GUEST EDITORIAL

A role for physicists in STEM education reform

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I. INTRODUCTION

The national crisis in K-12 STEM education is thoroughly documented, and calls are loud and clear for immediate action to maintain the status and competitiveness of the United States in the global economy.[1] Even so, education reform continues to flounder despite massive investments from the U.S. government. It is natural to wonder why.

To serve as an authoritative guide for deep and coherent STEM education reform, the National Research Council (NRC) has recently published *A Framework for K-12 Science Education*.[2] The "Framework" was developed by a distinguished committee of the NRC led by physicist Helen Quinn. They did a masterful job of updating previous recommendations and broadening them to include engineering and technology, with a balanced emphasis on scientific inquiry and engineering design.

As a guide for implementing the Framework, the *Next Generation Science Standards* (NGSS)[3] was developed collaboratively with states and other stakeholders in science education and industry in a process led by a nonprofit organization called Achieve.[4] Progress has stalled since then. Many states have been slow to adopt the NGSS, while others created committees to pick it apart and, in the name of accountability, establish a hodgepodge of hurdles and hoops for schools to prove that they are teaching the students something. The details are left to the schools and school districts.

The outcome can be predicted with certainty. For we have already seen how the last generation of National Science Education Standards[5] was diluted and butchered almost beyond recognition at state and local levels. Typically, the schools solve the problem of STEM education by ordering textbooks from publishers who carefully note how each particular standard is covered in their books. Too often, teaching is reduced to passing out textbooks and assignments, followed by drill and practice with hope for a good return on mandated exams. Too seldom, the principal encourages and supports independent/innovative initiatives by the teacher.

How could it be otherwise? Schools and school districts are ill-equipped to implement reforms and conduct the necessary professional development on their own, because 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. Nor can we expect reform from schools of education. The education establishment is too slow and ponderous to cope with the rapid evolution of the STEM disciplines, and responsibility is too broadly distributed for decisive action.

Fortunately, there is a better way. A new approach to STEM education reform that has emerged from the physics community and will depend on its support for continued success. My aim here is to argue that certain elements of this approach are essential for ultimate reform. This is not to deny the value of other approaches; indeed, diversity is welcome, and continued progress will require contributions from across the scientific community. But I am offering a perspective drawn from a program that I have been intimately involved with for more than two decades. Only a brief description of the origin, state, and potential of this new approach to broad STEM education reform is possible in this editorial. More details are given elsewhere.[6,7]

II. CULTIVATING TEACHER EXPERTISE

The serious problem of pre-service preparation for physics teaching has been thoroughly addressed in a recent editorial in this journal,[8] and I fully concur with their assessment. But pre-service preparation is only one side of the coin; the other side is in-service professional development. I am not the only one who thinks that such continuing professional development is important. As the prestigious Glenn Commission[9] concluded:

> "We are of one mind in our belief that the way to interest children in mathematics and science is through teachers who are not only enthusiastic about their subjects, but who are also steeped in their disciplines and who have the professional training—as teachers—to teach those subjects well. Nor is this teacher training simply a matter of preparation; it depends just as much—or even more—on sustained, high-quality professional development."

This conclusion is abundantly supported by the remarkable success of the *Modeling Instruction Program* over the last 24 years. Since I have been involved from the beginning, I can give you an insiders view of its evolution. The program is grounded in a decade of physics education research that led to the development of a scientific pedagogy called *Modeling Instruction*, so named because it takes the creation and use of conceptual models as the core of scientific practice. Modeling Instruction was then embedded in a series of summer *Modeling Workshops* on teaching introductory physics, which began in 1990. Over the next fifteen years, with support from the National Science Foundation (NSF), Modeling Instruction evolved into a national program for physics teaching reform. To date, more than 3000 physics teachers—10% of physics teachers in the U.S.—have taken a Modeling Workshop.

Many participants in the physics Modeling Workshops were "crossover teachers" from chemistry, biology, and mathematics. They were so impressed with the pedagogy that they demanded similar workshops in their fields. Thus, the teachers themselves took the lead in developing Modeling Workshops in chemistry, physical science, and biology, and they are well on their way to creating a fully integrated set of STEM curriculum materials in full accord with the NRC Framework for science education. To my knowledge, no other program is half so far along in curricular development—and this by teachers themselves without significant external funding.

In 2005, when NSF funding for Modeling Instruction ceased, the teachers created their own organization, the *American Modeling Teachers Association* (AMTA),[10] to keep the program going. To date, the AMTA has more than 2000 members, and coordinates 80 Modeling Workshops for science teachers each summer. Approximately 7500 teachers have attended one or more Modeling workshops, and of these teachers, almost 6000 of them are still subscribed to one or more of seven Modeling listservs.

I used to worry about the fact that some two thirds of high school physics teachers do not have even an undergraduate minor in physics, and the pipeline for new teachers can hardly keep up with the retirement rate.[8] But, in my years directing the Modeling Program, I have seen that many crossover teachers do a much better job teaching physics than most physics majors. I attribute this partly to their embrace of Modeling pedagogy and partly to the intellectual curiosity and self-confidence of those who venture to crossover teaching. Outcomes have convinced me that training in summer Modeling Workshops is sufficient to develop any capable individual with some background in science or engineering into a competent STEM teacher—especially with the continued support and fellowship provided by the AMTA.

To my utter surprise and delight, the Modeling Program has morphed into a large, cohesive community of practice with a common vision of effective STEM teaching. Though I helped get it started, the teachers did the heavy lifting, and the AMTA is prepared to marshal the teachers in a collaborative effort to reform STEM education across the board. It is time now for the community of scientists, especially physicists, to step up in support.

III. AN ESSENTAL ROLE FOR PHYSICISTS IN STEM ED REFORM

Physicists know that physics must play a leading role in STEM education. This has been expressed explicitly in the American Association of Physics Teacher (AAPT) advocacy of *Physics First*,[11] a reorganization of high school science that puts physics in 9th grade, before chemistry and biology. Opponents claim that physics is too difficult for most students and point to failures in implementing Physics First. On the contrary, the AMTA has decisive evidence[12–14] of successful implementation with Modeling pedagogy and clear benefits for STEM courses that follow.

Another successful approach called *Physics Union Mathematics* (PUM)[15] expressly addresses the important problem of integrating physics with mathematics at the 9th grade level. It draws from the *Investigative Science Learning Environment*[16] for introductory physics developed by Eugenia Etkina and Alan Van Heuvelen, which is fully compatible with the Modeling approach. A common ingredient of these successful courses is grounding in Physics Education Research. Besides serving as the keystone course for the ideal of physics for all citizens, 9th grade physics is the lynchpin for unifying the entire STEM curriculum.

There are also deep psychological reasons why physics should play a central role in the STEM curriculum. It is no accident that physics and astronomy were the first sciences to develop historically. Physics is the science most closely related to our basic perceptions of matter, motion, and light. The science of force and motion should be taught first, because it relates directly to the students sensory experience. Furthermore, physics provides the foundation for quantitative methods in the rest of science, and it stands as the first exemplar of scientific method. Quantitative reasoning with number and unit goes hand-in-hand with modeling and measurement, which couples mathematics to science.

For nationwide implementation of STEM education reform, the AMTA needs strong support from the physics community. Reform can move rapidly forward without waiting for new funding because the AMTA already has a stable of accomplished teachers ready to move, and only physicists have the resources at hand to support them. In particular, PhysTEC,[17] a partnership between the American Physical Society (APS) and the AAPT to help a coalition of more than 300 universities upgrade their physics teacher education programs.

PhysTEC has concentrated on pre-service teacher education and recently engaged the AMTA to give an online course on modeling pedagogy for coalition members.[18] As a natural next step, PhysTEC should be encouraged to hold sessions on building in-service programs at its conferences. For any university committed to serving the educational needs of its local community or region, the AMTA is prepared to guide development of a *Local Teacher Alliance* (LTA) of STEM teachers and link it to the national AMTA network for teacher enhancement and STEM education reform. All that is needed to start is sponsorship from the physics department. There are too many details about establishing a thriving LTA to discuss here;[6] suffice it to say that the AMTA is already linked to high-functioning LTAs scattered across the nation. The good news is that these LTAs have been created and run by the teachers alone. The bad news is that in most cases, local universities have not learned of the great advantages in linking up with them. For starters, the LTA can provide a direct pipeline of students from high school to the STEM disciplines in college, and such links are prerequisites for successful STEM education reform.

The proposal that physicists must take the lead in organizing scientists and engineers to support STEM education reform may seem gratuitous, but the fact is that other disciplines are not nearly so well prepared to do it. Consider chemistry, for example. Though the AAPT has been supporting physics teachers for the better part of a century, the *American Chemical Society* (ACS) created the comparable *American Association of Chemistry Teachers* (AACT) only recently.[19] Making up for lost ground, the ACS is also partnering with APS to create a ChemTEC to link up with PhysTEC, and the AACT is discussing collaboration with the AMTA. Already, some 400 chemistry teachers are taking Chemistry Modeling Workshops each year. Likewise, links of the physics department to other STEM disciplines provide a natural pathway to involve them in supporting LTAs for STEM teachers.

IV. WHAT TEACHERS NEED

The expertise of a master teacher and the effort needed to acquire it is vastly underestimated by nearly everyone. Development of expertise in any domain requires approximately ten years (or 10,000 h) of "deliberate practice" specifically aimed at improving performance.[20,21] This applies as much to physics teachers as to physicists. But look at the disparity in their opportunities. Teachers are thrown into the classroom immediately after college graduation, whereas physicists typically have another five to seven years of graduate and postdoctoral work before they become independent scientists. To make up the difference, teachers need access to lifelong professional development like that provided by the AMTA in Modeling Workshops. University science and engineering departments must be involved in helping to supply it.[7]

Empowering teachers is the key to STEM education reform, and STEM teachers need resources and support more than accountability. More than anything, teachers need to be integrated into the community of scientists as respected colleagues in ways that strengthen their expertise, their credibility, and their impact in the schools.

Teachers themselves should be the local experts on the STEM curriculum and how to teach it. They should be advising their principals and school districts on what needs to be done, rather than the other way around. To command that authority, teachers need the direct support from the scientific community that connection to a university and a *Local Teacher Alliance* can provide. Only then can they freely implement up-to-date STEM education in their schools. To be sure, many districts and principals will not readily yield their prerogatives even to teachers and curricula that have endorsements from the broader scientific community. But I know of many who are eager for it, and their successful engagement will stimulate others to follow. Reform is for the long haul.

Physicists must take the lead in bringing all this to pass, because they have unique access to resources for building the necessary infrastructure. As I have discussed, a crucial first step for a physics department is to establish an LTA linked to the AMTA. Then colleagues from other disciplines can be invited to join in expanding the LTA from physics to a larger STEM LTA or a coalition of LTAs for different disciplines.

With their direct connections to STEM teachers and students, LTAs are ideal vehicles for university Outreach Programs as well as sponsoring student symposia, summits, and retreats. In short, LTAs can be powerful mechanisms for bonding universities to their communities.

David Hestenes
Emeritus Professor of Physics,
Arizona State University,
Tempe, Arizona 85287

[Hestenes is cofounder of Modeling Instruction. For this work he received the 2002 Oersted Medal from the American Association of Physics Teachers, the 2003 Education Research Award from the Council of Scientific Society Presidents, and shared the 2014 APS Excellence in Physics Education Award.]

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