mostly (18%), Half (11%), Less (48%)

Prep for teaching (self-assessed):	Very good	Adequate	Not adequate
Basic physics:	72%	27%	2%
Recent physics:	15%	50%	35%

10% report some PER influence

Attitude toward Physics First: For (22%) Neutral (17%) Against (61%)

Morale: strong élan and satisfaction:
- 76% would choose physics teaching career again (82% in 1997)
- 2.5% attrition rate after 4 yrs.

Quite apart from the manifold problems of improving pre-service training, the data in Fig. 2 shows that its impact on physics teaching is sure to be small. The current trend will continue with 70% of physics teaching positions filled by crossover and post-baccalaureate teachers. This is not necessarily deplorable, for more than half of the teachers spend most of their time teaching other science and math courses. In small rural schools, for example, a single teacher is often responsible for all the science and math. This reality is not addressed in typical pre-service teacher training.

The bottom line is that to have a significant impact on science education in the schools, we must deal directly with the in-service teachers as they are. Accordingly, we maintain that

The impact of pre-service science education reform is small and slow!
Only in-service professional development can be broad and fast!

The latter claim is abundantly confirmed by our extensive experience with in-service physics teachers in the *Modeling Instruction Project* [10]. We have found that the vast majority is *eager and able* to profit from professional development. Most of the crossover teachers are not intimidated by physics or technology, and their physics teaching can improve quickly to compare favorably with that of teachers with a physics degree.

Our conclusions are supported by data in Fig. 2. The vast majority of physics teachers (most without a physics degree) love the job and are confident they can do it well. They are too confident, perhaps, as few are aware of the serious deficiencies in high school physics. Few see the need for improving physics pedagogy as advocated by the NSES and supported by Physics Education Research (PER). Furthermore, they know that their understanding of recent physics is inadequate, but they don't that as a big problem, because it lies outside the standard textbook-driven physics curriculum. Finally, they do not realize that a shift to a "physics first" [11] is an essential step in establishing a science curriculum that prepares students for the incipient age of nanotechnology and molecular biology. The upshot is that 80% or more of the in-service physics teachers are ill-prepared and unaware of the need for science education reform; nevertheless, they are ready and willing to work hard to improve their teaching. Since the schools are equally ill-prepared to give teachers the quality professional development they need, we must look to universities for help. That turns out to be more promising than one might at first expect.

A University Program to Cultivate Teacher Expertise.

Ultimately, all reform takes place in the classroom. Therefore, the key to reform is to *cultivate teacher expertise*. The need is especially critical for high school physics and chemistry teachers, because they are in the best position to set the level and tenor of science in their schools and serve as local leaders of education reform. *Above all teachers need opportunities for professional growth and a supportive school environment.*

Lifelong professional development is as essential for teachers as it is for doctors and scientists. It takes at least ten years to reach a high level of expertise in any profession [12]. Few teachers have adequate opportunities for sustained professional development, and many have an inadequate background in science to start with, so most remain far from reaching their full potential as teachers. The NSES emphasizes that "coherent and integrated programs" supporting "lifelong professional development" of science teachers are essential for significant reform. It states that "The conventional view of professional development for teachers needs to shift from technical training for specific skills to opportunities for intellectual professional growth." Such a program cannot be consistently maintained and enriched in any locality without dedicated support from a local university.

Though universities proudly proclaim rich opportunities for life-long learning, most science courses are designed for professionals, and the task of adapting the subject matter to the high school scene is too difficult for teachers to handle on their own. As the Modeling Instruction Project propagated across the country during the last decade, we heard a rising chorus of teachers calling for more of the same: more opportunities to collaborate and learn; better curriculum materials; deeper science. The demand was so great and the need was so obvious we felt compelled to respond with a full-fledged summer graduate program for them. The Modeling Instruction Project gave us a running start.

The very successful Modeling Workshops had already been institutionalized at ASU as a "methods of physics teaching course" for pre-service as well as in-service teachers. Moreover, ASU had an ill-defined graduate degree called the *Master of Natural Science* (MNS) that had long been used to cobble together a graduate degree for in-service teachers. It was a simple matter, then, to redesign the MNS with a coherent program of courses expressly designed to meet the needs and demands of the teachers. The new MNS requires significant participation of research physics faculty, so we were delighted when it was unanimously ratified by the whole department. Then it sailed through administrative channels to be incorporated in the official university catalog.

Fig. 4. **What teachers say about the MNS program**

The MNS physics degree is more valuable than I thought it would be, not only in my physics classes, but my chemistry classes as well. The content courses such as Physics and Astronomy, Light and Electron Optics, Structure of Matter, and Matter and Light not only deepened my understanding of quantum mechanics, models of atomic structure, and basic physics (other than mechanics) not emphasized in my undergraduate years, but I finally "saw" how much physics impacts the understanding of chemistry, especially at the atomic scale. I realized how much physics is needed to "do" chemistry and biology when I was exposed to the current technology and equipment including the SEM's and AFM microscopes. I was "blown away" at how little 20th and 21st century chemistry is taught in the high school, let alone in the physics high school courses. I not only feel I've developed a deeper understanding of the models in chemistry and physics and how they interact with one another, I've been able to use these models in my classroom. *Kristen M. Guyser, New Trier HS,Winnetka, IL*

The MNS program at ASU has provided enhancements to my ability to teach physics on multiple levels. First, the subject matter courses have broadened my own knowledge of physics. The modeling curriculum materials are invaluable. Second, the integrated courses allow me to work with my students in ways that make them more successful in mathematics and other sciences. Third, the degree itself is enabling me to offer my students premium opportunities such as dual-enrollment credit through the community college district. Finally, the direct contact with the university physics community has given me "connections" which I value highly. *Brian Bingham, Deer Valley HS, Glendale, AZ*

Everything offered in this program has been valuable to me, and relevant to what I do. I believe I have taken every course currently offered in this program. Most teachers I know have completed masters' degrees for the pay raise. As a private school teacher with 20 years experience there is no pay advantage. I took the courses purely for personal enrichment--because having done so *I have become a better physics teacher, learner and thinker.*"
Colleen Megowan, Jeff Schwartz HS, Scottsdale AZ

I started a Masters in Secondary Ed about 4-5 years ago and got nearly half way through it when I realized it was not making me a better science teacher. . . .*I finished the MNS Physics last summer and am very pleased with my choice. I am a better science teacher!* I upgraded my skills in science in every class I took. My confidence has improved, and I know many science teachers now.

*Action research was also a very valuable experience for me because for the first time I did primary research on the teaching of science in my own classroom. This has had a big impact on my understanding and appreciation of what goes into curriculum writing, but it has also sharpened my evaluation skills***.** I feel that I am operating at a new teaching level in the classroom. *Pam Herriman, Arizona School for the Arts, Phoenix AZ*

The MNS program has been in place for three years, and it has fulfilled our highest expectations. The response of the teachers could not be more enthusiastic (Fig. 4). This has stimulated the mathematics department to create a comparable program for in-service math teachers and couple it to the physics program. A movement is afoot to extend the MNS to a comprehensive graduate program for professional development of all in-service high school science and math teachers with the general objectives enunciated in Fig. 5. These exciting developments have induced us to submit our physics MNS program to a national audience as an exemplar for how physics departments can contribute most effectively to upgrading K-12 science education. The rest of this article describes the program, problems remaining and future prospects.

Fig. 5 **Objectives** of the MNS graduate program for science teachers:

1. To fulfill the obligation of higher education to provide science/math teachers with opportunities for relevant, *life-long professional development*.
2. To enhance the *professional status and qualifications* of inservice teachers.
3. To *link scientists to high school students* through direct contact with their teachers, and thus create a channel for effective outreach activities.
4. To support *continuous improvement* of K-12 science/math curriculum and instruction.

Design of the MNS Graduate Program

Although the program is intended primarily for physics teachers, much of it is appropriate for teachers of chemistry, physical science and mathematics. The main purpose of the program is professional development, so the MNS degree is almost incidental. (Indeed, half of the participants to date already have a masters degree). The program is also well designed for post-baccalaureate certification of graduates in science or engineering who want to switch to high school teaching.

All the MNS courses are designed specifically to meet the needs of inservice teachers for up-to-date science content and pedagogy. The courses are in three categories (Fig. 6), about which a few comments are in order:

Category I. Physics pedagogy. Core courses on Physics Teaching (PHS 530 & 531) are required for everyone in the program. *These courses provide thorough grounding in research-based physics pedagogy* in full accord with the NSES and in the use of computer technology in physics teaching. As the courses institutionalize the well-developed Modeling Workshops [10], their effectiveness has been thoroughly documented. Even so, the courses are continually updated with new developments in educational research and curriculum materials.

Most of the Category I courses are taught by 2-person teams of outstanding inservice physics teachers. This conforms to the "*peer teaching principle*" espoused by the NSES, which holds that professionals are best taught by peers who are exceptionally well-versed in the objectives, methods and problems of the profession. The Modeling Instruction Project has already prepared a large pool of such teachers who are eager to serve as workshop instructors. We draw on this pool to staff the Category I courses and assist in improving them.

Although all courses are subject to faculty oversight, professors and educational researchers play facilitory roles only in the Category I courses. Quite apart from the fact that master in-service teachers do a better job, it should be noted that there are not nearly enough professors to teach all the courses.

Fig. 6 **Master of Natural Science in Physics for inservice teachers**

- **Eligibility.** The program is open to inservice high school teachers who have completed college-level physics and a semester of introductory calculus. Under-prepared teachers can make up deficiencies in regularly scheduled courses.
- **Requirements.** A total of 30 graduate credits is required, selected from the *Courses in physics and physical science for teachers* listed below. A minimum of 15 credits must be taken in the "Teaching Methods" and "Integrated Science" categories listed there. This must include
- Six credits in "Methods of Physics Teaching," unless courses with an equivalent emphasis on physics pedagogy have been taken as an undergraduate.
- An Action Research Project for at least three credits.

  Graduate courses in physics or other natural sciences can apply toward the remaining credits if approved by the student's supervisory committee.

Courses in physics and physical science for teachers

Category I: Teaching Methods

PHS 530: Methods of Physics Teaching I (3-4)
PHS 531: Methods of Physics Teaching II (3-4)
PHS 534: Methods of teaching physical science (3)
PHS 598: Action Research in Physical Science (1-12)
PHS 594: Leadership Workshop (1-3)

Category II: Interdisciplinary Science

PHS 505: Energy and the Environment (3)
PHS 540: Integrated Physics and Chemistry (3)
PHS 542: Integrated Mathematics and Physics (3)
PHS 550: Physics and Astronomy (3)

Category III: Contemporary Physics

PHS 560: Matter and Light (3)
PHS 564: Light and Electron Optics (3)
PHS 581: Structure of Matter and its Properties (3)
PHS 570: Spacetime Physics (3)
PHS 556: Astrophysics (3)
PHS 593: Advanced Projects in Physical Science (1-12)

Category II. Interdisciplinary science. Courses in this category aim to (1) enhance teacher understanding of interdisciplinary connections to physics and relations of science to society; (2) help teachers determine how to use that understanding to enrich their own teaching, and (3) foster collaboration between physics teachers and teachers of other subjects.

As no precedents exist for most of these courses, they are under continual redevelopment with vigorous input from the teachers. For example, the course on integration of physics with chemistry (PHS 540) is taught by research faculty in both subjects. An innovative design has emerged with some excellent curriculum materials. However, there remain some knotty problems about modeling molecular bonding that challenge the faculty and intrigue the teachers. The purpose of the course is to stimulate true integration of physics and chemistry in high school with due attention to the rationale for a "physics first" sequence. The course is appropriate for chemistry teachers as well as physics teachers. Enrollment of physics/chemistry teacher teams from the same school is encouraged. As many physics teachers also teach chemistry, teachers have exerted tremendous pressure to develop a modeling approach to chemistry comparable to modeling physics.

Category III. Contemporary physics. These courses are taught by research faculty who work in areas addressed by the courses. The listed courses span the range of major research areas in contemporary physics and astronomy. They introduce teachers to ideas, methods and results of 20^{th} century physics that are ordinarily taught only to physics majors in advanced undergraduate and graduate programs. The courses bring high school physics teachers into extended contact with research faculty to share the excitement of scientific research. They provide unprecedented opportunities for researchers to explain their fields in lay terms to highly-motivated, well-informed teachers and thereby influence their students.

Leadership Workshop. This one-day-per-week workshop is directed by an experienced Teaching Associate. The main purpose is to build a cohesive peer learning community. Teachers share and compare what is going on in the various courses they are taking for information and feedback that might improve the courses. They consider collectively what needs to be done to improve their own teaching, and how they can contribute to broader reform of the science curriculum. Finally, they learn to conduct Action Research in their classrooms.

Course scheduling. We have learned from the Modeling Instruction Project that immersive summer workshop-courses of 3 to 4 weeks duration are most effective in changing teaching practices and melding teachers into a cohesive learning community. Consequently, most of the MNS courses are given in the summer when school is out. This also makes it possible to accommodate teachers from out of state and rural communities.

Faculty and Teaching Associates. ASU is a Research I university, so most of the faculty are committed to scientific research and research conferences during the summer. It is therefore imperative to organize their teaching of core content courses in a flexible manner that does not impede their research activities. This is achieved through *shared responsibility* that distributes responsibility for courses in the program across the faculty. Eventually there should be at least two faculty who are responsible for each course and its development, and course content will be closely related to their research specialties.

A Teaching Associate is assigned to each course to assist faculty in course design, development and conduct. **Teaching Associates** (TAs) are outstanding, experienced inservice physics teachers who are thoroughly versed in the methods and objectives of the Modeling Instruction Project. Their responsibilities include the following:

- Advise faculty on course level and pace and on specific course objectives
- Help with course design and selection of instructional materials. This will include a survey (with help from the project staff) of suitable instructional resources, including websites.
- Help organize and manage teacher work in collaborative groups.
- Provide faculty with objective feedback on teacher needs.

Course objectives. The ultimate target for the MNS program is not the teachers themselves but rather their students. Therefore each course addresses the subject at a level that prepares them to entice and inform their students. The teachers are engaged in activities and projects that they can set up for their students. As the standard high school curriculum does not include "contemporary physics," teachers need the material developed in a modular form that can be used for extracurricular projects and interest groups or in advanced enrichment courses for seniors. In the long run, this serves to prepare teachers for sorely needed content reform of high school science. Such reform, as advocated by AAAS Project 2061, will never be achieved without preparing the teachers.

Teaching Guidelines. Faculty who teach the MNS courses agree to support the objectives of the project and adhere to the following teaching guidelines, in accord with the general philosophy of Modeling Instruction. Their compliance is monitored, and their performance is assessed.

- *Selection of topics* is influenced by preferences and needs of the teachers.
- *Assignments* adapt course material to instructional modules that teachers can use with their own students.
- *Level*. Subjects are addressed at the level of a *Scientific American* article, although some use of algebra, calculus and vectors may be appropriate.
- *Modeling*. Teachers are involved in explicit formulation and analysis of the models inherent in the subject matter.
- *Collaborative learning*. Teacher expertise in collaborative learning is exploited in the design and conduct of class activities, experiments, discussions and presentations.
- *Lecturing* is limited in favor of discussion and collaborative learning.
- *Laboratory experience* acquaints the teachers with operation and use of modern scientific instruments such as the laser and the electron microscope.

Results and conclusions from ongoing evaluation of the program:

Response from both professors and teachers has been overwhelmingly positive, though we receive plenty of critical feedback on how to improve the courses and the program. Feedback is formally solicited through extensive questionnaires, and informally through many conversations and discussions, especially in the Leadership Workshop for teachers. Evaluations by teachers are solicited during the courses, as well as at the end.

The faculty has been uniformly delighted by the eager and receptive attitudes of the teachers, as shown by such comments as: "This was the most rewarding teaching experience of my career." "I really grew professionally." One professor, who has always been dismissive of teaching reform, began his course with the announcement "I don't do pedagogy, I just teach." Nevertheless, he adhered to the guidelines in conducting a very demanding course, and the teachers responded enthusiastically. He remarked, "I never had a group of students so eager to hang around and talk physics."

On a 10 point scale, teachers have given most courses an average overall rating close to 9. Written comments confirm that these numbers mean high teacher satisfaction with every course. Teachers are delighted with the respectful, open and collegial manner of the faculty. They are pleased with the demanding academic level of the courses. They have to work hard to keep up, and most of them relish the opportunity! Contrary to assertions that research faculty are insensitive to teacher needs, teacher feedback strongly confirms that the courses are meeting our primary objectives as to level and content:

- **Level.** The teachers in this program have a huge range of academic backgrounds, from minimal introductory physics to graduate physics or engineering and even a doctorate, though they share an enormous enthusiasm for science. Reports from teachers with the weakest backgrounds show that even they were not overwhelmed in any course. One reason for this remarkable outcome is the collaborative and supportive instructional design of the program. The teachers organize into study groups outside of class, with support from an experienced Teaching Associate and/or an advanced graduate physics student.

- **Content.** A primary objective of the courses in contemporary physics is to develop teacher appreciation and understanding of physics on the atomic and molecular scale, to prepare teachers for reforms needed to move high school science into the 21st century. The following typical teacher comments show that this objective has been well served: The course "renewed my interest in the small scale." "I need to incorporate more lessons on how technology is used in research and industry." "Wow! The hands-on field trips were extremely valuable . . . to touch and use the (electron and atomic force-probe) microscopes. It was so *exciting* to be in the presence of research and cutting-edge stuff!" "The class exceeded my expectations in every respect."

The teachers do not subordinate their critical faculties with undiluted praise. They have provided many important observations and suggestions for improving the courses, and the faculty have been most appreciative and responsive to this. Unlike most academic programs, the teachers work collaboratively with the faculty in shaping the courses.

Outreach and recruitment. A major objective of the MNS program is to foster professional ties between teachers and research faculty, thereby recognizing teachers as valued members of the scientific community. *Through the teachers scientists can establish a presence in high school classrooms to inspire students with the wonders of modern science and technology*. We submit that such ties between scientist, teacher and students will be far more effective in recruiting students to science and engineering than admonitions and advertising.

Consolidating the MNS program. The above case study shows that, with committed leadership and support from the physics department, it is not costly or difficult to set up an effective professional development program for physics teachers at a major state university. That is about all that can be done at the grass roots level. However, for the program to thrive and realize its potential to revitalize science education in the local schools, *leadership at the highest levels of the university administration is essential* to ensure commitment of adequate resources and establish partnerships with local school districts. To consolidate the MNS program at ASU, the following steps remain to be taken:

1. *Expand the MNS across all disciplines* to meet the professional development needs of all math/science teachers.
2. Supply *core faculty lines* in math/science education research to anchor the MNS program and drive sustained research to improve it.
3. Provide *incentives for research faculty* to participate, such as counting summer MNS teaching as part of teaching load.
4. Provide formal recognition and *adjunct faculty status* to outstanding in-service teachers with leadership roles in the MNS program.
5. Establish a university *office to promote school-university partnerships* that link the MNS program to curriculum and instruction reform in the schools.

School-University Partnerships to Implement Reform

No matter how well qualified, an individual teacher can do little to promote reform without support from his or her school. Sad to say, school policies tend to suppress individual initiatives. Systemic K-12 science education reform must be orchestrated at the school district level where policy is made [13]. School districts lack the necessary resources to plan and implement reform on their own. The missing resources can be supplied by a local university with a strong MNS program like the one we have discussed. Through school-university partnerships the MNS program can be designed to optimize support for coherent district-wide reform. Partnerships need not increase costs of education, though funds would have to be diverted to support them. On the contrary, they provide a mechanism for more efficient use of available funds.

The design of effective school-university partnerships to drive sustained K-12 science education reform is a very important and complex subject that we cannot do justice to here. Suffice it to say that a strong graduate program for in-service science teachers is an essential prerequisite for such a partnership, and that is a matter for the physics community to address.

Creation of partnerships will require leadership at the highest levels of local university and school administrations. This miracle is not likely to occur without strong stimulus from the scientific community.

Organizing National Resources to Promote Science Education Reform

The sorry state of science education today is due in large part to neglect by the science community. We attribute that neglect to inadequate institutional mechanisms rather than indifference or irresponsibility of individual scientists. To correct the deficiency, we recommend that the APS create a **National Center for Physics Education (NCPE)** to organize meetings and workshops in support of science education reform, especially to energize, inform and consolidate a growing community of leaders.

We submit that a major function of the NCPE should be to encourage and assist physics departments in creating and sustaining graduate programs for in-service science teachers like the MNS program described above. Though many universities have sufficient resources to put an MNS in place, they will need stimulus and support from the NCPE to get them engaged. Ultimately, the NCPE should aim to organize mutual support and collaboration for a network of universities to drive science education reform nationwide.

Of course, there is much more that the NCPE can do to organize resources of the physics community for science education reform, such as training master teachers and coordinating efforts in PER. It should not be overlooked that the major mechanism for federally funded research projects, including National Labs, to influence science education in the schools is through *Educational Outreach and Training (EOT)* programs that bring in-service teachers into direct contact with research scientists. The influence of EOT programs could be greatly amplified and improved by linking them to the NCPE.

Finally, we contend that the NCPE will not take long to get started if the physics community at large is behind it. The National *Center should be a Virtual Center*, not bricks and mortar. Presuming that the NCPE is sponsored jointly by the AAPT and the APS, it can be run by a small staff housed at the Center for Physics in College Park. For the most part, NCPE meetings and workshops will be held elsewhere, such as at supportive universities and in conjunction with APS/AAPT meetings.

This is not the first time that we have recommended creation of an NCPE. Our previous experience has convinced us that no action will be taken without strong advocacy from APS leaders (Fig. 7).

Fig. 7. Extract from an AAPT WHITE PAPER: **To improve the K-12 physics curriculum**
by John Hubisz, (NCState University), AAPT president elect for 2000-2001

"I have attended several meetings of folks who wanted to set up a Center for Physics Education (other names have been used) that would bring together all worthwhile resources in one location to serve as a place for teachers and researchers/authors to go to review what was available. Often the APS was involved and the Forum on Education perhaps even evolved from these discussions. The Database Project of the Forum certainly reflected that interest. In the past couple of weeks **I have received over 50 e-mail messages encouraging me to support the proposal of David Hestenes for a National Center for Physics Education.** If you have read this far you know that I will heartily endorse this project. **What has been missing in the past has been the enthusiasm expressed by these messages.** My paper at Beloit pointed out the problem of great efforts falling apart after the initiators moved on. The Hestenes proposal should help solve that problem. Perhaps the wheel will not be re-invented so often."

Despite this strong support, the AAPT Executive Board failed to act on the NCPE proposal or even to hold open hearings on the subject!

[1] For example: National Commission on Excellence in Education*, A Nation at Risk, The Imperative for Educational Reform;* US Dept. of Education. Washington DC (1983). *George, Melvin D.,* Shaping the Future; *NSF Report # 96-139 (1996). Third International Mathematics and Science Study* (TIMSS); Report issued by the US Dept. of Education and the National Center for Educational Statistics (1998).

[2] Committee on Science, U.S. House of Representatives, 105th Congress (1998), *Unlocking Our Future: Toward a New National Science Policy;* Washington, DC: U.S. Congress. Ehlers, Vernon J., *Calling for improvement in Math and Science Education in America*, Congressional Record—House: H11679 (November 8, 1999).

[3] National Research Council, *National Science Education Standards*, National Academy Press, Wash. DC, (1996).

[4] NCTM Standards (2003), http://standards.nctm.org

[5] R. Hake. Interactive-engagement vs. traditional methods: A six thousand-student survey of mechanics test data for introductory physics courses. *Am. J. Phys*.*,* **66**, 64-74 (1998).

[6] For example, APS Council "Policy Statement on K-12 Science and Mathematics Education" (#00.5, Nov. 2000), and statement on "Physics Education Research" (#99.2, May 1999)

[7] APS News, November 2003.

[8] M. Neuschatz & M. McFarling, "Broadening the Base," AIP (2003). Findings from the 2001 nationwide survey of high school physics teachers.

[9] Personal communication from Michael Neuschatz.

[10] Home page for the Modeling Instruction Project: http://modeling.asu.edu. After a deliberative process of more than two years by a Panel of Experts commissioned by the U.S. Department of Education, in January 2000 the *Modeling Instruction Project was the only*

high school science program in the nation to receive an exemplary rating. Ratings were based on (l) Quality of Program, (2) Educational Significance, (3) Evidence of Effectiveness, and (4) Usefulness to Others.

[11] "Physics first" is code word for a physics-chemistry-biology course sequence in high school. M. Bardeen & L. Lederman (1998), Coherence in Science Education, *Science* **281**: 178-179. Project ARISE, http://www-ed.fnal.gov/arise/

[12] K. Ericsson and N. Charness, "Expert performance, its structure and acquisition," *Am. Psychologist* **49**, 725-47 (1994).

[13] National Research Council, *Designing Mathematics andf Science Curriculum Programs, a Guide for Using Mathematics and Science Education Standards*, National Academy Press, Wash. DC (1999).

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