

FINDINGS of the MNS Project (2002-2006)

This is one section in the Final Report submitted to the National Science Foundation in October 2006 for the grant entitled *A Graduate Program for Secondary Physics Teachers*. David Hestenes, Professor of Physics at Arizona State University, was the Principal Investigator. Extensive information about the program is at <http://modeling.asu.edu>.

We take for granted the pedagogical effectiveness of *Modeling Instruction*, as that was thoroughly documented in the Findings (2000) of an NSF Teacher Enhancement grant entitled *Modeling Instruction in High School Physics* (available at the modeling website).

I. Major Findings

This project has *conclusively demonstrated the feasibility and effectiveness of a university-based graduate program dedicated to professional development of in-service science teachers*. We refer to this program as the *MNS program*, as it can culminate in a Master of Natural Science degree.

Our conclusions here are drawn from six years of experience in organizing and running the MNS program (2001-2006), including two years without external funding bracketing the four years funded by the present grant.

A. Essential Components of the MNS program

1. **A complete graduate curriculum** of courses
 - designed expressly for in-service teachers,
 - offered in 3- or 4-week sessions **in the summer**,
 - providing extended **intensive peer interaction among teachers**.
2. **Core courses** that model ideal high school courses (i.e. Modeling Workshops)
 - in **workshop format that integrates pedagogy and content**,
 - **taught by experienced in-service teachers** (not university professors!),
 - providing teachers with instructional materials and course designs ready for immediate implementation.
 - These courses are also ideal for pre-service science education majors.
3. **Engagement of university research faculty** in teaching advanced courses
 - aimed at educating teachers about current developments in science,
 - linking research faculty to high school students through their teachers,
 - with academic recognition and rewards for participating faculty.
4. **An integrated program of interdisciplinary courses**
 - especially in chemistry and introductory physical science as well as physics, since many participants teach all these subjects.
 - [Integration with mathematics courses, though highly desirable, is much more difficult because of severe institutional barriers.]
5. **A full-time program coordinator** and part-time assistant are essential to
 - organize and staff the courses, and arrange housing for participants,
 - communicate directly with teachers year round,

- maintain the modeling listserv and website,
 - coordinate regional modeling workshops with other universities,
 - meet teacher demand to scale up the program to other subjects and grades.
6. **Full-time faculty in science education research and development to**
- drive continuous improvement of the MNS courses and pedagogy,
 - evaluate effectiveness of the MNS program, including impact on the schools.
 - [3 faculty lines would be ideal; likely to attract more than enough funding to pay for the lines.]

B. Implications for K-12 Science Education Reform

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. We argue here that there are no practical alternatives, and we explain how the MNS program can be rapidly ramped up to a national program to drive sustained improvements in K-12 science education.

1. Lifelong professional development is as essential for teachers as it is for doctors and scientists. Many school districts spend substantial sums on in-house professional development activities, but our teachers report that this is a depressing waste of time, because it is invariably superficial. Teachers are also given salary incentives to pursue professional development on their own through university courses and degree programs. However, our teachers report that this does little to improve professional competence, because the courses provide them with neither time nor expertise to translate miscellaneous information and insights into coherent classroom practice.

2. 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. Most of them advocate the remedy recommended by the American Physical Society [APS Council “Policy Statement on K-12 Science and Mathematics Education” (#00.5, Nov. 2000)] to *increase the production of new physics teachers from universities and colleges*. However, a cursory look at available data reveals that *this remedy is hopelessly inadequate!* [M. Neuschatz & M. McFarling, “Broadening the Base,” AIP (2003). Findings from the 2001 nationwide survey of high school physics teachers.] 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/yr is needed. 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. Accordingly, 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 already addressed the physics education needs of hundreds of **crossover teachers** (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 necessary to be a proficient physics teacher.

3. How to address the science education crisis. We concur with the following recommendations of the K-12 focus group for the report, "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future." <<http://www.nap.edu/catalog/11463.html>>

K-12 Education Focus Group Top Recommendation Summary (Roy Vagelos, Chair. The focus group met in August 2005.)

1. 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.

Successful implementation of all these recommendations in the MNS program confirms their practicality and effectiveness. Unfortunately, as is so often the case, the practitioners were overruled by the policy-makers. In the final report of that commission, the focus group recommendations were relegated to an appendix (Appendix C-4) and replaced with misguided recommendations to fund AP and IB summer institutes. Many modeling teachers have decried that decision (to us and to their Congressmen) as a huge mistake that will waste much money and fail to improve science instruction.

The following facts and trends should be considered when designing a graduate program for physics and chemistry teachers:

- i) **Some states require teachers to get a Master's degree.** Most physics teachers would rather learn more physics than take education courses. The 70% who don't have a degree in physics especially feel the need to learn content.
- ii) **Modeling Instruction is growing in reputation nationwide by word of mouth.** Teachers of subjects other than physics want to learn Modeling Instruction, too (especially chemistry teachers).
- iii) **Physics teachers are an older bunch, and they are retiring in droves.** To get replacements, principals ask science teachers (chemistry, biology, math) in their building, who've had a year of algebra-based physics, to teach physics.
- iv) In many states, **the "Physics First" movement is growing**, thus increasing the demand for physics teachers.
- v) Texas is leading a trend of states to **require that all high school students take physics.**

4. Scale-up and replication of the MNS program for national science education reform.

About 7% of the 22,000 physics teachers in the U.S. have already taken a Modeling Workshop, and most of them are strong advocates of the approach. With adequate funding, ASU could easily double and perhaps quadruple the number of teachers served in the MNS program each year (currently 130). Steps to extend the program to all the sciences and mathematics are underway, though progress is heavily grant dependent. The upshot is that ASU is already prepared for the role of national leadership in professional development for K-12 science teachers.

ASU is well prepared to serve as a resource for other universities that aim to develop comparable MNS programs. That would significantly reduce the ten years it took to develop the program at ASU. We estimate that a network of 8 or 10 programs distributed at major metropolitan universities throughout the country would be sufficient to serve the nation's professional

development needs. We say network because the programs should be sufficiently coordinated to allow automatic transfer of credits. Each program should take advantage of special expertise at the local university. However, it is crucial for every program to offer a validated research-based teaching pedagogy. We are prepared to help them adopt Modeling pedagogy if they don't want to develop their own. Of course, there is much more to be said about all of this. We aim here only to point out a productive direction.

Warning: On-line vs. In-person courses. There is a disturbing trend to deliver education courses on-line. A major conclusion from Modeling Instruction is that skill in managing classroom discourse is crucial to effective instruction, and this can be efficiently acquired only through interpersonal interaction with teachers who have that expertise. On-line courses can play a useful role in subject matter delivery and correcting deficiencies in undergraduate background, but their potential for improving teaching practice is slight.

C. Maintaining and Improving the MNS Program

Continuous NSF funding over more than a decade was essential to create and institutionalize the MNS program at ASU. The program is now well-established, well-known nationally, and teachers are clamoring to participate. The tragic irony is that **teachers cannot afford to attend!** There is plenty of money for professional development, but we have been unable to divert any of it to the MNS program, despite several years of trying! Here is an analysis of the problem as we see it.

As the MNS is a regular academic program, classroom facilities, course scheduling and payment of instructors are covered by the university. The remaining costs for teacher recruitment, tuition, travel, housing and per diem must come from other sources; the total is about \$300,000/yr to maintain a participant level of 150 teachers/summer. That is the cost to continue the program at the level established during the NSF grant. The total will be much higher if the program is expanded, or if teachers are paid stipends to attend, which is highly recommended for many reasons.

Since the MNS is a complex and unique approach to professional development, it cannot be sold with sound bites. Educators at all levels from the schools to academia (and proposal reviewers) are skeptical of new initiatives. Consequently, they tend to be dismissive of the details necessary to understand and justify the MNS program and its benefits. The uniform enthusiasm for the MNS among practicing teachers counts for little among "education experts." (This is one more example of endemic low regard for the professional judgment of teachers.) All this makes the MNS a hard sell!

Local schools and school districts have funds available to support teachers to attend the MNS. However, these funds must be extracted from administrators on a case-by-case basis. We have supplied teachers with all the documentation necessary to make the case, but our data show that only a handful have been successful, and then only to cover a fraction of the costs. This approach to funding is clearly impractical.

States have substantial funds for professional development allocated by the Federal government. However, these funds cannot be used to support the MNS program, because most of the participants come from out-of-state. Moreover, the distribution system of state funds to school districts does not allow for support of anything like the MNS program even for in-state participants. This reduces the funding problem to the impractical district level already described.

The U.S. Department of Education and the NSF-EHR have solicitations to fund professional development. However, they come with guidelines that are incompatible with the unique needs of

the MNS program. The guidelines are not sufficiently flexible to support truly innovative initiatives like the MNS.

It may be said that the EHR's mission is to support educational innovation rather than existing programs. Sad to say, the legacy of EHR-supported projects after funding has ceased is dismal; most have left hardly a trace. One reason for this, we submit, is that the NSF does not seek to identify exceptional projects and earmark them for continued funding and institutionalization. In our long experience with EHR, every proposal for continuing a project has to be justified *ab initio*, with little credit for previous success. (Contrast this with practice in the NSF science research divisions, where continued funding of successful research projects is high priority.) Ours is one of the few EHR programs with a stellar record of success over many years. Despite extensive documentation in submitted reports and repeated attempts to open a dialog, EHR administrators have not paid attention. We conclude that they are deaf to practitioners in the field, a familiar failure of bureaucratic systems!

From our frustration with U.S. Department of Education and NSF-EHR funding policies, we have concluded that the only feasible source of stable funding for the MNS program is from a private foundation, preferable through an endowment. Here the problem is access, of penetrating the bureaucracy to present our case to a sympathetic and informed decision maker. We are still looking for the right levers to pull.

The costs discussed above are only for maintaining the MNS at its current level. But the MNS is the product of science education R&D, and R&D grants are needed to keep improving it. Support of such R&D is supposed to be a primary mission of the NSF. But here we have encountered the same catch-22 that has submarined our attempts at maintenance funding. The guidelines are not sufficiently flexible to accommodate our programmatic R&D needs. In repeated attempts over the last three years, we have been unable to match our needs to EHR guidelines to the satisfaction of reviewers and program managers. Though reviewers acknowledge our stellar record, that counts for little in rejecting our proposals. **Our primary objective of cultivating the Modeling Instruction and the MNS program as a national resource** was completely ignored, evidently because the guidelines do not call for it!

We have delayed our final report so we could describe what happened to the MNS in the first year without funding. Of course, lack of support prevented many teachers from attending. Amazingly, attendance was down only to 130 from 150. **Collapse of the entire program was prevented only by the efforts of dedicated personnel who continued to work hard without pay!** Clearly this cannot be sustained. The program will not survive if the funding problem is not solved within the next year.

II. Specific Findings

A. Findings about the fourfold reforms of our mission:

1. Pedagogical reform. The RTOP evaluator reported that the MNS courses rated an incredibly high mean score on the RTOP of 82.8 points ($n = 9$, std. dev. = 5.7). The significance of this level of instruction is apparent when compared to other groups. MNS instructors were compared to five different groups. The only other group with comparably high scores is the 12 ACEPT college methods group (80 points). This is to be expected, because college methods courses are directly responsible for educating students about effective methods of instruction and thus are expected to provide a model of exemplary instruction. The average score of 55 ACEPT science and mathematics content courses was 62 points, and that of 16 non-ACEPT college science and mathematics courses was a low 38 points.

Data for the comparison groups were collected during evaluation of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) project. ACEPT courses in college science and mathematics were those taught by faculty who had participated in at least one ACEPT-sponsored faculty workshop. The aim of ACEPT workshops was to help instructors to teach in an inquiry-based manner that was aligned with constructivist pedagogy.

2. Technology infusion. Computers are used extensively in each Modeling Workshop and in all other courses. Each class is held in a room that has 8 computers, and Modeling Workshops use MBL probes as well. Computer use is coupled to reform in science pedagogy. Thus, each course includes model-centered labs and activities that can be used in high school. Some are adaptations to modeling instruction of labs in the Kansas State University NSF-funded project 'Visual Quantum Mechanics'.

Computer use is coupled to reform in teacher professional development through use of the internet via ASU's BlackBoard in two courses: Integrated Math and Physics (PHS 542) and Leadership Workshop (PHS 598). The response was amazing! In summer 2003, for Integrated Math and Physics, there were 396 posts on BlackBoard in 17 different folders -- most of these were discussions of articles that students were assigned to read dealing with pedagogy, math and physics education research and cognition; but one was on classroom and school reform and integration issues. The Leadership Workshop had 185 posts on BlackBoard in 9 different folders, on reform strategies at school and district level, brainstorming about the mission and vision of modeling, action research planning and design, and the RTOP.

3. Incorporating contemporary physics. Physics and chemistry are united in some courses (PHS 540, 581, 505) into a common science of the structure of matter and its properties, and other courses (PHS 560 and 564) focus on physics of the atomic world. Principles of physics are used in contemporary astronomy (PHS 550), and Einstein's theory of relativity is made accessible to high school students in Spacetime Physics (PHS 570.)

Regarding classroom implementation, a chemistry teacher (who began to teach physics after a Modeling Workshop) who finished the MNS degree in summer 2003 wrote later: ' 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 and expose my students to the 20th and 21st century topics in physics and chemistry - which are the really fun ones! ... Being able to apply what you learn is so often emphasized to students when we are teaching them. This program allowed me to apply what I learned in my classes to my classroom.'

Another teacher wrote about PHS 570, Spacetime Physics: ' Dr. Hestenes' obvious enthusiasm for GA [Geometric Algebra] sort of overwhelmed me, but it is interesting how much has become clear as I have had a chance to digest and even introduce some concepts to my Honors Algebra students.'

4. Cultivating physics teachers to lead reform. We are seeing significant effects of the workshops on teachers' leadership in their schools. A few anecdotes will suffice.

A young teacher in Fairfax County, Virginia wrote in fall 2003: ' [My 1-hour inservice on whiteboarding] went really well and many people told me that they went out to purchase some tile board from Home Depot the next day. I had geosystems, physics, chemistry and physical science at the session and everyone felt they could try and implement whiteboarding into the classroom. For my ongoing class, I have five physics teachers taking a modeling workshop with me two hours a week after school....' Her academic year school-based Modeling Workshop resulted in one of her participants' taking a Modeling Workshop here during summer 2004. The two of them convinced a university faculty member to apply for state NCLB funding for a full-fledged regional Modeling

Workshop for July 2005. The grant was funded. They obtained funding for a second modeling workshop in summer 2007 for middle school and ninth grade science teachers in their district.

A Texas teacher wrote in fall 2003, ' An amazing thing happened to me this week. Wednesday afternoon, my department head asked me to do an 'Intro to Modeling' the NEXT afternoon! I was afraid if I told him I didn't have time to prepare that I'd never get another chance so I did one. ...It was really hard presenting to this group. We have several teachers who just don't want to try anything different from what they've been doing for years. ... I have a new appreciation for presenters now. Teachers are tough and highly critical ... More good (??) news: There is a one-day science and math workshop being held at our local university and I am going to apply to present...' She did, and she wrote afterwards, 'Three of the participants at my workshop on Saturday expressed interest in attending a modeling workshop next summer.' (One did so in 2005.) This teacher continues to seek leadership opportunities. Unfortunately, her city is isolated and no local supportive faculty member has come forth.

Numerous other teachers have taken similar actions. Modeling Instruction is truly a grass-roots, bottom-up program, led by enthusiastic, dedicated, smart teachers, with help and direction from physics and chemistry education research faculty.

A recently retired high school physics teacher from St. Louis, Missouri who participated in our Modeling Workshop in summers 2002 and 2003 was asked by a university to teach a 'methods of science teaching' course. He wrote in January 2005: 'I am using the modeling materials and philosophy entirely in the course (these are MAT students in science) with great success. I have had students indicate that their college physics experience was not their favorite and that for the first time they really understood mechanics and Newton's Laws!! WOW...some endorsement of the modeling approach!'

B. Findings about the three specific goals of our project:

1. Maintain and strengthen Modeling Workshops as a national resource. In spring 2003, teachers who had participated in a Modeling Workshop the previous summer were asked to respond to an e-mail survey about their implementation. Many did, and the responses were overwhelmingly positive, indicating a great deal of implementation and much satisfaction.

After each summer's Modeling Workshops, teachers new to this program spontaneously write e-mails expressing thanks and thoughts such as these: 'Most useful course I have taken since becoming a teacher.' 'It was a great class. As soon as you know anything about next summer's classes, let me know. I would like to attend the next class in the series.' 'It was a very intense 4 weeks but well worth it. I learned an incredible amount!' 'It was an incredible experience and it has changed my outlook on how to teach completely.'

2. Accelerate development of MNS courses in interdisciplinary science and contemporary physics to prepare teachers for reform in the structure and content of the science curriculum. The testimony of the chemistry teacher cited above who teaches in a physics first, biology last program is indicative of preparation for such reform. Twenty-three teachers, i.e., 1/3 of the teachers who were on campus during the second summer session in 2003, taught 'physics first' that fall. Most are cross-over teachers who took a Modeling Workshop in preparation.

3. Foster professional ties between teachers and research faculty, thereby recognizing teachers as valued members of the scientific community. Our surveys of teachers each summer revealed that *most teachers don't know even one supportive college faculty member!* In other words, teachers are isolated from the scientific community. This is an unsatisfactory situation,

detrimental to the advance of the profession. Each teacher who takes an interdisciplinary or contemporary science course has direct contact with physics faculty. A local teacher who finished the MNS degree in summer 2003 wrote, 'the direct contact with the university physics community has given me 'connections' which I value highly. I look forward to maintaining these connections and hope to see a time where high school students have opportunities to view and experience physics at that level.'

C. Secondary findings:

1. Teaching Associates (TAs) are crucial to success of most courses. On the evaluation form for each course, the question was asked: 'How did the Teaching Associate's work add value to the course?' Typical responses in most courses were such as these.

- * 'Give Rich an A+! His help was invaluable and his availability outside of class was fantastic! 'Incredible! I couldn't have gotten through this class without his help. His help was invaluable.' (Every teacher in PHS 560: 'Light and Matter' expressed these thoughts about the TA.)
- * 'Bill [the course instructor, a chemistry professor] was awesome – but only with Lorna's help! "Lorna did a great job keeping the class moving.'

2. Faculty have a learning curve, for most aren't accustomed to courses and students like these. To illustrate this finding, Dr. Robert Culbertson, the ASU physics professor who taught PHS 540: Integrated Physics and Chemistry, wrote in response to the question, 'How did teaching this course compare with other teaching experience?

"Quite different in a number of ways.

- a. All the students were motivated.
- b. No students were hesitant to speak their minds.
- c. I have never taught chemistry and initially felt out of my element. Consequently, I had to work a little harder on my own with some of the material. I think I could teach a chemistry course now.
- d. The atmosphere was positive and energizing all the time. I looked forward to every class, and I hated to see the course end.
- e. I had to work extra hard on this course. Just the website work alone is a couple of hours per class.'

3. Synergy between instructor and Teaching Associate is important. For instance, Lorna is the wife of Bill (above); they developed the 'Energy and the Environment' course together. And consider this response by Joy, a semi-retired chemistry teacher who was the TA for PHS 540, to the evaluation question: 'How satisfactory was your interaction with the instructor during the course?' Joy's reply: 'This was one of the most worthwhile summer workshop experiences I have ever had. I felt I made giant steps forward in my understanding of physics and chemistry concepts that were dealt with in the course, both from my interaction with Dr. Culbertson during our planning meetings, and during the course itself.' Dr. Culbertson wrote similarly about Joy, in response to the question: 'How helpful was the Teaching Associate? In what ways? Should the practice of assigning a TA to each course be continued?' 'Very, very helpful. She was wonderful at taking care of details, such as arranging for the out-of-print textbook to be legally reproduced. As a very experienced chemistry teacher, she brought her considerable knowledge and experience to the course and filled in areas where I was less knowledgeable. She also benefited a lot from the course, so I think it was a win-win-win (her, the class, and me).'

4. Preservice teachers value Modeling Workshops: The Workshops attract a few preservice teachers each summer. Here are excerpts from weekly reflections of a participant in two Modeling Workshops in summer 2003 who student-taught in Flagstaff, Arizona in fall 2003. Her cooperating teacher, David Thompson, is a modeler who received the NSTA Shell Award a few years earlier.

WEEK 1: I'm going to sound like an advertisement for the modeling workshops, but I think I was able to jump right into working with the students and lesson planning because of those workshops. ...

I really have to credit the research behind the modeling workshops because a lot of the things I was told would happen, really do happen. The fact that the students are resistant to taking a more active role in their learning at first and some of the common misconceptions they have were brought out over and over again in the workshop so I wasn't caught off guard by anything (yet – I know it's bound to happen). ...It was also really cool to be able to talk to my cooperating teacher about lesson planning with this group and actually be able to contribute a lot of ideas and create a lot of activities and assignments based on the physical science modeling workshop. ...

Student teaching with a modeler is great because it is helping reinforce some of the ideas and methodologies I picked up during the workshops.

WEEK 2: I can see even more of the benefit of the modeling workshops now! I can't imagine how lost I'd be without them!

WEEK 6: ... Our CIT [freshman physics] students are really starting to shine and come into their own at this point. The biggest pleasure for me is watching the girls, especially the more quiet Native American ones, start to get things. Then their confidence starts building and they start participating more and more. ...

I am reassuringly comfortable with the CIT material because it is all the material that I just covered in the modeling workshops this last summer and I picked up all kinds of great tools to help guide students to a deeper conceptual understanding of mechanics concepts. I feel confident that I can explain things to students and help them get through their misconceptions.

WEEK 8: I received the best 'evaluation' I could ever hope to receive this week. Dave was going through his mid-semester evaluation with me and he said the best way he could put it is that he would want his own child to be in my class. I know how high his standards are, so hearing that almost made me faint from shock!

I do have full control of the freshman class now – lesson planning and all. I'm really having a blast with it!

D. Impact factors, insights, and recommendations by Project Manager Jane Jackson:

The MNS program has been extraordinarily popular with teachers and effective in transforming their teaching practices, in some cases rejuvenating them to the extent that they tell us it **saved their careers**. Teachers vote with their feet. Many return for more, even if they are not seeking a degree. Consistently, 130 to 150 teachers come each year. Many more say they would come if they could afford it.

Indicators of impact on teaching practice include:

- teachers' posts to the modeling listserv and chemistry modeling listserv,
- organizing and leading of local modeling workshops from one hour to three weeks duration by many teachers,
- numerous unsolicited comments about the transformational power of Modeling Instruction.

My day-to-day project management gives me a perspective that results in these crucial insights and recommendations.

1. The need for professional development programs for high school physics teachers is overwhelming and nationwide; states can't solve the problem. Participating teachers live and teach in 41 states. Overwhelmingly they state that *nowhere else can they get comparable professional development in content with effective methodology, nor even in physics content alone.* They tell us that graduate courses in education are mostly a waste of their time. Most are not qualified to take graduate courses in physics, and such courses aren't held in summer anyway -- nor would they be applicable for their teaching. Online content courses such as NTEN's "General Relativity", the University of Virginia's "How Things Work", and North Carolina State University (Bruce Sherwood's "Matter and Interactions" I and II) are well regarded by teachers, but these courses are insufficient to meet their needs for a coherent degree program that is applicable to their classroom teaching, nor for effective pedagogy and depth of content understanding that are provided by our seven modeling workshops in physics, chemistry, and physical science. *Hardly any states have enough physics and chemistry teachers to support a statewide professional development program* for them.

2. Modeling workshops are fundamental courses. This is evident from their popularity with teachers of all content backgrounds and degrees, from all states, and from ages 21 to 69. On a scale of 1 (poor) to 10 (excellent), teachers gave almost every modeling workshop an overall rating above 9, with very little individual variation in their ratings; in other words, *all teachers perceived the modeling workshops as essential and worthwhile learning.* This contrasts with our other courses such as PHS 540: Integrated Physics and Chemistry" or PHS 550: Physics and Astronomy, in which individual ratings varied greatly -- some rated a course a "10" and others rated that same course a "5", for example, to average out to an "8".

3. Costs to teachers must be minimal. Most local teachers wrote in a survey 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 unless tuition is free and housing is cheap* -- except if their school can give financial help. We find that in most cases only upper-middle class suburban schools and some private schools can give financial help, so this severely restricts participation when no grant funding is available. Only one-third of out-of-state teachers were able to get any financial help from their school, and typically it was only about \$500. Almost all Arizona schools do not give any financial help, even though we urge teachers to ask for it and we give them a sample proposal that they can modify to submit to their school administration. Teachers give up the opportunity for summer employment to attend. *Teachers want only to have tuition, room, board, and travel expenses met; they tell us that they don't expect an additional stipend. States can't or won't pay; the national government or some wealthy benefactor(s) must.* (See the recommendations of the K-12 Focus Group of "Rising Above the Gathering Storm".)

4. Chemistry modeling workshops are essential. Of the teachers in our program each summer, 80% teach at least 1 section of physics. Of those, half teach only 1 or 2 sections; and 30% teach only physics -- so it's a bimodal distribution. *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 masters degree programs exists nationwide for chemistry teachers. Several teachers in our MNS degree program have never taught physics; they are strictly chemistry teachers. They came here for the science content and exemplary modeling pedagogy, rather than "jump through hoops" to get a meaningless education masters degree. The bottom line is: any professional development program should include courses in both physics and chemistry.

(Supporting data: Of the 70% of physics teachers who teach multiple subjects, physical science and chemistry are most frequent. The 20% who don't teach physics teach physical science, integrated science, chemistry, and math.)

5. Lifelong learning must be the focus. ASU's MNS program is unique: it is the only 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. Most other programs for physics teachers (such as the University of Wisconsin at River Falls, University of Virginia, Morehead State College in Minnesota) are remedial programs for out-of-field teachers, or are primarily degree programs (Buffalo State College in New York). We must do better as a nation, and the success of our program shows the way. Half of the 150 teachers who participate each summer at ASU already have a master's degree, almost all in education. Others live in states in which a master's degree is not required for teachers. *Ninety percent of the participating teachers wrote on a survey that their chief reason for taking our courses is to become a better teacher, and half wrote that the joy of learning content was a prime reason.* Only 20 to 30 teachers at a time were enrolled in our Master of Natural Science degree program while we had NSF funding, even though ASU provided tuition waivers for most courses and ASU made it easy for teachers to get into the degree program. This means that most teachers really did not need a degree; they were here for lifelong learning. Indeed, in a survey that we gave in summer 2006 to 100 physics and chemistry teachers, most wrote that lifelong professional development is extremely important or very important to them. Overwhelmingly they indicated that *three-week summer modeling workshops are their preferred type of professional development* rather than summer internships in business, Saturday workshops in the academic year, short content courses in summer, and several other choices.

6. Modeling workshops must be in-person; thus regional centers are needed. This problem has two aspects.

a) Teachers and modeling workshop leaders are unanimous in stating that modeling instruction can't be learned online; a three-week intensive in-person workshop is a minimum to begin to understand this complex methodology (and improve one's content knowledge). Thus *many universities nationwide should be encouraged and given incentives to hold modeling workshops.* We have worked with 30 universities for this purpose. (It appears that any effective high school physics pedagogy must be learned in-person.) Preservice teachers should be included.

b) Teachers tell us that an in-person graduate degree program is preferable to on-line courses. It is easiest to sustain such a program for physics teachers in a large metropolitan region, for most teachers can commute and thereby stay home with their families and not incur much cost. The Phoenix metropolitan region is approaching four million people; this is below the minimum population for an MNS degree program in physics that is for commuters only. If the ASU Department of Chemistry joins us in building their MNS degree program for teachers, sustainability is assured because the number of local chemistry teachers is double the number of physics teachers. The MNS degree is inherently interdisciplinary, so teachers will draw from both departments for courses. With interdepartmental cooperation, courses can be held in a two- or three-summer rotation that makes sense for teachers. We find that courses need not be consecutive; thus cohorts are not needed. This increases the flexibility and convenience of the program for teachers. This is an important consideration, for teachers in the degree program are of all ages, with a wide variety of family, work, and health considerations that call for flexibility in when they take their courses. Some teachers drop out for a summer or two and then rejoin the program. Some take courses for only half of each summer -- notably women who have young children. A hybrid program can work, for some content courses can be online. *Every large metropolitan region in the United States should have a graduate degree program for high school physics and chemistry teachers, if we are to meet the looming huge challenges of the 21st and 22nd centuries.*

Again, see the top recommendation #1 of the K-12 Focus Group in Appendix C-4 of "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future." <<http://www.nap.edu/catalog/11463.html>>. This recommendation, quoted on page 3 of our report, should be implemented!

SUPPORTING EVIDENCE

We present four types of evidence for the importance and effectiveness of the MNS program:

- reports from three independent evaluators,
- feedback from participating teachers informally gleaned from unsolicited email, conversations and discussions,
- course evaluations of teachers and faculty formally solicited through extensive questionnaires,
- objective data about teacher performance on the Force Concept Inventory (FCI) and Mechanics Baseline Test (MBT).

I. Reports by independent evaluators

A. External academic review. In April 2005, the ASU Department of Physics and Astronomy was evaluated by an external Review Committee commissioned by the North Central Accreditation Academic Program. The committee included a Nobel prize winner. The committee report in May 2005 states: '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. Unfortunately, this program is threatened with termination by the end of the NSF grant which supported teachers during their course period at ASU. The Review Committee believes that it is essential for ASU to continue this invaluable program, perhaps with a grant from a corporate source, a private foundation, or through direct state support. The university's development office should assist with this goal.'

B. The external project evaluator, Dr. Francis Lawrenz concluded: 'In summary, the project appears to be meeting its goals. Courses have been developed, teachers are enrolling in them and finding them valuable, the MNS program is in operation with large numbers of participants, and aspects of the project are being institutionalized. It seems likely that the MNS program will continue at ASU although the numbers are dependent on the availability of funding. Also for the courses to have large enough enrollments to support instructors' salaries, out-of-state students are necessary.'

C. The independent RTOP evaluator, Eugene Judson, wrote: 'The Master of Natural Science (MNS) program is atypical of conventional post-baccalaureate programs in both focus and approach. Rather than provide a collection of classes necessary for acquiring a particular graduate degree, the Master of Natural Science program offers a cohesive set of courses that focus on the goal of better preparing high school science and mathematics teachers. This goal is achieved by deepening content knowledge and aiding teachers to teach in a standards-based manner (NCTM, AAAS). Though this seemingly simple goal is shared by many teacher preparation programs, the MNS program distinguishes itself by attracting a motivated group of learners, providing useful and challenging courses, modeling the type of student-centered instruction promoted by the program's developers, supporting student-to-student and student-to-instructor collaboration, and following up on the impact of the program as teachers return to their high school classrooms. Simply put, the MNS machinery is doing what it claims. These statements do not stem from a repeat of the program's rhetoric but arise from a synthesis of weeks of observation and multiple conversations with instructors and participants.'

II. Feedback from teachers

A. Professional development for teachers not seeking a degree. Half of the participating teachers already have a Master's degree, and many others don't need one. They simply want to be better teachers. They find the Modeling Workshops and courses to be of great value. Here are a few examples of e-mails received in academic year 2004-2005.

* 'I'm happy to tell the world that both our crew(s) and leaders this past summer, and the work we all did, were some of the best experiences in my life. I have a Master's and three prior careers, so I take these courses for technique practice, curriculum content, and collegial sharing. I like it; I love it; I want some more of it!' (From an East Coast teacher in his 50's.)

* 'I really do appreciate the opportunity that you and the NSF have provided me. The value of the modeling course is well beyond any other teaching support or education I have ever had, or expect to receive. I am disappointed to hear that the funding and therefore opportunity for educating more physics teachers has been lost. I can not overstate the value of what I learned.' (From a teacher in a Department of Defense school overseas.)

* (A letter to Dr. Michael Crow, President of ASU): 'I am a student in ASU's Modeling Physics program, a graduate program for working high-school physics teachers run by your Physics department under the auspices of Dr. David Hestenes and Dr. Jane Jackson. As their National Science Foundation grant comes up for review, I want to express my strong enthusiasm and gratitude for the existence of the program. I live and work in suburban New York City, have an MA in Education from Columbia University Teacher's College, and have been teaching high school physics for 18 years. That said, the last three summers that I've spent in ASU's Modeling Physics program have been unquestionably the most valuable education courses I've ever taken.

I don't know if you are aware of the fact that ASU's Physics Education/Master in Natural Science Program is one of the very few graduate programs in the nation aimed at physics teachers (actually I think it is the only one, but I'm not certain). Teachers come to ASU from all across America for this program because there is simply nothing else like it - which makes it all the more wondrous that the program also happens to be excellent. While the lack of well-trained science teachers in America is nothing new, for the last 20 years the lack has been most keenly felt in physics, which makes your program vitally important for American science education. There are approximately 21,000 high school physics teachers in America, and more than 1000 have passed through ASU - that's 5% of a national industry! Specifically, the Modeling Physics approach to education developed by ASU's Physics Department is being recognized as a 'best practice' in the field. While 1-to-3 week introductory workshops in the methodology are now being offered by graduates of the program nationwide, nobody else is continuing to research, develop and publish the approach, or offer the range of courses in the method, that ASU does.

It is not hyperbole to claim that this program is a national educational treasure. Please continue to support the program, while we graduates continue to encourage our teaching colleagues to come to ASU for the best education available in the field.'

Dr. Crow's office replied: 'Thank you for your e-mail regarding the ASU Modeling Physics Workshop. I was very pleased to read about your positive experience at ASU, and I appreciate your willingness to articulate the specific value the program had for you. In the weeks since its conclusion, our office has received several highly complimentary communications regarding the quality of both its administration and content. As you well know, this type of feedback is incredibly important when it comes to evaluating the numerous programs offered by our university, and we have made it a point to share this with Drs. Hestenes and Jackson, along with our own accolades for a job well done.

You can be sure that ASU is proud of this groundbreaking program, and that we will continue to dedicate our efforts to the advancement of science and science education. We are genuinely grateful for your contributions as a participant, and for helping to spread the word about the great work we are undertaking here at ASU.'

B. The MNS degree program is highly valued. Five inservice teachers finished the MNS degree in summer 2003: three women and two men. Only one has a degree in physics education; the others had a weak physics background. Ages range from 30 to 53. Years of high school teaching experience range from 2 to almost 3 decades. Their opinions were solicited, regarding the value of the degree program to their teaching and their students' learning. All used descriptors such as 'extremely important', and 'I loved this program'. Here are excerpts from their statements.

* 'In the case of this program, everything offered has been valuable to me, and relevant to what I do, so I took all of it. ... As a private school teacher with 20 years experience there is no pay advantage. I took it purely for personal enrichment--because having done so I have learned to be a better physics teacher, learner and thinker.'

* '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. I can also support and try to develop course integration in my school. Third, the degree itself is enabling me to offer my students premium opportunities such as dual-enrollment credit through the community college district. The master's degree programs available through the college of education would not qualify me for this option. Finally, the direct contact with the university physics community has given me 'connections' which I value highly.'

* '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 ...This program allowed me to apply what I learned in my classes to my classroom. I LOVED this program!!!!'

* 'The opportunity to take both content-rich classes and methods classes that were also content-rich with colleagues sharing ideas and stories was very fulfilling. The content classes were excellent. I still think however, that the professors didn't understand what the program was about. I think Dr. Menendez made great progress towards that understanding. I believe he really is serious about being a part of the program; don't let him get away. ...'

* 'I started the Masters in Secondary Ed at NAU 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 was very unhappy with what I saw as a waste of my time. ... 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. Except for the modeling pedagogy, I think that interacting with other science/math teachers was the greatest benefit to me. ... Most science teachers I know have been called upon to teach in more than one science or math discipline, and the integrated classes are perfect in meeting that need. 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.'

III. Course evaluations

Teachers rated each modeling workshop and other course overall on a scale of 1 (poor) to 10 (excellent). The mean rating for the 17 other courses was 9.0. (The range was 5.9 to 9.5).

To help research faculty instructors of MNS courses other than modeling workshops meet pedagogical goals of the program, we set the following explicit teaching guidelines (overwhelmingly important ones are in boldface):

- 1. Selection of topics is influenced by preferences and needs of the teachers.**
- 2. Course material is developed in ways that teachers can use with their own students.**
3. Subjects are addressed at the level of a *Scientific American* article, although some use of algebra, calculus and vectors may be appropriate.
4. Teachers are involved in explicit formulation and analysis of the models inherent in the subject matter.
- 5. Teacher expertise is exploited in the design and conduct of class activities, experiments, discussions and presentations.**
6. Lecturing is limited in favor of discussion and collaborative activities.
7. The course involves laboratory experience that acquaints teachers with operation and use of modern scientific instruments such as lasers and the electron microscope.

On each course evaluation, participants rated the degree of implementation for each guideline and declared whether the guideline was important, somewhat important, or unimportant. The table shows the number of courses each year for which each guideline was considered important by two-thirds or more of the participants.

| | (2001) | 2002 | 2003 | 2004 | 2005 | (2006) | Total 2002-06 |
|-------------|--------|------|------|------|------|--------|---------------|
| # courses | 5 | 4 | 5 | 4 | 2 | 2 | 17 |
| guideline # | | | | | | | |
| 1 | 2 | 3 | 4 | 2 | 2 | 2 | 14 |
| 2 | 1 | 3 | 5 | 4 | 1 | 1 | 14 |
| 3 | 0 | 0 | 2 | 1 | 0 | 0 | 3 |
| 4 | 3 | 2 | 4 | 1 | 1 | 0 | 8 |
| 5 | 1 | 4 | 4 | 1 | 2 | 2 | 13 |
| 6 | 1 | 2 | 3 | 3 | 1 | 0 | 9 |
| 7 | 3 | 2 | 2 | 2 | 0 | 1 | 7 |

In 10 of the 17 rated courses, respondees indicated that 100% of the important teaching guidelines were greater than 75% implemented.

Thirteen of the 17 courses employed a teaching associate who taught high school. Two of the four courses with no teaching associate were taught by an advanced physics graduate student who is well-schooled in modeling instruction; those two courses got among the highest overall ratings. Participant comments indicate that the most important factors in the success of those two courses were that the instructor (a) used modeling instruction, (b) knows the content very well, (c) was extraordinarily patient with the teachers.

Faculty teaching experience was probed with a questionnaire after each course. The faculty were 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.”

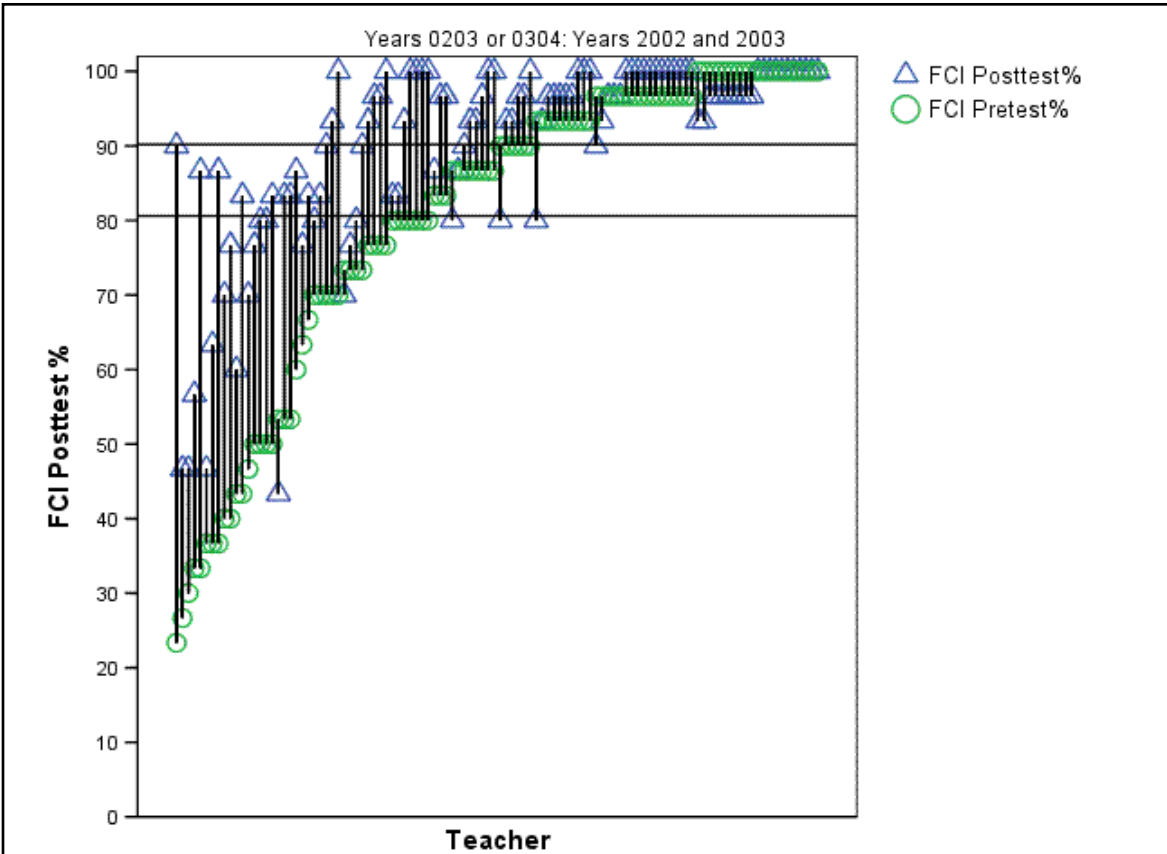
IV. Teacher competence as measured by the FCI

The uniformly enthusiastic testimonies from teachers about the benefits of Modeling Workshops are often discounted as mere anecdotal evidence. Here we adduce objective evidence that supports their claims.

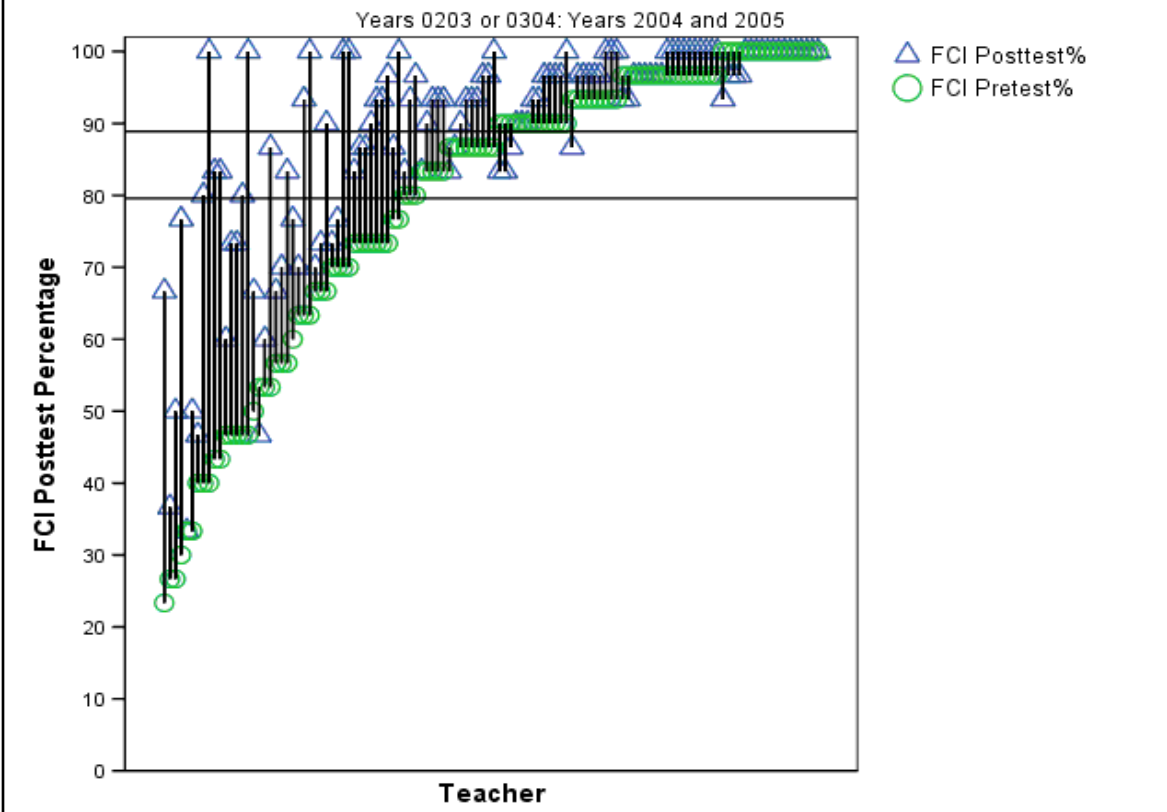
To all teachers taking the 3-week Modeling Workshop in mechanics during the 4 summers covered by the grant, we administered the FCI at the beginning and end of the Workshop. Actual test questions were not reviewed during the Workshop, though how to teach the force concept was a central theme of the course. Pretest and posttest results for every teacher are plotted in Figure 1, showing the gain for each teacher and a substantial net gain overall. Note how similar the data are in each plot. The 10% gain overall is clearly significant. Of course, most of the gain comes from teachers with lower pretest scores.

To interpret the results, one should know that 60% (called the Newtonian threshold) marks the beginning of competence with Newtonian concepts and scores of 85% or more indicate expert understanding. Accordingly, about half the teachers can be classified as expert from the pretest score. On the posttest about 2/3 are classified as expert on the posttest, including many with pretest scores below the Newtonian threshold.

The low pretest scores come from crossover teachers (many from biology) with very little background in physics, so 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. 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.



Years 2002 and 2003 Mean (SD): Pretest%: 80.6 (21.2) Posttest%: 90.2 (13.0)



Years 2004 and 2005 Mean (SD): Pretest%: 79.6 (21.0), Posttest%: 88.9 (14.5)

Figure 1

The MBT was given near the end of the modeling workshop in mechanics. Matched data for 152 teachers who took both the FCI posttest and MBT are plotted in Figure 2; the correlation is moderate. Outliers (lower right section of graph) were diligent, studious teachers who had little recent experience in physics problem-solving (e.g., teachers of other subjects, out-of-field newly drafted physics teachers). The modeling workshop does not focus on problem solving.

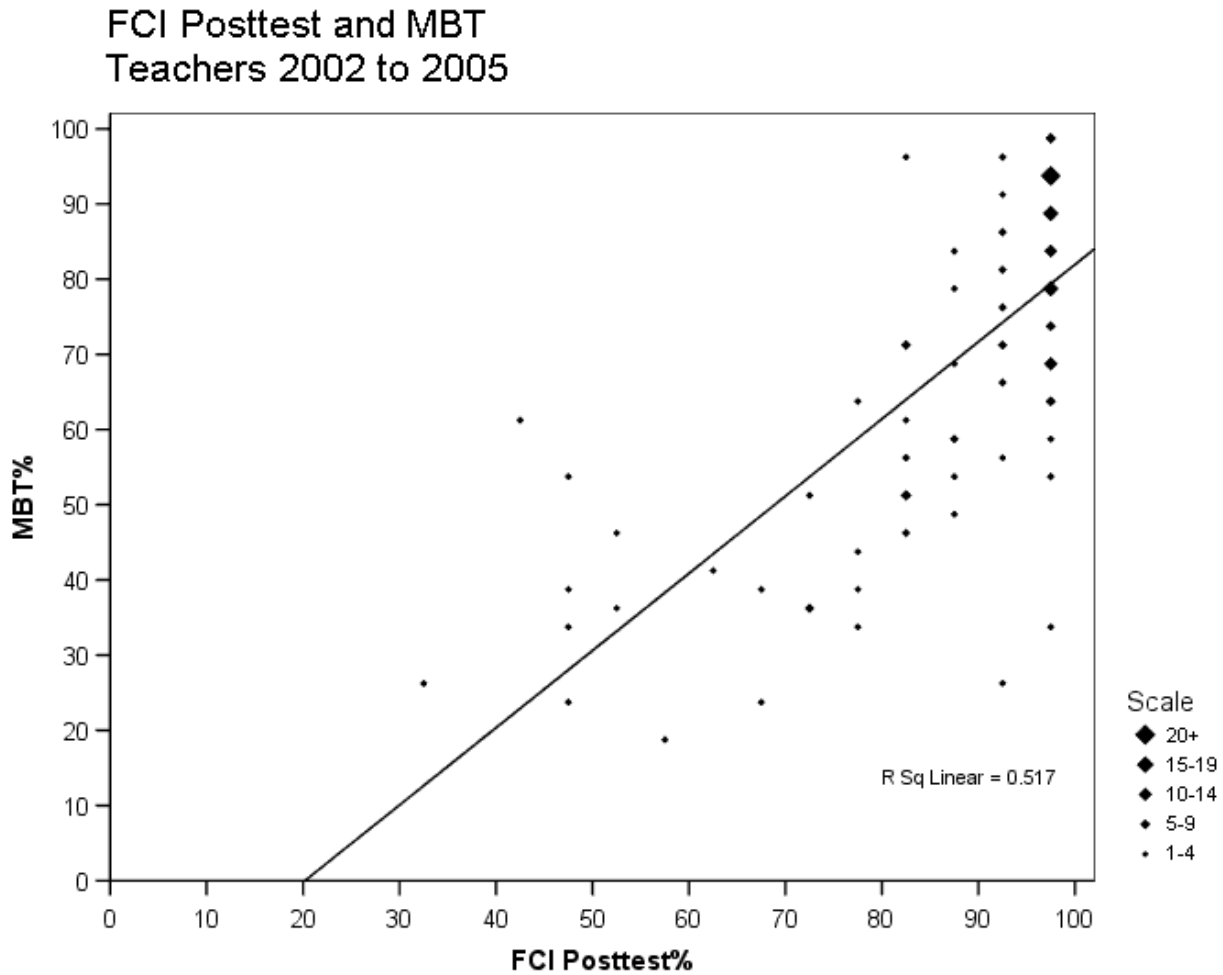


Figure 2: Matched FCI posttest - MBT scores for 152 teachers. FCI posttest mean is 90.02% (SD 14.05); MBT mean is 71.71% (SD 20.07). The R^2 is 0.52, indicating a moderately high degree of relationship between the two scores. (The R^2 between the MBT and the mean FCI pretest is 0.53.)

A further analysis reveals that for the 81 men and 38 women who had taught physics for two or more years and who took the FCI and MBT, the Pearson correlation between the FCI pretest and the MBT was 0.63 for men and 0.71 for women, and between the FCI posttest and the MBT was 0.37 for men and 0.70 for women. The low correlation for men is due to restriction of range; a ceiling effect of the FCI – the men’s FCI scores were all very high..

Item analyses on teacher data from 2002 to 2005 reveal:

- Cronbach's alpha estimate of internal consistency reliability of the FCI on 226 teachers is 0.87, high for a homogeneous sample such as this.
- Cronbach's alpha coefficient for estimated reliability of the Mechanics Baseline Test (MBT) on a sample of 90 teachers is .874, more than satisfactory for making inferences about groups of examinees. (MBT scores of an additional 62 teachers in 2002 to 2005 are scattered throughout several different files; merging in more of the item details is a time-consuming process and therefore must wait until time permits.)

The vast majority of teachers who took the modeling workshop in mechanics were inexperienced in teaching physics. Among the 226 teachers who took the FCI, about one-third had never taught physics. **Almost half had taught physics for one year or less.** Two-thirds had taught physics for four years or less. All but two taught high school or intended to teach high school; one taught middle school and one taught junior college. Although many were in their twenties, many were in their 40's and 50's; the oldest was age 69.

About one-fourth of the 226 teachers (i.e., 62) majored in physics or physics education. The next most popular degrees were biology and chemistry, with about 17% each (39 and 35 teachers, respectively). Engineering was fourth (9%: 21 teachers). The remaining 30% had content majors in geology, general science, social sciences, humanities, elementary education, and home economics.

Of those who had never taught physics, 16 (i.e., 7%) were pre-service physics teachers or beginning teachers, newly graduated from post-baccalaureate programs and intending to teach physics. Another 38 (17%) were experienced teachers of other subjects who had been drafted into teaching physics and took the workshop to review and deepen their physics content knowledge and learn effective pedagogy at the same time. Another 19 were teachers of other subjects (most taught chemistry or physical science) who wanted to upgrade their physics content knowledge and/or learn modeling pedagogy for their teaching but who had no intention of teaching physics.

The 226 teachers were put into four categories based upon their FCI pretest score, and the normalized gain $\langle g \rangle$ for each group was calculated. Results are in Table 1. Teachers whose FCI pretest score was between 60% and 80% (i.e., above the Newtonian threshold but not at expert level) had the highest normalized gain, $\langle g \rangle = 0.59$.

| category | number | $\langle g \rangle$ | mean FCI pre | SD (%) | mean FCI post | SD (%) |
|-----------------|--------|---------------------|--------------|--------|---------------|--------|
| FCI < 60% | 43 | 0.47 | 42.4% | 9.7 | 69.5% | 16.9 |
| 60% < FCI < 80% | 46 | 0.59 | 72.5% | 5.8 | 88.5% | 9.6 |
| 80% < FCI < 97% | 98 | 0.42 | 91.9% | 4.5 | 95.2% | 5.3 |
| FCI = 100% | 39 | n/a | 100% | 0 | 98.6% | 2.1 |

Table 1. Normalized FCI gain for four categories of teachers, based on their FCI pretest score.

One of the most important findings is that **a gender gap exists, and the modeling workshop helps to close it.** The FCI and MBT data were disaggregated according to gender, content major, and physics teaching experience. Results are shown in Figures 3 and 4. Important findings are:

- Women had lower FCI pretest scores than men, in all content majors except biology, where FCI mean scores were equal, and at beginning levels (zero to three years) of physics teaching experience.
- **The modeling workshop was especially beneficial to women; it partially closed the gender gap,** in that women gained more percentage points on the FCI than did men.

- For both men and women, the modeling workshop was the most benefit to teachers with the least physics teaching experience, in improving their understanding of the force concept.
- Women had less physics teaching experience than men. Equal numbers of men and women with no physics teaching experience (i.e., about 3 dozen each) took the modeling workshop, whereas among teachers with four or more years physics teaching, fewer than half as many women as men participated (26 women and 58 men). An NSTA report in 2003 on teacher quality states, "the percentage of female physics teachers rose from 22 to 28 percent from 1990 to 2002." The modeling workshop enrollment is in accord with this trend. Thus *the modeling workshop may become increasingly important in future years to improve the force concept understanding of the enlarged number of new female physics teachers.*
- Women had lower MBT scores than men, in both categories of majors and for all years of physics teaching experience.

Results are shown in Figures 3 and 4. For convenience, teachers' content majors are in two logical categories. Category 1 includes physics and physics education, physical science, and all types of engineering degrees. Category 2 includes all other majors: biology (and related majors such as agriculture, pre-medicine, and natural resources management), chemistry, geology, general science, social sciences (including home economics), humanities, and elementary education.

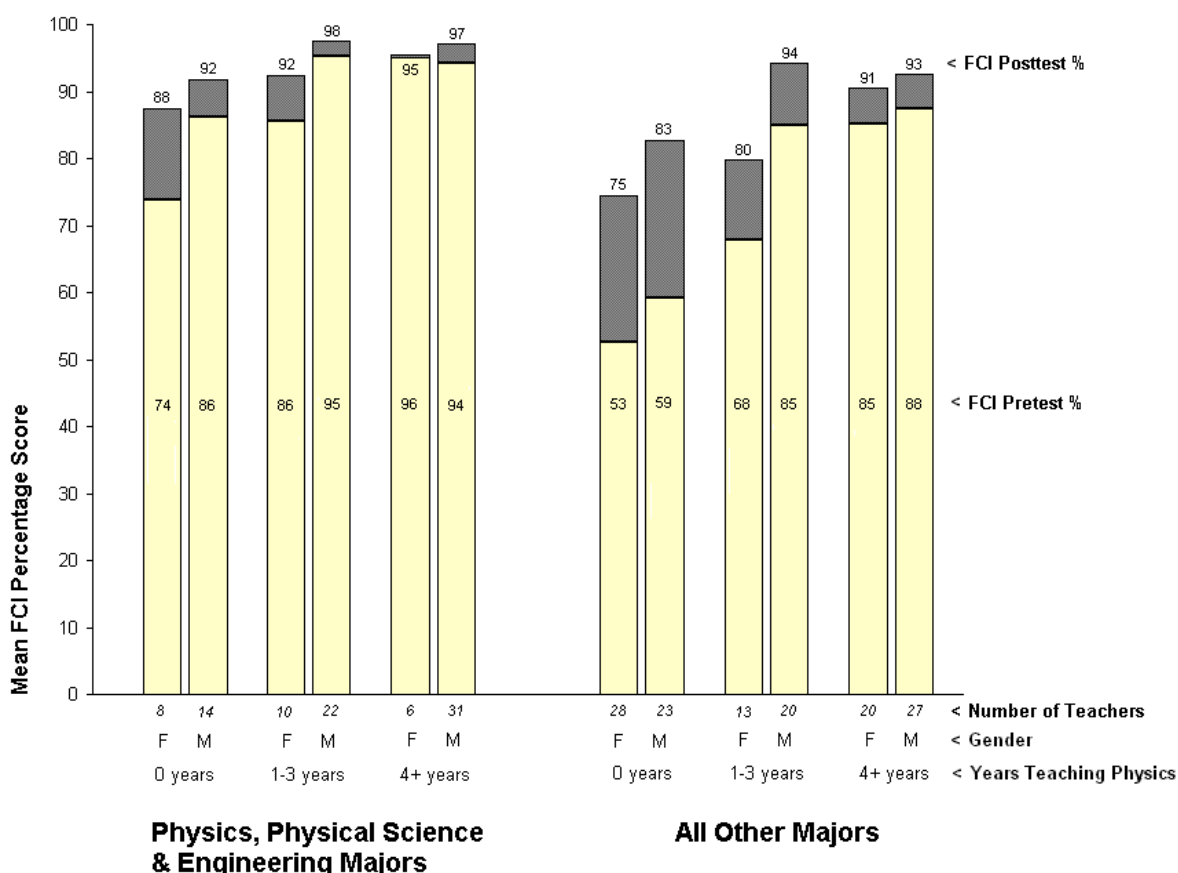


Figure 3: Force Concept Inventory mean percentage scores (pretest and posttest) for 222 women and men in Modeling Workshop in mechanics, correlated with physics teaching experience and content major in college.

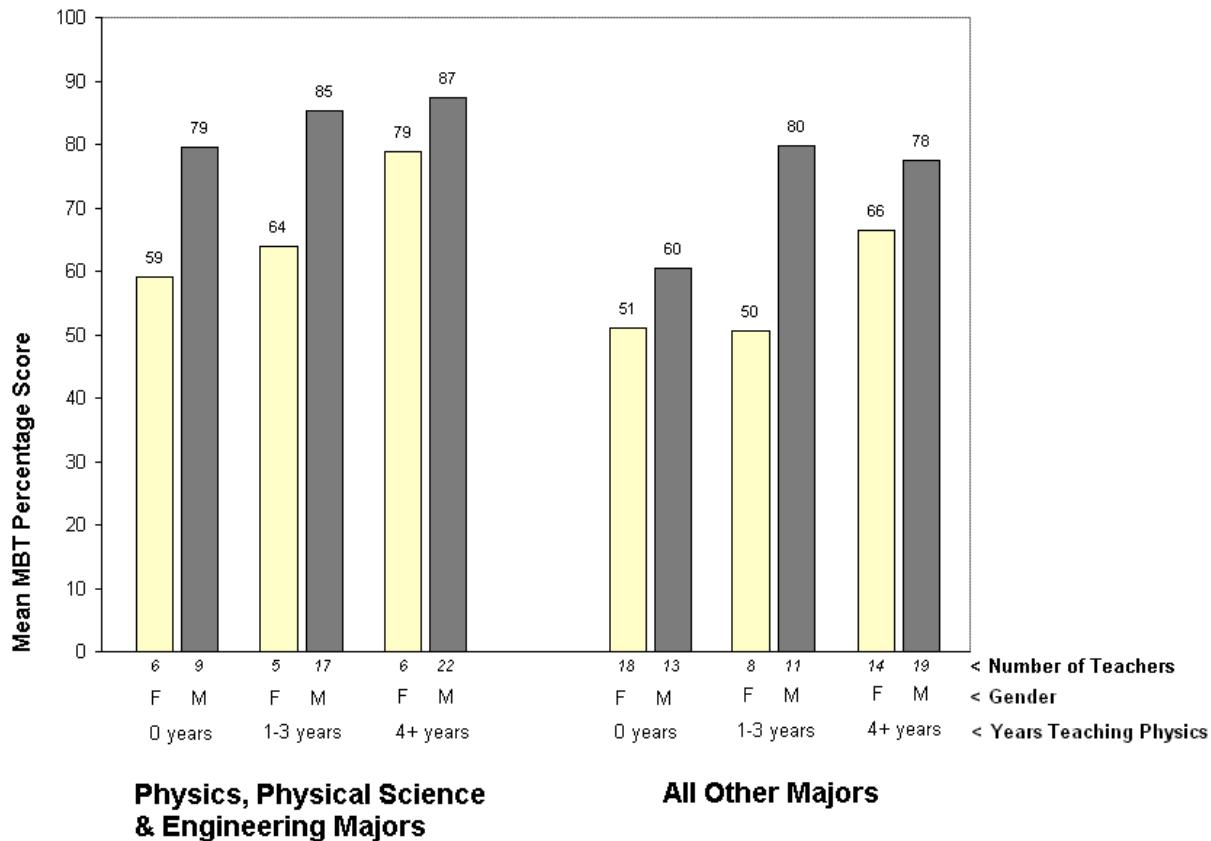


Figure 4: Mechanics Baseline Test mean scores for 148 women and men in Modeling Workshop in mechanics, correlated with physics teaching experience and content major in college.

FCI and MBT data give only a partial picture of gains in concept understanding. Pretests and posttests of concept inventories were given in all other modeling workshops. Research-based instruments were the Conceptual Survey in Electricity and Magnetism (CSEM), the Electricity Diagnostic (David Brown's diagnostic for CASTLE electricity), and an adaptation of the Wave Diagnostic by Michael Wittman, Richard Steinberg, and Edward Redish. For models of light, chemistry I, and physical science with math modeling workshops, in-house instruments were developed and used, since none were available for those high school curricula. Teachers gained in concept understanding in all courses, as measured by those instruments; and they were asked to administer the inventories to their students to measure the effectiveness of their teaching. Results will be reported elsewhere.