Arizona State University's preparation of out-of-field physics teachers: MNS summer program

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Arizona State University (ASU) has demonstrated the feasibility and effectiveness of a university-based graduate program dedicated to professional development of in-service physics teachers. This article is an expansion of my contributed talk at the AAPT Summer Meeting in 2010; included is an overview of the program, why it is needed, how it prepares out-of-field physics teachers, outcomes, and advice on how similar programs can improve high school physics nationwide.

I. Introduction:

Physics is crucial to civilization in this time of great challenges in technology, environment, and society. Our nation faces a severe shortage of scientific and engineering professionals and technical workers. The problem starts in K-12 education (BHEF, 2005). High school physics is crucial for hundreds of types of jobs, including automotive technicians, machinists, heating/air conditioning mechanics, physical therapists, and engineers.

More broadly, we need a populace who can think critically and creatively. That is a chief goal of Modeling Instruction. Joseph Vanderway, a young physics teacher near Los Angeles who graduated with a degree in physics from M.I.T., tells his physics classes on the first day, "I'm here to teach you to think, and physics is my vehicle."

A problem is that two-thirds of all physics teachers in the U.S.A. do not have a degree in physics or physics education (Neuschatz et al., 2008). They need professional development! In fact, even teachers who have Ph.D.s in physics need research-informed professional development such as Modeling Instruction workshops to improve their effectiveness (Hestenes et al., 1992, Wells et al., 1995).

Arizona State University (ASU) has demonstrated the feasibility and effectiveness of a university-based graduate program dedicated to professional development of in-service physics and physical science teachers. We refer to this program as the MNS program, as it can culminate in a Master of Natural Science degree.

A snapshot view of the program: in summer 2010, 120 teachers participated in the MNS program, choosing from five different Modeling Workshops, an astronomy course, and a Leadership Workshop. Most are Arizona teachers, supported financially by ASU physics professor Robert Culbertson's and my NCLB Title IIA "Improving Teacher Quality" state grant (ESEA, 2002) and by ASU's College of Liberal Arts and Sciences, which provides 55 tuition exemptions. (No Child Left Behind – NCLB -- is the nickname for the Elementary and Secondary Education Act, ESEA.) Among the 120 teachers were 16 who are enrolled in our summers-only MNS degree program in physics; one-fourth of these degree candidates are from other states, and only one majored in physics.

From inception in 2001 through 2010, about 840 different teachers participated in the MNS program, including twenty-one of Singapore's best physics and chemistry teachers. (Singapore's K-12 science scores are best in the world! For four years the Singapore Ministry of Education has had a yearly competition to send teachers to ASU; and each summer they fly two Modeling Workshop leaders to Singapore to lead introductory workshops for a week.)

Of these 840 teachers, 515 took one or more Modeling Workshops in physics, 175 took chemistry Modeling Workshops, and 140 took physical science Modeling Workshops. Of the 515 teachers who completed a physics Modeling Workshop (called a "methods of teaching physics" course), only 25% have a degree in physics or physics education. Thus 385 did not, and of this group, about 35 did not intend to teach high school physics. In ten years of existence, therefore, the MNS program has contributed to the professional development of about 350 out-of-field physics teachers. About 20% of these out-of-field teachers have a degree in biology, 20% chemistry, 15% engineering, and the rest in other sciences, mathematics, and non-science disciplines.

This article is an overview of our MNS program, why it is needed, how it prepares out-of-field physics teachers, outcomes, and advice on how programs like ours can greatly improve high school physics nationwide. The MNS program is described at http://modeling.asu.edu/MNS/MNS.html.

We take for granted the pedagogical effectiveness of Modeling Instruction, as that was thoroughly documented in the Findings of a National Science Foundation (NSF) Teacher Enhancement grant entitled *Modeling Instruction in High School Physics* (Hestenes, 2000). Modeling Instruction is an inquiry method for teaching science by actively engaging students in all aspects of scientific modeling. Modeling is about making and using scientific descriptions (models) of physical phenomena and processes (Wells et al., 1995, Jackson et al., 2008). Two Panels of Experts commissioned by the U.S. Department of Education evaluated modeling Instruction. In 2000, Modeling Instruction in High School Physics was designated as one of seven Exemplary or Promising K-12 educational technology projects out of 134 projects reviewed. After a nationwide study, in 2001 Modeling Instruction was one of two K-12 science projects designated as Exemplary out of 28 projects reviewed. Ratings were based on: (l) Quality of Program, (2) Educational Significance, (3) Evidence of Effectiveness, and (4) Usefulness to Others (Expert Panel Reviews 2001, 2000).

II. Essential components of the MNS program are:

1) A complete graduate curriculum of eighteen courses designed expressly for in-service teachers, offered in three- or 4.5-week sessions in summer, providing extended intensive peer interaction.
2) Core courses that model ideal high school courses (i.e. Modeling Workshops) in workshop format that integrates pedagogy and content (Wenning, 2007), taught by a team of experienced in-service teachers (not university professors!), providing teachers with instructional materials and course designs ready for immediate implementation (Schneider et al., 2002). The courses are cross-listed as undergraduate courses and offered for pre-service science education majors.
3) Engagement of university research faculty in teaching advanced physics and chemistry courses aimed at educating teachers about current developments in science, and thus linking research faculty to high school students through their teachers,
4) An integrated program of interdisciplinary courses, especially in chemistry and physical science, since many participants teach all these subjects.

III. Why the MNS program? The need.

Ultimately, all educational reform takes place in the classroom. Therefore, the key to science education reform is to cultivate teacher expertise. That is what the MNS program is designed to do. Lifelong professional development is as essential for teachers as it is for doctors and scientists.

The national physics teacher workforce crisis: Many observers of the science education scene are alarmed by the severe and growing shortage of qualified physics teachers (PTEC). The annual graduation rate of 400 teachers with degrees in physics or physics education is scarcely half the replacement rate for in-service teachers. The attrition rate is about 1,000/yr, so a replacement rate of 600-800/year is needed (Neuschatz et al., 2008). Obviously, the problem will be compounded if the widely advocated increase in high school physics courses is implemented. The bottom line is that to have a significant impact on physics education in the schools, we must deal directly with the in-service teachers as they are. Thus we conclude that the impact of pre-service physics education reform is small and slow! Only in-service professional development can be broad and fast!

The MNS program confirms this conclusion, as it has addressed the physics education needs of a hundred or more out-of-field (crossover) teachers who are new to physics (coming in about equal numbers from chemistry and biology, and even larger numbers from all other majors considered together). Moreover, we have good news to report: In the Modeling Instruction Program the vast majority of crossover teachers soon lose any lingering fears of physics and technology to demonstrate that they are eager and able to learn what is needed to be a proficient physics teacher.

As of 2009, 8% of the currently active 23,000 physics teachers in the U.S. had taken a Modeling Workshop, and most of them are strong advocates of the approach. This 8% figure is troubling, for an American Institute of Physics nationwide survey of high school physics teachers reveals that only 8% report that physics education research (PER) has an impact on their teaching (Neuschatz et al., 2008). We surmise that it is mostly the same 8 percent, for PER is a specific emphasis in Modeling Workshops. The success of Modeling Instruction is largely attributable to its thorough grounding in PER and its design for continued upgrades in methods and materials with strong PER input. We physics educators must greatly improve the influence of PER on high school physics.

Steps to extend the MNS program to all sciences are underway, though progress is heavily grant dependent. The need is great, for the problem of out-of-field teachers is even worse in physical science (Ingersoll, 2002) and almost as bad in chemistry. ASU is prepared to be a national leader in professional development for K-12 science teachers.

IV. Strengths, weaknesses, and prospects of the MNS program.

Strengths of the ASU MNS program are these:
1) It is high quality and effective in student learning, since it is founded on Modeling Instruction.
2) Therefore it attracts smart, committed teachers and peer leaders like Tim Burgess of Mobile, Alabama,

and Michael Crofton of Minneapolis, Minnesota, both of whom regularly have student mean posttest scores on the Force Concept Inventory of 80% or higher, with normalized FCI gains (Hake, 1998) of 0.75 to 0.80 -- better than in any other reform program that we are aware of.
3) ASU is located in a metropolitan area approaching four million, where a large number of physics, chemistry, and physical science teachers can commute. Of Arizona's 280 physics teachers, more than half live within commuting distance of ASU.
4) Affordable housing is available, essential for long-distance teachers.
5) It has support from the ASU Department of Physics and the Dean of Natural Sciences, who has authorized 55 tuition exemptions each summer.

Weaknesses of the MNS program are these:
1) Only one state funding source is available: the Elementary and Secondary Education Act (ESEA) Title IIA "Improving Teacher Quality" (ITQ) program (ESEA, 2002). This is an intervention program of the U.S. Department of Education; 2.5% of formula Title IIA funds that currently go to each state are set aside for the State Agency of Higher Education (SAHE) and are must be used for a yearly competition among institutions of higher education in the state for sustained, high quality K-12 in-service teacher and/or principal professional development in core academic subjects.

Unfortunately, the ITQ program is slated to die if/when the ESEA re-authorization occurs (probably in early 2011); it is not part of the published "Blueprint" of the U.S. Department of Education (ESEA, 2010, SHEEO, 2010). We have applied for NSF grants to partially replace the imminent loss of ITQ funding.

The state Math-Science Partnership program, another intervention program of the U.S. Department of Education (ESEA, 2002), is not an option, for the state designed it for each grant to be for one high-need school district; the paperwork and procedures are daunting for state-level high school science programs such as ours, which has participants each year from two dozen school districts, a dozen charter schools, and several parochial schools, with one or two participating teachers from each school.

NSF Math-Science Partnerships are not an option, for they are highly competitive and not cost-effective because they require research and $1000 per week stipends; too few teachers could be funded.
2) Instability: ITQ grants are short-term (one or two years), and they require yearly requests for budgets. Also, physics competes with all other K-12 academic core subjects and grade levels.
3) Tuition and fees at ASU are expensive. In summer 2011 the cost is almost $2000 for a three-semester-hour Modeling Workshop for Arizona teachers and $2900 for out-of-state teachers. Our dean's authorization of 55 tuition exemptions is dependent upon our having a grant to pay 17% of tuition back to ASU. Teacher salaries are typically around $35,000; three-fourths of Arizona physics teachers are men, many of whom are young, have children, and are the chief breadwinner of their family. The economic downturn exacerbates their financial problem.

Future prospects: The ASU Department of Chemistry has expressed interest in developing a few courses so that high school chemistry teachers can earn a MNS degree with concentration in chemistry. Currently some chemistry teachers earn the MNS degree, but their concentration must be in physics.

V. Supporting evidence:

In our Final Report submitted to the NSF for the grant entitled *A Graduate Program for Secondary Physics Teachers (2002 – 2005)* (Hestenes and Jackson, 2006), we documented four types of evidence for the importance and effectiveness of the MNS program. Here we discuss only teacher competence as measured by the Force Concept Inventory (FCI) (Hestenes et al., 1992).

We administered the FCI to all 226 teachers who took the three-week Modeling Workshop in mechanics during the four summers of the NSF grant (2002-2005), at the beginning and end of the Workshop. Actual test questions were not reviewed during the Workshop, though how to teach the force concept was a central theme of the course. Pretest and posttest results show a substantial gain. Low pretest scores come from out-of-field teachers (many from biology) with very little background in physics, and their gains are impressive. We know from previous studies that their scores will continue to rise during a year of teaching what they have learned in the Modeling Workshop (Hestenes, 2000). We conclude, therefore, that most participants are adequately prepared for teaching mechanics after the initial Workshop, and many have excellent preparation. Of course, this is the result of just the first in a sequence of four Workshops on high school physics.

Of participating teachers during the NSF grant period, 85% were assigned to teach physics: half taught one or two sections and 30% taught physics only. Crossover teachers indicated they were 'retooling' from other disciplines, often to teach "Physics First" (23 teachers in one summer!). Two-thirds of the teachers who took Methods of Teaching

Physics I (the Modeling Workshop in mechanics) had taught physics for four years or fewer. One-third had never taught physics, including 38 (17%) who were experienced teachers of other subjects who had been drafted into teaching physics, and 16 pre-service teachers. One-third of participants were female.

To analyze FCI data, we categorized these teachers as follows. In-field: One-fourth of the 226 teachers (62) majored in physics or physics education. Twenty-one teachers (9%) majored in engineering. Eight teachers had degrees in physical science, for a total of 91 in-field teachers (40%). Out-of-field: The second and third most popular degrees were biology and chemistry, with about 17% each (39 and 35 teachers, respectively). The remaining 30% of teachers had content majors in geology, general science, math, social sciences, humanities, elementary education, and home economics. A total of 131 teachers were out-of-field (60%).

FCI data were disaggregated according to content major, physics teaching experience, and gender. FCI results are in Figure 1.

The Modeling Workshop produced the largest FCI gains for out-of-field teachers and teachers with little physics teaching experience. Sixty-five new physics crossover teachers were prepared: 32 who had never taught physics but intended to, and 33 who had taught physics for one to three years. (One might consider adding the 21 teachers with engineering degrees, who are in some sense out-of-field but have had courses in what is essentially applied physics.) (Note that women had less physics teaching experience and lower FCI scores than men.)

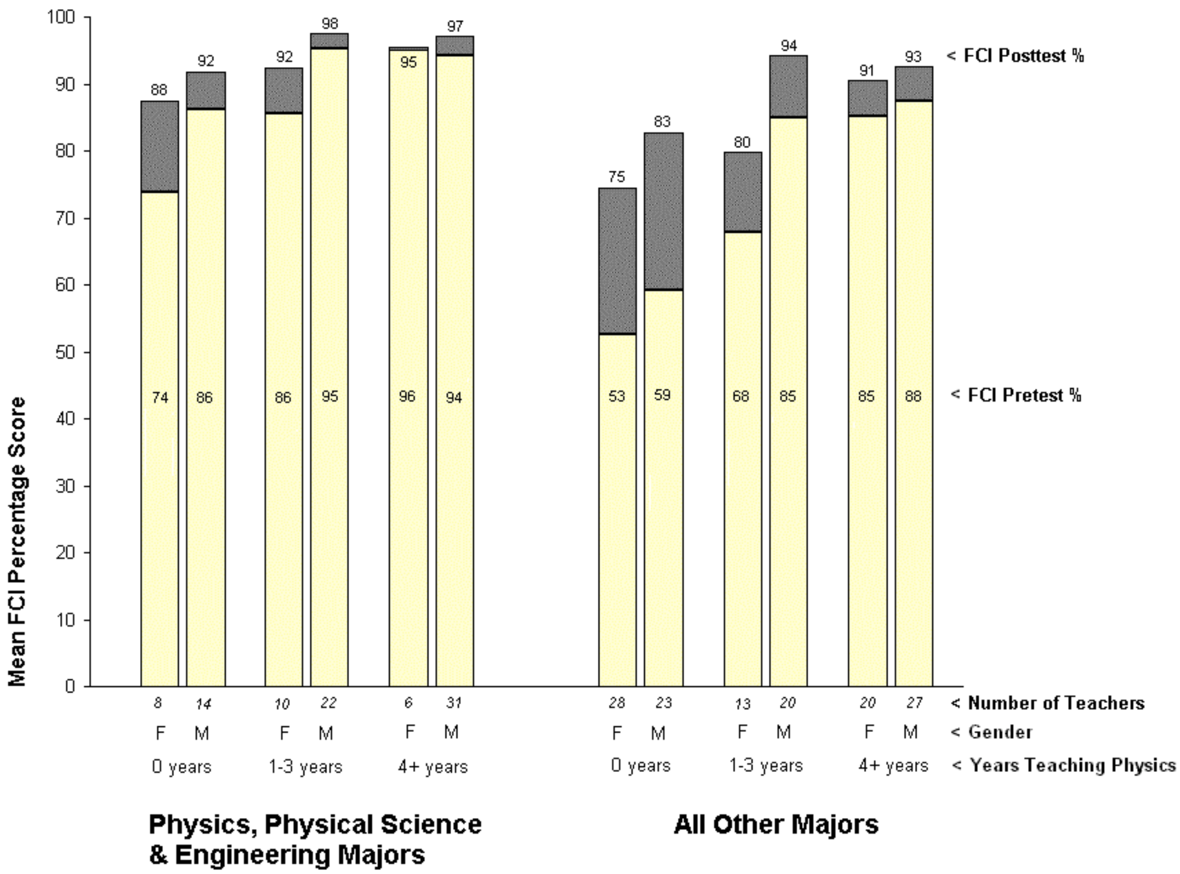

Figure 1: Force Concept Inventory mean percentage scores (pretest and posttest) for 222 women and men in Modeling Workshop in mechanics, correlated with physics teaching experience and content major in college.

Additional quantitative data and graphs on the Mechanics Baseline Test (MBT) are in the NSF final report; also qualitative data and feedback from these teachers (Hestenes and Jackson, 2006).

VI. Outcomes of the MNS program

Reactions to the MNS program from both teachers and professors have been overwhelmingly positive. A North Central Accreditation Academic Program Review Committee evaluating the ASU physics department reported in May 2005: "One of the important ways that ASU is currently elevating science education in Arizona is its unique Master of Natural Science (MNS) program for in-service teachers. There appears to be no comparable program at any other university in the United States, and it stands as an exemplary model of how physics departments can improve high school physics education" (Brodsky et al., 2005).

Most outcomes are similar for in-field and out-of-field teachers, but here we highlight outcomes of Modeling Instruction for out-of-field physics teachers in regard to their preparation and retention, and their students' choices of STEM majors in college.

1) **Certification and NCLB Highly Qualified status.** In fall 2008, Dr. Stamatis Vokos of the National Task Force on Teacher Education in Physics (see http://www.ptec.org/webdocs/TaskForce.cfm) asked us to report on effects of the ASU MNS program on physics certification and Highly Qualified (HQ) status (ESEA, 2002) of metropolitan Phoenix physics teachers. We conducted a survey and found that half (24 out of 52 respondees) of the 60 newer local public school physics teachers (i.e., those who taught physics six years or less) became certified or were progressing toward HQ due to ASU Modeling Workshops. Eighteen (~75%) did not have a degree in physics, physics education, or physical science. All 24 teachers cited Modeling Workshops as their most important preparation. (Thirty-eight of the 52 teachers, i.e. three-fourths, had taken a Modeling Workshop, but some of them took it after becoming HQ and/or physics-certified). Also, eight long-distance out-of-field Arizona public school physics teachers were progressing toward HQ via multiple ASU summer Modeling Workshops.

We did a preliminary survey of non-Arizona teacher participants (65 responses out of 220 teachers surveyed) and learned that six out-of-state teachers and four Arizona teachers had recently achieved National Board Certification. All ten of them cited Modeling Workshops as their most important preparation. Most of the ten are out-of-field.

On both surveys, prevalent comments are that Modeling Workshops improved or transformed their classroom teaching. Typical comments by Arizona teachers are, "By far the Mechanics modeling course was THE best preparational course." "… the modeling courses were a tremendous help. Waves, Light and Mechanics helped the most." "I am a big supporter of the modeling program ... the courses have been more useful to me in terms of helping me teach than any courses I took through the College of Education while I was getting my post-bac certification."

2) **Retention of physics teachers.** Out-of-field and in-field physics teachers have written that Modeling Workshops "saved their careers" and kept them in the profession. Quotes by teachers are at http://modeling.asu.edu/SuccessStories_MI.htm.

A response from the 2008 Arizona survey that may become more common and bears noting is this one: "As an alternative track teacher, I teach 4 different types of classes (math and physics) and take education courses to become fully certified, so it has been wonderful to have many of the physics lessons planned out before the school year started. … Without the Modeling course I could have easily become one of the many alternative track teachers that leave the teaching profession before they have a chance to become proficient."

Several crossover teachers have become Modeling Workshop leaders, notably Larry Dukerich, whose degree is in chemistry. After teaching chemistry and physical science for a decade, he became a physics teacher and seven years later took two five-week Modeling Workshops from Malcolm Wells in 1991 and 1992. He has distinguished himself from 1993 to the present day by leading many Modeling Workshops in physics, chemistry, and physical science and leading teams of experienced teachers and faculty researchers to develop educative curriculum materials (Schneider et al., 2002). In summer 2007, Kelli Gamez Warble, a long-time mechanics Modeling Workshop co-leader at ASU whose degree is in mathematics, surprised a group of us by stating that she would have left teaching years ago for a more lucrative career in finance if it weren't for Modeling Instruction.

3) **STEM majors in college.** Many teachers, in-field and out-of-field, report that a larger percentage of their students choose STEM majors in college than before they began using Modeling Instruction. We have not had funds nor time to conduct research on this, but anecdotal reports by teachers are at http://modeling.asu.edu/SuccessStories_MI.html. For example, Carmela Minaya, a chemistry teacher in Hawaii who earned an MNS degree, wrote: "I have several [former] students who are majoring in science

related fields largely due to the implementation of Modeling Instruction in my classroom. The percentage has gone up from 13% (pre-modeling) to 51% in more recent years."

VII. Recommendations: how the nation can improve high school physics.

Modeling Instruction is a grass-roots, bottom-up nationwide program of 2300 active physics teachers and 700 chemistry teachers, led by enthusiastic, dedicated, smart teachers, with guidance from physics and chemistry education research faculty. Our decade-long summer program at ASU and our experience helping to coordinate 300 intensive three-week Modeling Workshops nationwide has convinced us of several key insights to improve physics, chemistry, and physical science teaching and learning in the U.S.A. The problem of out-of-field physics teachers will persist, and our recommendations take this into account.

1. The need is overwhelming for in-depth, stable, research-informed professional development programs that unite physical sciences content and effective pedagogy. K-12 teaching is a 'revolving door', even in physics. The job turnover, the huge percentage of out-of-field teachers (Ingersoll, 2002), and the low 8% of physics teachers who are influenced by physics education research are evidences of the need.

2. School districts can't solve the problem; it needs regional and Federal solutions. Few school districts have enough physics, chemistry, and physical science teachers to support professional development for them; and school districts are not equipped to conduct the necessary professional development on their own because they lack expertise in science and technology as well as resources to keep up to date on science curriculum and pedagogy. These intellectual resources reside in universities, chiefly in physics and chemistry departments. Note that a recent report by the business community puts STEM professional development as the responsibility of universities (BHEF, 2007).

In the impending ESEA reauthorization, helpful legislative action would be an ITQ-like program that gives priority to high-need STEM subjects and that encourages long-term grants and interstate cooperation. The ITQ program is intervention, not research nor development, and thus cost-effective.

The best legislative action, we believe, would be to implement the top recommendation of the K-12 Focus Group of "Rising Above the Gathering Storm". That group was charged to come up with the "top three actions the federal government could take so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century" (NRC, 2005). The top recommendation has not been implemented. It is:

> "The federal government should provide peer-reviewed long-term support for programs to develop and support a K-12 teacher core that is well-prepared to teach STEM subjects.
>
> a. Programs for in-service teacher development that provide in-depth content and pedagogical knowledge; some examples include summer programs, Master's programs, and mentor teachers.
>
> b. Provide scholarship funds to in-service teachers to participate in summer institutes and content-intensive degree programs.
>
> c. Provide seed grants to universities and colleges to provide summer institute and content-intensive degree programs for in-service teachers."

Apparently current NSF policy prevents a solution of NSF funding, for the NSF's mission is research and development, not intervention. The NSF Education and Human Resources (EHR) Division set policy under Judith Ramalay's leadership that they lack enough resources for interventions (Colby, 2010).

3. Modeling Workshops are fundamental courses. This is evident from their outstanding evaluations by teachers of all content backgrounds and degrees, from all states, and from ages 21 to 69. In the ten years at ASU, on a scale of 1 (poor) to 10 (excellent), teachers gave almost every Modeling Workshop an overall rating above 9, with little individual variation in their rating.

Modeling Workshop leaders are convinced that in-person, face-to-face Modeling Workshops are essential to teach the pedagogy, including model-centered discourse and use of classroom technology in modeling cycles. They believe that hybrid advanced Modeling Workshops can be developed but are inferior to in-person workshops. We will explore this if we can get funding.

4. Costs to teachers must be minimal. Eighty Phoenix-area physics teachers wrote in surveys in 2006 and 2007 that they can afford to pay a maximum of about $150 for a three-credit course. Out-of-state teachers tell us that costs are prohibitive. We find that in most cases only upper-middle class schools, mostly private, can give financial help; and the economic downturn is hampering even these. Almost all Arizona schools have not given any financial help to their teachers, even though we urge teachers to ask for school district Title IIA funds and we give them a sample proposal. Teachers want only to have tuition, room, board, and travel expenses met; they tell us that they don't expect an additional stipend (Hestenes and Jackson, 2006).

To amplify our recommendation #2: school districts and states can't or won't pay; so the funding initiative must come from the Federal government or private philanthropy. How else can education in the physical sciences serve the nation's needs for 21st century technological workforce preparation and economic development? Our nation neglects in-service STEM teacher development at our peril.

5. Chemistry Modeling Workshops are essential. Many physics teachers are primarily chemistry teachers. They need instruction in chemistry modeling, they need to deepen their understanding of chemistry content, and they must relate the two subjects. A dearth of professional development and masters degree programs exists nationwide for chemistry teachers. A result is that several teachers who have earned a MNS degree in physics are strictly chemistry teachers.

6. Cultivate physics teachers to lead reform. We see positive effects on teachers' leadership in their schools and regions. Many out-of-state teachers lead Modeling Workshops in their regions, thereby building local communities of practice. Teachers become more effective by this type of leadership. A promising prospect is to prepare instructional leaders in science to serve in schools and school districts, as called for in the Blueprint for the impending ESEA re-authorization, with its emphasis on data-driven instruction and effective teachers via job-embedded professional development (ESEA, 2010).

7. Lifelong learning must be the focus. ASU's MNS program is unique: it is the only content-centered, research-informed graduate program in the nation specifically designed for all physics teachers, no matter what their background, and focused on lifelong learning, with a degree as a subsidiary focus. Few other research-informed programs for physics teachers exist. Some remedial programs for out-of-field teachers are conventional lecture/problem solving and don't give teachers what they really need. (We believe that MNS-like programs are insufficient for lifelong learning; ideally, they should anchor local physics alliances.)

We must do better as a nation, and the success of the MNS program shows an effective way. Most teachers come to ASU for lifelong learning. In written surveys that we gave in summers 2006 and 2007 to 80 participating Arizona physics and chemistry teachers, almost all teachers responded that lifelong professional development is "extremely important" or "very important" to them. (See http://modeling.asu.edu/MNS/ProfDevNeeds-STEMtchrs.htm for a summary.)

Overwhelmingly these teachers indicated that three-week summer Modeling Workshops are their preferred type of professional development, rather than short content courses in summer, summer research in business or university, Saturday workshops in the academic year, online courses, and several other choices. Example responses are, "It is exactly what I need" and "the only useful professional development I have ever had".

Acknowledgement: My thanks to David Hestenes, founder of the MNS program. Many of the best ideas expressed here are his. A pertinent quote that he had from his father, and that he shares with us, is: "Ideas belong to whoever wants to work on them."

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State Higher Education Executive Officers (SHEEO March 2010): "The Obama Administration's blueprint for ESEA reauthorization and FY 2011 Budget proposal eliminate ... ESEA Title II Improving Teacher Quality (ITQ) State Grants, administered by state agencies of higher education and reserved for partnership grants between higher education institutions and local school districts, currently funded at $72.5 million. The blueprint proposes moving these funds into a new authority in ESEA called the "Teachers and Leaders Pathway" program, under which $405 million would be available for competitive grants to local school districts and states, but the role and responsibilities of institutions of higher education and state higher education agencies are vague and indirect at best." Available: http://www.sheeo.org in the legislation section.

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