FINDINGS of the Modeling Workshop Project (1994-00)

This is one section in the Final Report submitted to the National Science Foundation in fall 2000 for the Teacher Enhancement grant entitled *Modeling Instruction in High School Physics*. David Hestenes, Professor of Physics at Arizona State University, was Principal Investigator. Extensive information about the Project is at http://modeling.la.asu.edu.

We summarize our findings in four major categories and review some supporting evidence.

I. Evaluation of high school physics instruction with the FCI. We have used the Force Concept Inventory (FCI) to evaluate the effectiveness of physics instruction throughout our project. In agreement with other research, we have found FCI data to be extremely robust and informative. We have amassed data on some 20,000 students from the classrooms of more than 200 high school physics teachers, with the following conclusions:

- Students who score below the *Newtonian Threshold* of 60% on the FCI do not have a sufficient grasp of the principles of mechanics to use them reliably in reasoning and problem solving. They are therefore forced to use rote methods in coping with their physics courses. Moreover, they do not score well on any other measures of physics understanding even outside mechanics.
- The average FCI pretest score for students beginning high school physics is about 26%, slightly above the random guessing level of 20%, with few scores over 30%.
- The average FCI posttest score after *traditional (teacher-centered) instruction* is 42%. Therefore, at least 2/3 of the students failed to reach a minimal understanding of physics in their high school course.
- For teachers using traditional methods of instruction the correlation between teacher FCI score (teacher competence) and the FCI scores of their students (student learning) is nearly zero.
- After teachers have completed the first 4-week Modeling Workshop (*novice modelers*), their students have an average FCI posttest score of 53% — clear evidence for improved instruction.
- More than a third of the teachers who have completed the full two-summer program of Modeling Workshops can be described as *expert modelers*, meaning that they have adopted and fully implemented the Modeling Method of Instruction with evident understanding. For 647 students of 11 expert modelers, the average FCI posttest score was 69%, and several of these experts consistently have average student scores close to 80%. These are among the very best results reported for high school and even college physics.
- Student posttest FCI scores depend much more strongly on teacher competence than on student demographics.
- Correlation between student FCI scores and extent of the teacher's academic background in physics is small. This suggests that "crossover teachers" can be as effective as physics majors in teaching introductory physics.
- On the *Mechanics Baseline Test* (a well-validated problem solving test), students of confirmed modelers show an average posttest score of 59%, compared with 36% after traditional instruction. Problem solving performance is strongly correlated with FCI score.

We conclude that the FCI is a very good instrument for evaluating instruction in introductory physics. It is easy to administer and score. The huge database from high school and college courses enables reliable and informative comparative evaluation. It is easy to distinguish between poor, mediocre and excellent results. Until class averages exceed 70% on the FCI there is little point in using more demanding evaluation instruments such as the Mechanics Baseline Test.

II. Impact of Modeling Workshops on teachers. From extensive and repeated interviews, surveys and testing we can support the following conclusions:

- The physics content knowledge of most teachers is increased substantially by the Modeling Workshops. When beginning the Workshops, about a third of the teachers score below Mastery Level on the FCI (> 85%). Within the next year nearly all of them improve to Mastery Level.
- Modeling Workshops have been extremely successful in inducing transformations from *traditional* (teacher-centered) instruction to *constructivist* (student-centered) instruction in full accord with the *National Science Education Standards*. Nearly all of the participating teachers now use the constructivist Modeling Method for all or most of their physics teaching.
- 75% of Modeling Workshop graduates responded immediately and enthusiastically to a follow-up survey between 1 and 3 years after they had completed the program. More than 90% of them report that the Workshops had a highly significant influence on the way they teach. 45% report that their use of Modeling Instruction has continued at the same level, while another 50% report an increase. Only 5% report a decrease.
- Most Workshop graduates report that other teachers are very interested in how they use technology in their teaching but less interested what they have learned about science pedagogy.

III. What makes the Modeling Instruction successful?

Modeling Instruction is a research-based teaching methodology under continuous development over the last two decades. For the most part it is fully in accord with the pedagogy recommended by the *National Science Education Standards* (NSES). However, it develops the themes of *models and modeling* in science education far beyond the NSES recommendations.

The present project has provided an exceptional laboratory for studying the efficacy of Modeling Instruction. We have data on more than 300 teachers who have learned the approach in similar workshops and used the same materials in implementing it themselves. Evaluation with the FCI shows that nearly all of them improved their teaching significantly, but there remains a large dispersion in their results that can only be explained by differences in implementation.

The Modeling Method organizes course content around a small number of basic scientific models as units of coherently structured knowledge. Activities give students experience in constructing and using models to make sense of experience in a variety of situations. The teacher cultivates student understanding of models and modeling in science by engaging students continually in “model-centered discourse” and presentations.

From our observations, the most important factor in student learning by the Modeling Method (partly measured by FCI scores) is the teacher’s **skill in managing classroom discourse.** That, of course, depends on the teacher’s own ability to articulate the models clearly and explicitly as well use them to describe, explain, predict and control physical processes. Although the Modeling Workshops cultivate such skills and nearly all participants improve significantly, it takes many years to reach a high level of proficiency. We estimate that perhaps 20% had the background to reach a high level by the end of the workshops. The rest need a long-term program of professional development to reach their full potential.

IV. Implications for Professional Development and Institutionalization

In our estimation, the single **most important and encouraging finding** from our extensive experience with inservice high school physics teachers is that the vast majority of them are able and eager to be excellent teachers. However, they are seriously under-prepared in pedagogy, physics and technology. To remedy these deficiencies, universities need to support sustained professional development through graduate courses tailored to meet the needs of inservice science teachers. We are currently demonstrating how that can be done in Arizona. Indeed, Arizona State University (ASU) is anchoring a statewide program to cultivate high school physics teachers as local leaders of K-12 science and technology education reform.

At ASU the Modeling Workshops have been institutionalized as a two-semester course in Methods of Physics Teaching, that serves as a required “methods course” for preservice teachers as well as basic training in science pedagogy for inservice teachers. Already more than half the physics teachers in Arizona have taken the course. This has stimulated creation of a more extensive graduate program for teachers that is just now getting underway.

SUPPORTING EVIDENCE

I. FCI Data on Students and Teachers:

The validity of the FCI has been thoroughly documented in the published literature (see references for this project). It is clearly the most widely used evaluation instrument in Physics Education Research, as shown by its high citation rate in the literature.

Our FCI data for 20,000 high school students reveal that student normalized gains (i.e., Hake gain) in understanding under Modeling Instruction are typically *double* those under traditional instruction. Student FCI gains for “ordinary” Arizona teachers in the Eisenhower modeling workshops were not significantly different from those of teachers in the nationwide Leadership Modeling Workshops, even though only 20% of the Arizona teachers have a degree in physics, compared to 40% of the teachers in the nationwide workshops. Teachers who implement the Modeling Method most fully have the highest student posttest FCI mean scores. More teachers implemented the method more fully in succeeding years of their participation in the program, and their students’ gains went up accordingly.

Effects of our 2-summer sequence of Arizona Modeling Workshops were that students’ gains in understanding of the force concept typically *doubled to tripled***,** most teachers’ understanding of the force concept improved to mastery level, and the number of computers in classrooms of teachers doubled.

We used a pre–posttest comparison design with matched students. Here we report highlights of the data analysis of Phase I, II, preliminary III, and preliminary Arizona Eisenhower FCI baseline, pretest and posttest data for the Modeling Instruction Project for considerably more than 10,000 high school students of about 170 teachers.

- The average increase in *student* posttest FCI mean for Phase I teachers is 6 percentage points after two years of workshop participation (several teachers had previous exposure to aspects of Modeling Instruction and started out high). The average increase in student posttest FCI mean for Phase II, Phase III, and Arizona teachers is about 10 percentage points after only one year of participation. **Figures 1a, 1b, and 1c** present graphs of student FCI means of teachers in the Phase I, Phase II, and Phase III Modeling Workshops, ordered from lowest to highest baseline mean. (Phase III data are preliminary; not all have been analyzed yet.) Corresponding mean FCI posttest scores for students of matched Arizona physics teachers are 35.8% baseline in 1998 (507 students) and 54.5% in 2000 (572 students), a gain of 19 percentage points in 2 years!

Figure 1a

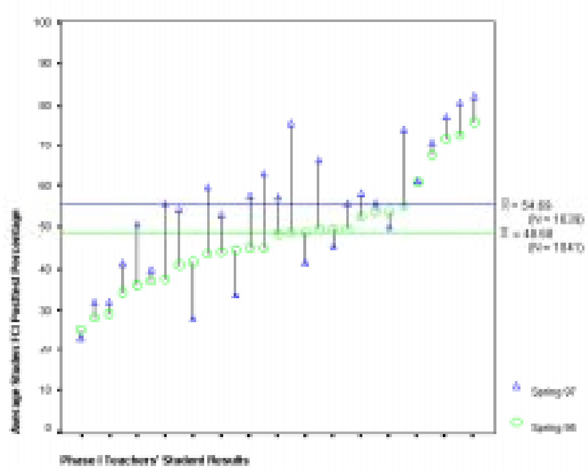


Figure 1b

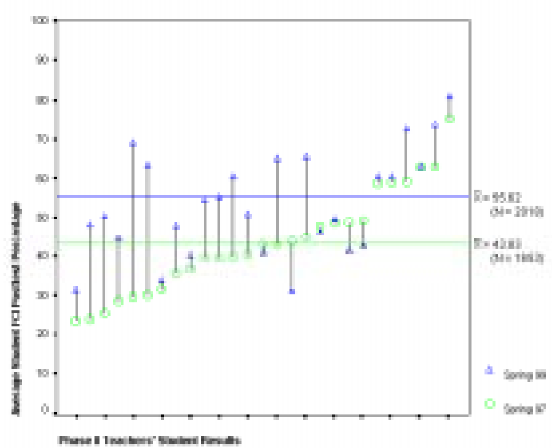
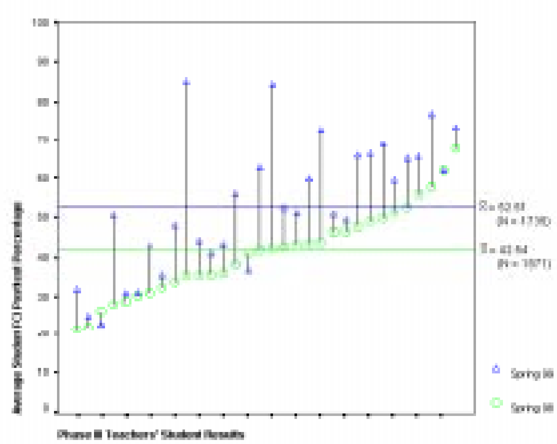


Figure 1c



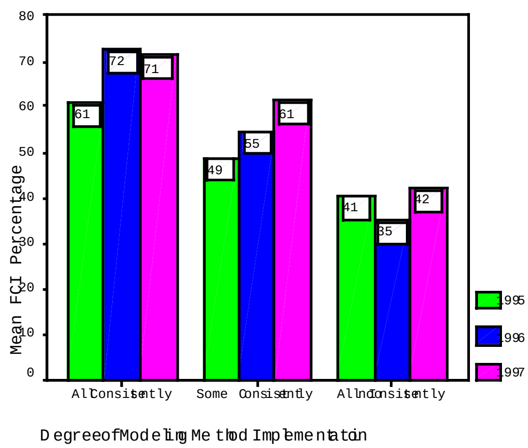
- When broken down by categories that reflect degree of implementation of Modeling Instruction, results show that teachers who report consistent implementation of most or all components of the Modeling Method have higher student posttest FCI means than their colleagues who report some implementation or little implementation**. Figure 2** presents a bar graph that shows average student posttest FCI mean for 23 Phase I teachers for whom we have complete data across three years. The graph is clustered by the modeling-implementation categories.

  The group that reported the *most consistent* use of components of the Modeling Method (on the 1996 experiences survey) also included some participants with some degree of prior exposure to reform courses. This group had an increase in average FCI posttest mean of over 10% (from 61% to 72%) and remained high after the following year (71%).

The second group, comprised of teachers reporting consistent use of *some* Modeling Method components, showed steady growth across the years, with a significant increase between 1995 (49%) and 1997 (61%). Many of these teachers reported consistent use of most or all components when resurveyed in 1997.

The third group, that reported the *least* degree of implementation of Modeling, showed *no significant difference* across years.

Figure 2

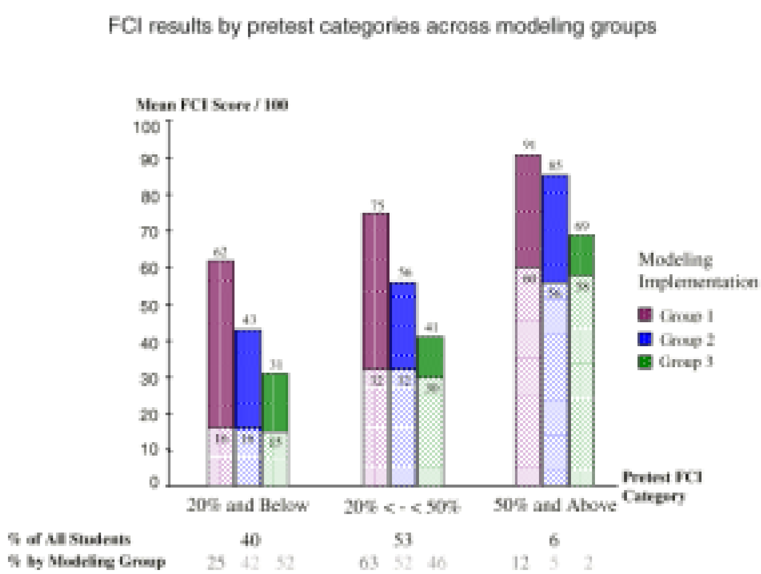


- Students at similar pretest levels of conceptual knowledge, as measured by the FCI, demonstrate different degrees of pretest - posttest gain, depending on the *degree of implementation* of Modeling Instruction by their physics teacher. **Figure 3** presents three categories of students, based on their pretest FCI performance (20% or below, 20-50%, and 50% or above). Each category of student is broken down by the degree of Modeling Method implementation by their teacher.

  Students with teachers who consistently use most or all components of Modeling Instruction have the *highest* pretest-posttest gains.

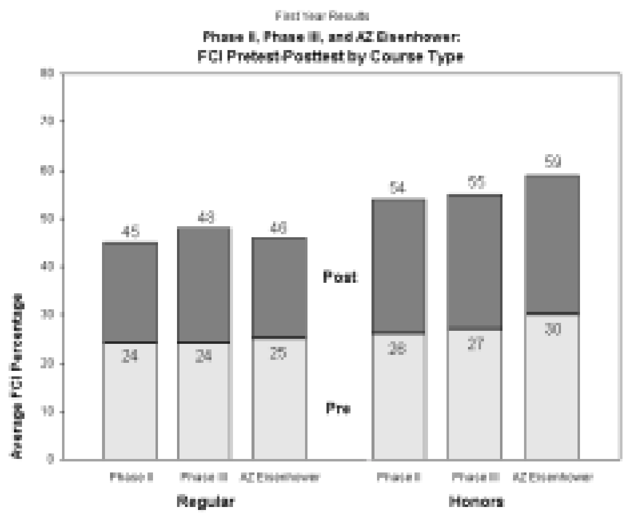
  Students with the *lowest pretest scores* show the *highest degree of gain* for the teachers in the *highest* Modeling implementation group.

Figure 3



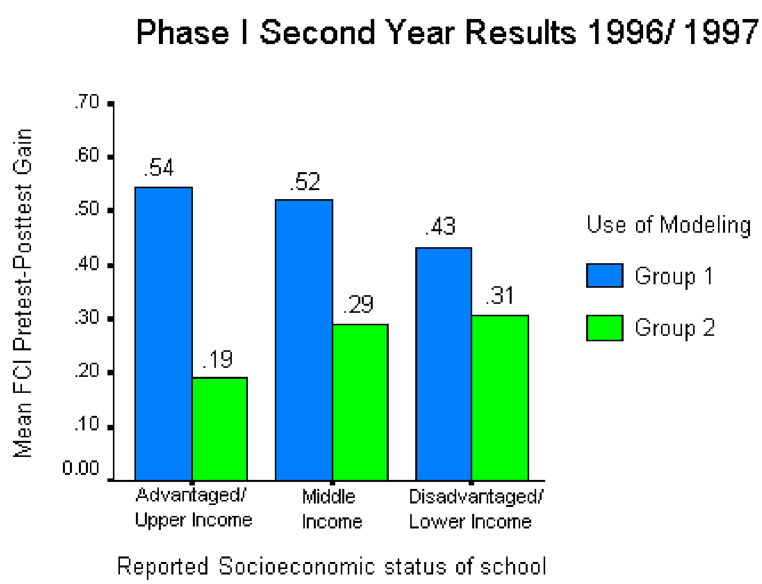
- When the matched student data are categorized into regular (algebra based and conceptual) and honors (trigonometry based) physics courses, the performance of "ordinary" Arizona teachers is like the groups of nationwide leaders. **Figure 4** shows this result.

Figure 4



- The program increases the achievement of *underserved learners*. Thirty-six Phase I teachers in our national modeling workshops reported their students' FCI scores in their second year of using Modeling Instruction. The teachers also completed a 50-question survey of their classroom experiences during that academic year. The survey contains questions regarding the teacher's perceptions of their understanding and implementation of the Modeling Method, their classroom practices and activities, and the socioeconomic status of their school. The teachers were found to be in two groups: those who were implementing all aspects of Modeling Instruction consistently (17 teachers), and those who were implementing some aspects of modeling consistently (19 teachers). **Figure 5** shows that in disadvantaged/lower income schools, the mean normalized FCI gains of the 93 students of the two teachers who implemented the Modeling Method consistently were 25% higher than for the 335 students of the six teachers who were implementing less modeling. Students of both groups did better than in traditional courses; the FCI gains of the 93 students were double that under traditional instruction, and the FCI gains of the 335 students were 50% higher than under traditional instruction.

Figure 5



- *Gender differences* are being explored where data are available. We find a significant gender gap under traditional instruction, with girls in regular courses attaining FCI (baseline) posttest scores averaging 9.5 percentage points less than boys, and girls in honors courses scoring 13 percentage points less than boys. (All other research studies in Western cultures find similar gender gaps in traditional physics courses.) For 900 Phase II students in *regular* physics courses in the first year of modeling implementation, Modeling Instruction dramatically increased the FCI gains both of boys (a mean increase of 14 percentage points compared to traditional instruction) and girls (a mean increase of 12 percentage points). For 666 students in *honors* courses, mean FCI gains improved by 3.5 percentage points for boys and 6.5 percentage points for girls relative to traditional instruction. Gender data from Phase I and III have yet to be analyzed.

- Assessment of *teacher* understanding of the force concept was via the FCI and the Mechanics Baseline Test. These two tests were given at the start of each workshop. For teachers nationwide and in Arizona who participated in the series of workshops and taught physics in the intervening year, the average FCI score increased to 93% and the MBT score increased to about 78%. Arizona teachers started lower: their average FCI score increased by 9 percentage points, whereas national workshop teachers' average FCI score increased by 6 percentage points. **Figures 6a and 6b** show these teacher FCI results for representative groups, ordered from lowest to highest baseline. The average MBT score of Arizona teachers increased by 14 percentage points and nationwide teachers by 6 percentage points. These improvements show that *the workshop in mechanics not only resulted in improved teacher understanding of the force concept but also sharpened teachers' problem solving skills*, for that is the focus of the MBT.

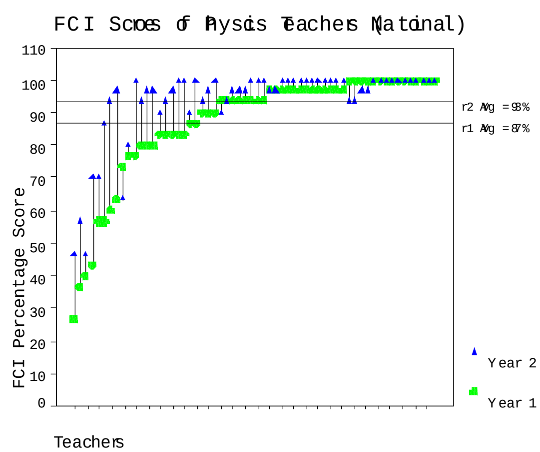


Figure 6a

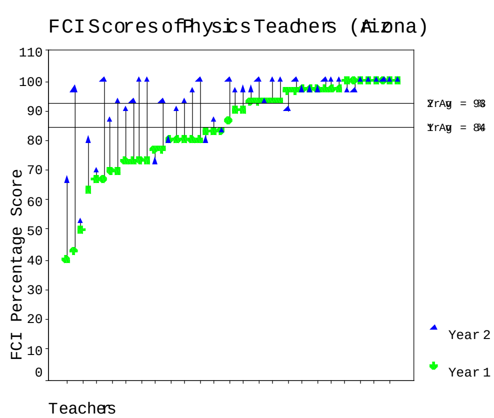


Figure 6b

The overall findings are that high school physics students of teachers in the *Modeling Instruction in High School Physics* Project demonstrate much greater gains on the FCI than a) physics students of the same teachers in the year before the teachers began the modeling workshop series, and b) a comparison group of 700 high school physics students a decade ago [D. Hestenes, M. Wells, and G. Swackhamer, Force Concept Inventory, *The Physics Teacher* **30**: 141-158 (1992) and private communication].

The comparison groups are:

a) 3529 high school students of the same Phase II and III teachers just before the teachers began the Modeling Workshop series. Those FCI mean scores were: pretest: 26%, posttest: 43.1%.

b) 808 students of 17 Arizona teachers in 1998 just before the teachers began the Eisenhower Modeling Workshop series. Those FCI mean scores were: pretest: 25.7%, posttest: 41.3%.

c) Over 700 high school students of 17 teachers, mostly in Arizona, a decade ago just before they participated in pilot Modeling Workshops. Those Force Concept Inventory mean scores were: pretest: 28%, posttest: 46%.

II. Impact of Modeling Instruction on the teachers: (Results from a follow-up survey of Tier-1 participants conducted in September 2000)

Current job status of the Tier-1 Modeling Workshop participants

146 still teach physics
14 have retired
12 teach other subjects now (physical science, math, chemistry)
12 teach in college, rather than high school
13 left teaching (most are school tech coordinators)
1 died
6 chose not to stay in contact
3 quit the program
5 took only the 3-week C3P modeling workshop
TOTAL: 212

[Note: **The original proposal was for 200 Tier-1 teachers.** Beyond that **more than 400 additional teachers have attended Modeling Workshops in 1999 and 2000** supported by Eisenhower funds and the supplement to this grant. Although these may be classified as Tier-2 teachers, most of the Workshops were comparable to the original workshops in quality.]

We report below the teacher responses from a single telling question on the survey. Among those who still teach physics the **response rate** was 112/146 = **77%.**

Question: All in all, what is the long-term impact of Modeling Instruction on your teaching practice?

Response statistics:

highly significant: 100. 90%
moderately significant: 9
significant in a few ways, but not in most ways: 2

60% of the responders chose to elaborate their answers. These are reported below because they are exceptionally revealing. Responses are classified by Phase (time) and site of the responder's Workshop experience. (All teachers have given written permission to quote them publicly.)

Phase I (1995-97)

ASU site

Art Woodruff, Orlando FL:
Highly significant. We have also used the modeling workshop for successful (I think) vertical training with middle school teachers. Because of expertise gained in workshops, *I have been assigned for one period per day to help other teachers with technology* (mainly probeware labs) in the department.

Mark Hines, Honolulu HI:
Highly significant - for those truly affected by this, *there is no turning back to the old way* - the leadership training affects a change in culture, which in my mind causes the teacher to change the internal model of learning a teacher has, much the same as David Hestenes points out that modeling changes the internal models that students use to explain and understand natural phenomena. The change in culture is difficult to accomplish (thus the need for extensive discourse and retooling) but it is definite.

Franceline Leary, Troy NY:
Moderately significant. I think that the new direction that physics is taking in NY will allow more opportunity for modeling.

William Doerge - formerly Phoenix, now San Diego CA
Highly significant. In my experience in teaching Modeling Physics classes ten years, I believe that *it is the most interactive, interesting, and effective program for learning physics* for students that I know. I am hopeful to see Modeling Physics become more widespread and develop further in electricity, magnetism, waves and optics, thermodynamics, fluid dynamics, and 20th (and 21st!) -century physics. I hope to participate in, or at least learn about, research and development in developing Modeling Physics in these curricular areas.

Earl Legleiter, Wichita KS
Highly significant. Modeling instruction has changed the way I teach. My students are learning better than ever before. *I am working to make modeling instruction the science instructional design of choice all across our state.*

Allison Lide - formerly Ohio, now Nepal
Highly significant -*Modeling has changed how I teach, completely and forever. I have a very strong sense of "there's no going back"*, as in, I could never go back to teaching science (and math also) in a traditional way. I have adopted/adapted Modeling techniques and philosophy in every class I teach, including middle school math and science. And I have even tried doing some Modeling while teaching at a Nepali village school while serving in the Peace Corps.

UIC site:

Kathy Andre Harper, physics graduate student at The Ohio State University.
Currently, I would only describe it as moderately significant as far as my actual time in the classroom is concerned, but I say *it's highly significant as far as the way I want to teach, once I'm given the opportunity.*

Ellis Noll, The Webb School of Knoxville, TN.
Highly significant*: the major reason that physics enrollment this year is over 80% of the senior class.*

Mary Lee Davis, Los Angeles, CA
Highly significant. Feedback from kids over the 8 years is significantly positive. *I would never revert to my former teaching methods*. Have only included the engineering process from Dartmouth with the studio techniques learned at Harvey Mudd.

Mervin Koehlinger, Fort Wayne IN
Highly significant: *it has also greatly influenced my chemistry teaching.*

Steve Hammack, Los Gatos, CA
Highly significant. Modeling has fundamentally and permanently changed the way I teach physics. I am still modeling and I think it is the best way for kids to learn the process of science and the concepts of physics. It is not a perfect system since there is a sacrifice in the breadth of concepts (there just isn't time to cover the traditional curriculum if you model properly) and I see no way this will change. I love to watch kids really discover things on their own and work independently. I would really enjoy getting back together with other modelers to discuss what works and what doesn't work in modeling. It is my hope that this curriculum with its unique pedagogy is kept alive and passed on to others. However, I would like to see the curriculum further developed since I think it has some weaknesses.

Louis Turner, Western Reserve Academy, OH
Highly significant. *I have changed everything I do in the classroom*. It moves students in the direction of being independent learners, and it puts the responsibility for learning where it belongs--on the students.

Phase II (1997-98)

ASU site:

Richard Spitzer, White Mountains of AZ
Highly significant, I think I'm fairly pure as a modeler in physics teaching. Much less pure in teaching astronomy. I'm trying to make astronomy a research based class.

David Boyer, Rhode Island
Highly significant. *Modeling is the best inquiry based, constructivist method* I have ever come across. I am using this methodology in Chemistry as well!

Roy Wilson, southern Mississippi
Moderately significant. *As a result of the modeling workshops, I do very little lecture any more*. My instruction is very student centered. Thanks.

Brad Katuna, north of San Francisco
HIGHLY SIGNIFICANT. I'm a better teacher after modeling, *I like my job more*, I feel the kids walk away with real transferable skills, I feel better about what I do.

Andrew Kartsounes, suburb of Detroit

Highly significant. I have completely changed my techniques. *Numbers in my classes have risen.* We passed a bond for a new high school and not a planning meeting goes by without someone (usually not me!) reminding everyone of the need for equipment in science classes and especially physics. Using modeling theory, I have convinced (I hope) board members and administrators that I already know how increased technology will be applied in my teaching and therefore have moved to the front of the funding line. *My department chair relies on me to be able to articulate how technology can be utilized in science education.*

Jay & Anna Zimmerman, Milwaukee WI

Highly significant. Modeling has completely changed the way we teach and we don't ever see ourselves going back to a traditional approach. *Students have come back from college and thanked us for the approach* because of the excellent preparation they received. One student's physics test average in a college course was so far above the class he is embarrassed to tell the other students.

Eric Gardner, southern Florida

Highly significant. I have been working closely with two physics teachers at nearby schools. They are very interested in Modeling. I would love to develop more materials in the other areas of physics. (ie continue where we left off). I was planning to attend the PEG workshop at U of Wash. next summer to build other areas of physics (e-m, optics) and learn more about the Physics by Inquiry curriculum. I went to a presentation at the Centennial Mtg. of the APS in which Lillian McDermott was honored and was very impressed by what her colleagues said about her. I do feel strongly about the effectiveness of Modeling so I would love to meet with the group at ASU again also! So little time...

Brad Talbert, Salt Lake City Utah

Highly significant. Modeling is a great way to teach physics. I think it could easily be adapted to other sciences as well if a person with the right knowledge and interest came along. *I see an increase in interest and understanding from my students* compared to my pre-modeling teaching. While I admit to having much to learn before I consider myself an expert, Modeling incorporates the quest for real student involvement that most teachers seek for. Students can not merely be passive receptacles of information, they must be active constructors of understanding.

UWRF site

Jon Fishwild, Oregon WI

Highly significant. Modeling has proven to be a career-saving change. I always felt OK about teaching, but *I never felt truly "alive" until implementing full-scale modeling*. Kids are truly engaged in what they are doing, and I learn something new every year about the process and how to improve upon it.

Fran Poodry, New Jersey

Highly significant. *This is the way I always wanted to teach but had been unable to figure out on my own after several years in the classroom!* It makes more sense to me than how I learned physics. I feel like the kids are really learning, and when they get to college they feel very prepared...several have told me so directly!

John Koski, St. Louis MO

Highly significant. Before Modeling I was using a curriculum and a teaching method that relied on students getting by with rote memorization It was not very stimulating for the students or me. Last year I took the plunge, threw out that curriculum, and embraced Modeling. What a positive difference! This year I am at a new school/new school district, teaching only physics and using only the Modeling method. (*One of my main motivations for accepting the new job was that the school was anxious to bring modeling into its curriculum!)*

Margaret Furdek, rural Wisconsin

Highly significant. The students seem to be learning so much and certainly appear to be having fun while being challenged. Several times I've heard students say, "This class seems to go so fast."

I'd like to help disseminate the methodology and technology during school time. Unfortunately, teachers seem to be assigned more tasks every year. This progression isolates us and takes away from communication between colleagues. It is a pity that we don't say "boo" to each other except at department meetings, and those have been eaten up by district-mandated requirements regarding state testing and state standards. *We just don't get a chance to talk with each other about our experiences or how best students learn.* Our department has purchased 2 LabPros and biology-oriented probes to use in biology labs but the biology teachers haven't yet had time to learn how to apply them.

Tony Nicholson, Greenwich CT

Highly significant; *modeling has changed my entire approach to teaching even though I was considered a very successful teacher before modeling (achieved a Presidential award* etc) I realize that modeling is what I was searching for to help my students achieve a more thorough understanding of the physics ideas I was interested in having them learn and appreciate. Modeling has also inspired me to continue teaching physics at a time I thought I had done it as best I could and was ready to retire. I only wish I had discovered modeling sooner.

Tom Todd, suburb of Chicago

Highly significant. Modeling has permanently changed my methodology. *I have taken modeling as learned in the physics content area and employed it in other classes (astronomy, geology, physical science).* It has forced me to "clean house", reduced content volume in these other courses and triggered a restructuring of lab/worksheet material to fit modeling. Student response to these changes have been overwhelmingly positive. In the past three years I have designed and tested two evaluative instruments similar to the FCI. My second editions of "Space Science Concept Inventory" and "Earth Science Concept Inventory" are being run in my building this year. While I'll need a while to accumulate more of an "n" before getting too statistical, already these tests have provided invaluable feedback on student progress and the efficacy of my instruction. It is my firm belief that elements of modeling can and must be applied to all content areas of science.

U of Akron site

Jerry Loomer, Rapid City SD

Highly significant. MODELING PHYSICS IS THE BEST TEACHING PRACTICE THAT I HAVE ENCOUNTERED IN 31 YEARS OF TEACHING. IT HAS PROVEN RESULTS. IT IS THE BEST WAY WE HAVE TO HELP STUDENTS.

Tim Battista, Ohio

Highly significant; *if I had not found the Modeling Instruction pedagogy when I did, I would most likely left teaching by now* because I was so discouraged with the mile wide, inch deep (1.64 km wide, 2.54 cm deep just doesn't sound as good) approach that I was using at the time.

Anne Mayher Hall, Pittsburgh

Highly significant *So many students who graduated from using modeling have returned to me saying they remember so much from the year,* so much so that most if not all who have pursued science-centered degrees have passed their calculus-based physics courses with A's or B's. I think it is a great program and I hope that it continues. Students and teachers can definitely benefit from it.

Phase 3 (1998-99):

UC-Davis site

Julia Eichman, rural Missouri
Highly significant. *I am a much improved teacher after the Modeling Experience.*

Colleen Kozumplik, Sacramento CA
Moderately significant - A number of aspects of modeling instruction were already a part of my teaching philosophy, but now I have a better idea of why they work and why they are good. Each year I get a little better at the discourse which is central to the method, and as I get better, my colleagues become more interested. *I am convinced that my students are better thinkers when they leave my class, and that this facility will help them in all their studies.* I am glad I have an opportunity to use the modeling method with freshman physics students because it allows me to give them better analytical skills and a more quantitative foundation for future science courses than they would get in a traditional descriptive course. I look forward to getting them back for Honors or AP physics in their senior year because I think I will be able to take them much further than I could their predecessors.

Steve Carpenter, northern CA
Highly significant...*makes me wonder how I ever thought I was really teaching physics before*...I have benefited from modeling not only through the pedagogical transformation that is taking place in my classroom, but also from *the wonderful exposure it has granted to basic physics content. I realize how little physics I actually learned in high school and college.* I am a life science 'convert', and *I won't ever go back without kicking and screaming* because modeling simply makes too much sense and provides far too much meaningful classroom discourse for me to ever want to return to a traditional classroom structure. I have grown a great deal, but realize even more how far I still have to go. Pursuing excellence as a modeler has helped me to establish a sense of purpose and focused effort for all that happens in my classroom. Unit and year-long storylines allow a much richer flow of content. Modeling can be humbling as well. *When you truly look for and evaluate student understanding by modeling standards, you realize that excellent teaching and learning are lifelong goals.* I now consider myself a learner and teacher of physics for life.

Paul Greene, Orlando FL
Moderately significant. Modeling instruction has not brought to me the results that it apparently has for some others. I like the modeling method to introduce concepts, but find that traditional methods are needed to keep things moving.

Don Higdon, Annapolis MD
Moderately significant. *Since I have been concurrently working with an NSF project dealing with another aspect of "modeling" (Maryland Virtual High School: using STELLA modeling software) I have chosen to blend content and techniques from both programs.* Mainly from the ASU Modeling Instruction I have employed pedagogical techniques such as specific modeling topics, experimental set-up, and whiteboarding. I had previously used computer interfaced technology pretty extensively, so that was not new. I had students work with STELLA curriculum materials developed by MVHS to support the focus on certain models (const vel, accel, Newton's 2 nd, ULG, and SHM) that are used in both programs. In all cases much attention is focused on graphical analysis, which is common to both programs.

It's not possible for me to evaluate what has the most impact. For the last two years my FCI scores have been great in my honors classes, and reasonable in my regular classes. *My sense is that the process of the students setting up and working though a lab, white boarding the data analysis, and the attendant focused discussion of the graphical analysis is a very powerful pedagogical sequence. I believe the STELLA modeling works as a powerful reinforcement*, and can function is an analogous way to setting up, running, and analyzing a probe-interfaced lab. In fact several times we did both. Of course the big issue is how much time one can devote to this merged sequence. I spent much more time on mechanics than is set out in the county curriculum. I have no answer to the problem of what I would do were I to be facing county or state written final assessments (which appears to be coming in two or three years). Right now my hybrid program works best following a "model" similar to an algebra based AP-C.

Mitch Johnson, Las Vegas NV
Highly significant. *Modeling physics instruction is more important to my students' success in physics than all of my education classes combined.* Prospective physics teachers should take modeling physics instead of regular education classes.

Fillis Friedman, Louisiana
Highly significant. Modeling has been highly effective in my physics classes. *I also use it in my calculus class.*

Ineika Nevarez, Sacramento CA
Highly significant - I now pay attention to the problems right and wrong. I look closely at the item analysis on exam questions to determine where errors may have occured and try to fix the problem. I consult Arons to go into a unit with what some preconceptions may be and work to dismantle them. *I love the modeling method and can not imagine teaching physics without it. Thank you sooooo much.*

Rob Lee, northern CA
Highly significant. *Modeling is the most relevant in-service training I have received.* I now approach every lesson or topic with models and student-centered practices. It is enabling me to achieve one of my primary goals as a teacher which is to get my students motivated and doing science.

Brenda Royce, Fresno CA
Highly significant !! *Thanks for empowering my teaching* (and my students).

U MARYLAND/St. Albans School site

Ed Benko, Pittsburgh
Highly significant. The Modeling techniques have essentially become my primary method of teaching both General Physics (regular/conceptual) and Chemistry. An objective this year is to access the Listserv and contact other Physics/Chemistry teachers who are gearing the Chem curriculum to the Modeling techniques.

Janice Hudson, Columbus GA
Highly significant. I have a student intern from Auburn University this semester. He was very excited to see modeling practiced. He had read an article about it but never seen it demonstrated. He is becoming quite proficient at it. When his supervising professor from the university saw him in action, he could not believe the discourse that was taking place in the classroom and how the students were coming up with the answers rather than the teacher. *I am so glad I learned to teach like this.*

Joe Spaccavento, New Jersey
I have taken many college physics courses, many education courses, attended numerous summer institutes, many were NSF funded, attended many other conferences. The Modeling Workshop experience was unique in that the main focus was not about the physics content, but rather it centered on how youngsters learn physics, and how the instructor can create the optimum

environment for this learning to manifest itself. *The Modeling experience taught me a little physics, a little technology, but a great deal about how to teach physics more effectively.*

Stan Hutto, San Antonio, TX
The numbers in Pre-AP doubled from 46 to 98 this year - I contribute it primarily to use of Modeling methodology. This is the largest number of Pre-AP and AP in the history of the school. Modeling Methodology is integral to my style in Pre-AP. I use the method to a lesser degree in AP due to time/topic constraints, and also because the course is dual-credit with local college I must meet certain lab requirements which put a further strain on the discourse time. I still insist on the students' use of "models" in explanations and lab write-ups and reference to what was "covered" or "un-covered" in Pre-AP.The same amout of methodology is used; I think I do a more concentrated effort on emphasis of the MODEL.

Suffice it to say that the modeling methodology has made a significant impact on my teaching style and on the learning of the students.

UCF - Orlando site

Elaine Carson, Chattanooga TN
Highly significant. I am in process of teaching Modeling Instruction to 2 other HS physics teachers in town. I certainly need to improve my ability to direct discourse. *Kids are leaving the physics classroom saying, "my head hurts but this is the most fun course I have had".*

Kim Freudenberg, San Francisco CA
Highly significant... incredibly!!!!!!!!!!!!!!!!
Teachers are also very responsive at state and national conference presentations we have given. I have also met teachers at other workshops who have gone on to take a modeling workshop at my suggestion.

Harlan Heitz, rural So. Dakota
Highly significant; since my BS was in general science and my MS was in chemistry, *I needed a deeper understanding myself so I could take my students deeper.*

Jane Nelson, Orlando FL
Highly significant. In thirty years of teaching, nothing has impacted my teaching, since my first days of learning how to teach science in undergraduate school, like the ideas I've learned in modeling. *It is the best idea to enter the teaching methods I have ever seen*. The ideas are so practical, but have not been made real before. *I thank David from the bottom of my heart for adding a new and wonderful dimension to my teaching...* and I thought that it was pretty good before. Others must have also because I was a Presidential Awardee for Science Teaching before I began modeling.

Roger John Siegel, Atlanta GA
Highly significant. *I love modeling!*