Engaging and Sustaining Physics Teacher Preparation Reform

JAMES EGGLESTON KERR

Michigan State University

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According to Hotep, Henn and Warren (2009), " High-school teachers are one of the most important factors in developing the science and technology workforce of the future. Institutions of higher learning in the U.S. will need to dramatically increase the number of high-school physics teachers they educate if every high-school student who wants to take a physics course is to have access to a highly qualified teacher." The necessity to increase the numbers of students enrolled in university STEM classes drives a focus on the established high school classroom environment. (Ogodo, 2019). This literature review will highlight examples of reform efforts to recruit and inspire excellent high school physics students. An emphasis is placed on a history of reform in physics teacher preparation strategies and contemporary examples of reform efforts championed by university faculty.

This review of literature will: 1) Address why reform in teacher preparation is needed, 2) Provide a brief history of reform, 3) Suggest a roadmap for sustaining reform, and 4) Feature examples of model teacher preparation programs and reform efforts.

Why Is Reform in Teacher Preparation Needed?

" In the United States there are over 23,000 teachers of high school students who serve students in 20,000 public high schools. While many of these high school teachers are excellent educators, we are concerned that only a third of U.S. physics teachers have a major in physics or physics education" (National Task Force on Teacher Education in Physics, pg. 3). Those who choose to teach physics in high school need not only an excellent pre-service experience but also ongoing professional development to support their evolving practice. Reforms in physics teacher preparation must address the current lack of appropriately certified highly qualified high school physics teachers (Hodapp, Hehn, Hein, 2009). The focus of sustained change must begin in the higher education classroom. To address physics teacher shortages, science education reform for 21st century learners must consider motivational factors, goal setting, student interest and self-efficacy (Larkin, 2019). Rather than engaging students in construction of learning and interacting around content, teaching physics is viewed as teacher-driven. Frequently, coursework in physics teacher preparation is separate from science technology engineering and mathematics (STEM) classes where physics content is mastered (Aiello-Nicosia, Sperandeo-Mineo, 2000). The separation of content and pedagogy in teacher training and in-service programs limits the opportunity to practice alternative productive teaching strategies. When new physics teachers reach the high school classroom, often they have limited experience in anything but the lecture to-lab format that they have observed in their STEM classes (Harr, Eichler, & Renkl, 2014).

A Brief History of Reforms in Teacher Preparation

The year was 1906, and physicists were already lobbying for reform of the high school curriculum. Charles Mann, from the University of Chicago, penned these thoughts:

> "When science was introduced into the schools, it was naturally taught . . . dogmatically and deductively. But it is now time for us to realize that science is our process of interpreting natural phenomena. . . . Hence if young people are to become adepts in science, they must be taught how to interpret for themselves. They should develop the habit of making sound interpretations of phenomena—a habit which can be acquired only by scientific study" (Otero, Meltzer, 2017).

"Throughout the late 1800s and early 1900s, physicists and teachers lobbied successfully to deemphasize lectures in physics curricula century, teachers and physicists alike pressed successfully to deemphasize lectures in physics curricula, especially in highschools, and expand the role of laboratories and projects that actively engage students (Otero et al., 2017 pg 53.)." More than 130 years of published articles and reports have consistently called for students to more deeply engage in the practice of inducing principles from data, the so called 'inductive method Remarkably, despite more than a century of broad agreement among physicists on the type of instruction that should take place in physics classes, such instruction has yet to be achieved in the majority of U.S. physics classrooms (Otero et al., 2017). The role of teachers and physicists as reformers continues, as conferences and papers today call for change in physics teaching and learning. Reformers stress the development of "habits of scientific thought" and the method by which actual scientists obtain results rather than "more or less scattered facts and theories" taught in such a way that they could only be committed to memory. Today the fashionable term "scientific practice" replaces the former popular reform terms: "the inductive learning method",and "scientific inquiry".

> "Our expectation is that students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves" (National Research Council 2012, Framework for K-12 Science Education).

A Roadmap for Sustained Reform

In 2008, the American Physical Society partnered with the American Association of Physics Teachers and the American Institute of Physics to form the Task Force on Teacher Education in Physics (T-TEP). The task force was charged with studying the challenges of physics teacher education in the USA. The comparative data suggests that traditional instruction is failing badly, and that the inadequacy is not due to the student. The years-long investigation by T-TEP demonstrated a need for designated point persons, or in the words of the task force, champions, who can work to ensure that physics departments' resources are marshaled effectively in teacher preparation efforts. (National Task Force on Teacher Education in Physics: Report Synopsis, 2010). Thriving physics programs do exist. These vibrant programs can provide models and resources for reform of physics teacher preparation programs.

A set of requirements for successful and ongoing reform of physics teacher education was compiled by the National Task Force On Teacher Education in Physics in 2010. A synthesis of these guidelines is presented here in a sequence of steps presented below:

1) Required first in a sequence of events is a significant level of internal administrative and external community support. One of the most important assets to the ongoing success of a productive physics teacher preparation program is the "champion," a dauntless personality capable of inspiring and sharing a vision for change. The champion must be deeply dedicated to physics teacher education, and willing to invest the time required with a tenacious grit to overcome significant obstacles.

2) A second requirement for the successful and ongoing reform of physics teacher preparation is collaboration within institutions of higher learning. Rather than isolated "silos" for STEM disciplines with an entirely separate camp for the resources of teacher education, an extensive synergistic structure must be fostered. A review of united and comprehensive crosscutting content for existing classes will be required. Collegiate physics teachers must model excellent teaching pedagogy and lead future teachers in practicing the application of these models in embedded classroom participation.
3) A third requirement for sustained physics teacher education reform is a focus on pedagogy, specific teacher experiences within the training sequence, and active models that express how resources can be applied to teach physics teachers, and also how students learn about physics.
4) A final component for ongoing reform is a significant commitment of time for mentorship and advisement of all teacher candidates. These relationships must be sustained long after the pre-service students have entered their professional practice. A professional learning community (PLC) can provide a sense of fellowship, with a potential to share in a rich ongoing intellectual dialogue inspired by professional relationships.

A Sampling of Exemplary Reform Efforts

The following digest of university physics education reforms highlight efforts within the community to recruit and sustain qualified teachers in high school classrooms. The samples include alternative approaches to pedagogy, additional counseling with tutoring support for teacher education and STEM classes, collaboration between high school and university structures, and an example of systemic focus on curricular reform in cross-cutting content themes.

Arizona State University

Dr. Malcolm Wells was an Arizona high school teacher and a part of the great generation of physicists that worked together to launch mankind into space. Working with his peers at Arizona State University, he used his extensive classroom teaching expertise to shape a movement for the training of future physics teachers. Employing and sharing the modeling instructional method, Malcomb understood that standard teacher preparation and in-service training alone could not guarantee the high level of performance required in modeling instruction. Years of practice in modeling instruction are required to master the technique. Therefore, he developed a plan for university and continuing education workshops. The workshops allowed participants to role play as students and teachers, practicing cooperative inquiry. His success underscored the need for permanent institutional mechanisms to support teacher growth and professional development (Wells, Hestenes, & Swackhamer,1995). His vision lives on through the dedicated work of Ibrahim Halloun, Larry Dukerich, Jane Jackson, Colleen MeGowan, and the American Modeling Teachers Association (Jackson, Dukerich, Hestenes, 2008). As a direct result of the dedicated work by Malcomb Wells, Arizona State University (ASU) has become a leader in the reform of physics teacher preparation.

ASU currently offers a “Methods for Science Teaching” class, co-taught by a high school teacher, Larry Dukerich. The three credit course, available to pre-service teachers and in-service high school teachers alike, combines physics content and teaching methodology in a modeling instructional framework. The STEM specialist in the co-teaching team supports content learning, and the high school teacher affords immediate credibility for both the pre-service teacher and peer in-service teachers. This combination affords a link between the university and high school physics communities, supporting the recruiting process for future students. The course works well for many high school physics teachers who were not trained as physics majors, addressing lapses in physics content knowledge. The structure exposes teachers to an alternative to the traditional lecture - to lab learning environment. Unlike most science preparation programs that include a generic science methods class, this modeling instruction class is specifically focused for physics teachers (Jackson, 1997).

Rutgers University

Euginia Etkina was born in the former Soviet Union to a family of physicists. She continued the tradition, training in Russia, then moving to the United States to become a faculty member at Rutgers University. She is internationally renowned for her creation of Integrative Science Learning Environment (ISLE), an approach to teaching and learning physics. In an address to a recent American Association of Physics Teacher (AAPT) conference entitled " Students of Physics, Listeners, Observers, or Collaborative Participants", she outlined the importance of learning to think in Physics. She explained how she came to the conclusion that after years of teaching that she had not taught her students to think scientifically. Steps of what she hopes her students will take away include: 1) The way scientists think is individual, 2) Knowledge is built on evidence, 3) We observe phenomena then come up with explanations, and 4) Test the explanations and apply them to new situations. She explained that the traditional methodology was not enough. "Students need to participate in the construction of this beauty". They need to see the process not just the product. The design of the Rutgers physics teacher preparation program includes five three-credit courses.

The key question she expects physics students to answer is “How do you know what you know?” She follows with a challenge for the AAPT: “Can physics students be trained to think like scientists? If students do not know why they know, they are not doing science. Rather, they are dwelling on the facts of science rather than developing an understanding of how the facts were established.” She stresses that construction of new ideas is as important as the application of new ideas. Textbooks are employed for reference to support the ISLE active learning cycle.

Eugenia is the administrator for one of the most successful physics teacher preparation programs in the nation where students make physics together, not just read about it. 85% of her students from the Rutgers physics teaching program graduate, and 70% are still teaching. In her address to the AAPT, she said “I feel like an Olympic coach, training Olympic champions. I cannot set any Olympic records, but my kids can” (Edkina, 2014).

The University of Arkansas

Gay Stewart is a PhysTEC director, a champion for physics educator preparation reform at the University of Arkansas. She excels at both recruiting and advising future physics teachers. Her work has resulted in a marked increase in the graduation rate of Physics majors from the University of Arkansas. She employed research-tested materials in the re-design of Introductory Physics coursework. The changes focused on interactive engagement, the introduction of a learning assistant program, and increased attention to the advising of enrolled physics students. Her efforts have helped to build a socially supportive departmental atmosphere that persists today. Her philosophy is that every physics student in the department might someday become a high school physics teacher. So, all enrolled physics students need to be exposed to good physics pedagogy in all of their classes. She believes that if teachers are prepared with experiences of excellent pedagogy in their content classes and teacher preparation classes, the result will be high school students who enter the university well-prepared for their prospective majors (Hodapp, et al, 2009) .

The University Of Colorado

Valarie Otero co-teaches a two-credit class for Learning Assistants (LA)s at the University of Colorado. The university introduced a Learning Assistant (LA) program to encourage induction into the university's teacher education program. The result has been increased learning gains in undergraduate physics classes. At the University of Colorado, LAs are selected from the top 20% of their class. They take a two-credit course that is designed to help them understand the relationship between theory and practice. LAs work directly with Introductory Physics students in small group settings. By use of guiding and probing questions, they help introductory students to gain confidence in understanding content. This experience helps the LAs to consider if the pursuit of a career in physics teaching is a good fit. Valarie says that through the LA program future teachers can experience the intellectual challenge that the teaching of physics provides. Many find the LA program to be a great support toward the pursuit of certification as a future classroom physics teacher (Otero, Pollock, & Finkelstein, 2010).

Western Michigan University

Drew Isola earned a PhD in physics education and also is an experienced high school physics teacher. He is also served as a Teacher In Residence (TIR) at Western Michigan University (WMU). WMU is among the leading success stories for PhysTEC institutions, producing a significant increase in certified physics teachers. Many physics teachers at universities have little or no experience in teaching at the high school level. A teacher in residence affords access to a wealth of insights including student learning styles. Drew served as a TIR for two years, helping to develop, operate, and improve instruction in both the physics classes and physics education classes. Drew worked with university faculty and teaching assistants, and organized departmental recruiting efforts. He used his personal knowledge of the high school context to help the teacher assistants (TA)s and university faculty to develop teaching techniques that would engage introductory physics students. He worked to inspire the education faculty to infuse science methods courses and physics specific pedagogy in the instruction of teacher preparation coursework. Drew also traveled to high schools where he mentored physics teachers, and he organized opportunities for the university to network with the high school leaders at the MWU campus. He also guided newly placed physics teachers to locate mentor teachers and developed useful professional development programs. Thought these interactions, Drew helped the new physics teachers to feel less isolated and simultaneously provided avenues to recruit future physics students to the university physics department (Hodapp et al. 2009).

Michigan State University

At Michigan State University (MSU), reform of STEM core class curriculum will be informed by changing norms promoted by the President's Advisory Council of Advisors on Science and Technology (PCAST). The MSU STEM faculty recognize that the time has come for change in the traditional format for instruction. Information must now be used, and not merely memorized. Responding to the President's Council on Science and Technology (PCAST) the MSU STEM faculty recognized that structural changes will relate to both recruitment and retention of students. Reforms must address expectations of what students should learn and themes that connect cross-curricular disciplines. While interactive classrooms have provided a starting point to address underprepared and underrepresented student populations, a deeper concern is for opportunities to support transferable knowledge. Student should develop a deep understanding of core ideas that crosscut disciplines. These understandings require carefully layered and progressive learning activities and assessments which inform teachers and learners alike.

Some “Big Ideas” or core ideas were identified, as Michigan State University (MSU) faculty attended cross-disciplinary meetings where streamlining curriculum was discussed. They suggested that students are often unable to apply what they have learned in one discipline to another. Furthermore, they stated that students must be able to extend and apply knowledge across disciplines. The MSU faculty members asserted that assessment of core ideas or crosscutting concepts must be integrated, as disciplinary experts or trained scientists do in good scientific practice. Finally, the faculty members advised that a student-centered approach, applying models, explanations, and argumentation facilitate the assessment of what students know and how they know it (Cooper, Caballero, Ebert-May, Fata-Harley, Jardeleza, Krajcik, Laverty, Matz, Posey, & Underwood, 2015).

Conclusion

The goal of teacher preparation reform is to help students to understand and to use good scientific practices. Physics departments and colleges of education should recognize their individual and corporate responsibility for including good scientific practice in collegiate instruction. Institutions that host physics teacher preparation programs should join regional organizations such as the Physics Teacher Education Coalition, American Association of Physics Teachers, American Institute of Physics, and the American Physical Society as a part of their institutional mission. These societies have the responsibility to share research results concerning successful innovative models for teacher preparation.

To sustain meaningful reform, physics preparation programs must take full advantage of this ongoing research and embrace approaches and clinical experiences that model effective learning environments. These experiences must allow the integration of content knowledge in physics as well as physics-related pedagogy and evolving technologies. Professional learning communities (PLC)s must be established to discourage professional isolation, support reforms, and simultaneously encourage collaboration among physics teachers. State certification programs must maintain a commitment to teacher preparation in physics-specific pedagogy as well as content knowledge, requiring evidence of both as part of the certification process.

To continually improve teacher education programs, collaborative introspection from physics departments and education departments alike must be expected. As future teachers transition from preparation programs to high school classrooms, alternative experiences in research based pedagogy must become increasingly supported. As future teachers transition from collegiate programs to high school classrooms, alternative experiences in research based pedagogy must become increasingly supported. A vision for a connected physics community will be needed to sustain change.

Annotated Bibliography

Aiello-Nicosia, M. L., Sperandeo-Mineo, R.M., (2000) Educational reconstruction of physics content to be taught and of pre-service teacher training: a case study, International Journal Of Science Education, Volume 22, issue 19, pp. 1085-1097.

Many conferences and papers are calling for change in physics teaching and learning. Reconstruction of the delivery of content must be accompanied by a reconstruction of teacher preparation. Proposed changes include emphasis on constructivism and teacher role in the classroom.pedagogical choice. This case study reports a teacher preparation course where future teachers practice modeling instruction acting as teacher and learner in a pre-service teacher training environment. This pre-service training involves significant alteration in the teacher role, providing opportunities for future teachers to experience the learning environment of a physics modeling classroom.

Changes in the high school classes must be accompanied by changes in physics teacher education programs. This reconstruction involves substantial modification in the role of the teacher, and in pedagogy. The teacher acts as a coach, helping to build the skills of the modeling student. Frequently coursework in teacher preparation is separated from science coursework where content is mastered. Teachers who participate in the teacher/ learner experience synthesize content and pedagogy in teacher training, as they receive an experience that can be transferred to their future classrooms. Training classes must provides a synthesis of relevant content and opportunities to evaluate student-generated models and practice with classroom instructional sequences and learning requirements.

A challenge in physics educational preparation has been to identify the conditions that support student learning in Newtonian Physics, and to devise more effective teaching methods. Modeling Instruction is a research-based pedagogy, stimulating reform in physics instruction. Rather than relying on lectures and textbooks, the core focus for student instruction is "doing science" as they construct mental models and conceptual models. The result is student-owned learning that lasts.

Cooper, M. M.,, Caballero, M.D., Ebert-May, D., Fata-Hartley, C. L., Jardeleza, S.E., Krajcik, J.S., Laverty, J.T., Matz, R.L., Posey, L.A., Underwood, S. M., (2015) Challenge faculty to transform STEM learning *Focus on core ideas, crosscutting concepts, and scientific practices*, Science, Vol.350, Issue 6258, pp. 281-282.

STEM faculty recognize that the time has come for change in the traditional format for instruction. Information must now be used, and not merely memorized. The President's Council on Science and Technology (PCAST) recommends change that will relate to both recruitment and retention of STEM students. Reforms must address expectations of what students should learn and themes that connect cross-curricular disciplines. While interactive classroom have provided a starting point to address underprepared and underrepresented student populations, a deeper concern is for opportunities to support transferable knowledge. Student should develop a deep understanding of core ideas that crosscut disciplines. These understandings require carefully layered and progressive learning activities and assessments which inform teachers and learners alike. Some "Big Ideas" or core ideas have emerged as Michigan State University

(MSU) faculty in cross-disciplinary meetings where streamlining curriculum has been discussed. “Students are often unable to apply what they have learned in one discipline to another”. Students must be able to construct understanding of big ideas or core concepts and extend and apply that knowledge across disciplines. Assessment of core ideas or crosscutting concepts must be integrated as disciplinary experts, or trained scientists do in good scientific practice. These practices include modeling and argumentation. A student-centered approach, applying models, and explanation as well as argumentation facilitates assessment of what students know and how they know it. The goal is to help students to use scientific practices to make sense of phenomena. As students are trained in good scientific practice in high school, these practices will be expected as they enter the environment of higher education.

Etkina, E., (July 30,2014), Students of physics, listeners, observers, or collaborative participants, American Journal of Physics, Vol. 83, No. 8, 669-679.

Euginia Etkina was born in Russia to a family of physicists. She continued the tradition, training in Russia, then moving to the United States to become a faculty member at Rutgers University. She is internationally renowned for her creation of Integrative Science Learning Environment (ISLE). As the 2014 Robert A Millikan Medal Winner for notable and intellectually creative contributions to the teaching of physics, she was a keynote speaker at American Association of Physics Teachers conference in Minneapolis in 2014.

In her remarks she outlined the importance of learning to think in Physics. She explained how she came to the conclusion that after years of teaching that she had not taught her students to think scientifically. Steps of what she hopes her students will take away include: 1) The way scientists think is individual, 2) Knowledge is built on evidence,

3) We observe phenomena then come up with explanations, and 4) Test the explanations and apply them to new situations. She explained that the traditional methodology was not enough. “Students need to participate in the construction of this beauty”. They need to see the process not just the product.

The key question she expects physics students to answer is ‘How do you know what you know? In her closing statements she said: 85% of my students from the Rutgers physics teaching program graduate, and 70% are still teaching. She said ‘I feel like an Olympic coach, training Olympic champions. I cannot set any Olympic records, but my kids can,” She proceeded to give examples of stellar students who are excelling in education, including Matt Blackman who is designing physics computer games featuring multiple representations, and also James Falkker, whose 150 student groups submitted experiments in a competition to be completed on the Space Shuttle. One group entry was selected for the honor.

Harr, N., Eichler, A., Tenkl, A., (2014), Integration pedagogical content knowledge and pedagogical/ psychological knowledge in mathematics, Frontiers In Psychology, Vol. 5, no 924, pp. 1-8.

In teacher education at universities, general pedagogical and psychological principles are often separated from subject matter knowledge. and may not be applied in the teaching subject. This experimental study (N = 60 mathematics student teachers) investigates the effects of providing aspects of general pedagogical/psychological knowledge and pedagogical content knowledge in an integrated or separated way. Participants individually worked on computer-based learning environments addressing the same topic: use and handling of multiple external representations, a central issue in mathematics. The set up experimentally varied whether pedagogical/psychological knowledge aspects and pedagogical content knowledge aspects were treated integrated or apart from one another. As expected, the integrated condition led to greater application of pedagogical/psychological aspects and an increase in applying both knowledge types simultaneously compared to the separated condition. Overall, the findings indicate beneficial effects of an integrated design in teacher education.

Hodapp, T., Hehn, J., & Hein, W., (2009), Preparing high-school physics teachers, Physics Today, Vol. 82., No. 2, pp 40-45.

High school teachers are essential to the developing American workforce. The number of highly qualified high school physics instructors must grow to meet the expanding needs of a vibrant economy. Poor teacher preparation can produce under prepared classroom teachers, leading to a depleted or insufficient experience for students in the physics classroom. In 2009, Physics majors represented only 1.4% of all science and math graduates, while 4o years ago, the percentage was 4%. A coalition of the American Physical Society (APS), the American Institute of Physics (AIP), and the American Association of Physics Teachers (AAPTT) banned together to create the Physics Teacher Education Coalition (PhysTEC). This organization, comprised of a range of large university and small college representatives, shares best practices and innovative methods, advocating for the enhancement of physics departments in the education of future teachers.

About 1200 new physics teachers are needed each year. These are difficult to fill with highly qualified teachers. Unfortunately, some university and collegiate faculty “think that mismatch between supply and demand is not their problem or that high school teacher education should be left entirely to schools of education. Those who hold this opinion jeopardise the sources of future physics majors, as inadequately prepared teachers alienate or discourage potential physics majors for years to come.”

Sustained effort in the recruitment of Physics educators, mentorships, improved faculty advising, creating of Learning Assistants and Teachers in Residence programs are examples of existing interventions. Example programs at varied universities and colleges are featured.

Jackson, J., (1997), Get real! A “ Methods of Teaching Physics” course instructed by a high school physics teacher, American Institute of Physics Conference Proceedings, Vol. 399, pp, 805-807.

Arizona State University is a leader in the reform of physics teacher preparation. At the writing of this article, the “Methods for Science Teaching” class is taught by Larry Dukerich, an expert high school teacher. The three credit course is available to pre-service teachers and in-service high school teachers. The course combines physics content and teaching methodology in a modeling instructional framework. The high school teacher possesses deep knowledge of recent educational research physics pedagogy and curriculum design. The course is a collaborative workshop course, where the participants role play both teacher and student as they practice techniques in building mental and conceptual models based on specifically selected systemic physics topics.

The course works well for several reasons. One is that most high school physics teachers are not physics majors and the course addresses lapses in physics content knowledge. Another is that teachers are exposed to an alternative to the lecture/ lab traditional learning environment common to many college and research university physics content classes. Most science preparation programs include a generic science methods class. This class is specifically focused for physics teachers.

The experience high school teacher offers immediate high credibility for both the pre-service teacher and peer in-service teachers. University professors many not have the knowledge of the high school classroom context. The high school teacher may, however, need to be a co-teacher with a faculty member. This combination affords the value of additional content expert support and the opportunity for the professor to get to know the high school teachers who are preparing their future students.

The format for this class has been duplicated in professional development classes offered at colleges and universities across the United States and internationally.

Jackson, J., Dukerich, L., Hestenes, D., (2008), Science Educator, Modeling Instruction: An Effective Model for Science Education. Vol. 17 Issue 1, pp. 10-17.

Modeling Instruction is a research-based pedagogy, stimulating reform in physics instruction. Rather than relying on lectures and textbooks, the core focus for student instruction is "doing science" as students construct mental models and conceptual models. The Modeling instruction pedagogy stresses active learning as opposed to a classical model that features lectures and labs. A key aspect of modeling instruction is the changing role of the teacher who no longer acts as an authority figure, but as a coach or facilitator.

The teacher starts the learning cycle with a demonstration. Students propose testable relationships within the experiment, and develop mental models followed by conceptual models. In Modeling pedagogy, students describe and defend their models in a non-threatening and supportive classroom environment.Students publically share, discuss, and debate their models with their peers The teacher listens for misconceptions and then employs a Socratic questioning technique to address any "fuzzy" thinking. In a second step in the modeling cycle, a redesigned model is deployed test new situations.

Success in modeling instruction is determined by a comparison of a pre and post FCI (Force Concept Inventory) test that measures student conceptual understanding of the force concept, an underlying construct in all study of mechanics and Newtonian concepts. Average pretest scores are 26%. After modeling instruction with expert modeling instructors, the posttest averaged 69%. This compares to a normalized gain of 56%. This gain is more than double the gain for students who took the FCI tests, but received traditional instruction. The FCI reveals student misconceptions (naive beliefs) based on personal experience, and measures conceptual gains. When compared to students participate in classical instruction, only a small change in student misconceptions can be observed. The comparative data suggests that traditional instruction is failing badly, and that the inadequacy is not due to the student.

Larkin, B. (2019), Attending to the public understanding of science education:

A response to Furtak and Penuel, Volume 103, Issue 1, pp. 167–186.

While the Next Generation Science Standards serves as a significant structure and content resource for science educators, reference to science pedagogy is not included. What is needed is scientific education reform and attention not only to content but also to how science is taught and how students learn about science.

Contemporary public visions of science classrooms are often defined by science knowledge delivered from the teacher to the student. This delivery has been characterized as alienating, unnecessarily difficult and frustrating, disconnected and dull. Nevertheless, public regard for the traditional model is commonly embraced over the potential risk presented by unfamiliar approaches. Rather than engaging in construction of learning and interacting around content teaching science is viewed as teacher-driven. Next Generation Standards place great emphasis on student learning based on research-based principles with limited attention to pedagogy. Emphasis on science pedagogy may be absent in the Next Generation Standards due to lack of consensus, and inertia.

Modeling Instruction suggests one successful pathway to reform, but the delivery pathways for providing teachers with opportunities to learn how to practice modeling instruction are limited. Science education reform must include motivational factors, goal setting, interest, and self-efficacy. As students pass through the reforming science classrooms and into college environments, future educators may demand reform of teacher preparation programs

National Task Force on Teacher Education in Physics: Report Synopsis (2010), retrieved from https://www.aapt.org/aboutaapt/reports/upload/PTEC_Task_Force_Report.pdf

The call to action begins with a description of the coalition of stakeholders that will be required to bring sustained reform to physics teacher preparation. These include: Physics departments, schools of education, university administrators, school systems, state agencies, the federal government, as well as businesses and foundations. Most important in the list of stakeholders are the high school students who will be the primary recipients and benefactors of sustained reform. The report states that the standards for physics endorsement which suggest a "highly qualified" status for educators hide the fact that many physics teachers lack the content knowledge and pedagogical preparation to provide excellent physics instruction for all students. The task force specifies that an effective pre-college physics education is "indispensable" in preparing U.S. students for global competition. The task force proposes that not only does a certified and unprepared teacher provide a disservice to the student, on a larger scale, the nation's economy, national security and even the foundations of democracy are at risk. Some exemplary models of physics teachers are preparing students for college level work. The key to reform is to identify knowledge skills and dispositions and to build physics teacher preparation programs that focus on the development of these qualities in future physics teachers. University stakeholders in particular must recognize how they gain from the transformed teacher preparation programs.

The PhysTEC project, is a joint reform effort of the American Association of Physics Teachers, The American Physical Society, and The American Institute of Physics. The project succeeded in supporting increased numbers of high school physics teachers while also raising awareness to issues in teacher preparation programs.

Ogodo, C., (2019) Comparing Advanced Placement Physics Teachers Experiencing Physics-Focused Professional Development, Journal of Science Teacher Education, Vol 30., No.6, pp 1-26.

Many high school physics classrooms have physics teachers who are teaching outside of their area of specific content expertise. Very few university programs are designed to specifically prepare pre-service physics teachers for everyday instruction. A shortage of highly qualified physics teachers may be attributed to a lack of program graduates and a failure to recruit and prepare candidates for the open classroom spaces. A need exists to improve the content knowledge and pedagogical knowledge base for these out-of-field teachers.

The framework for Professional development (PD) outlined by Desimone (2009) is used to emphasize the features of effective PD. Bandura (1997) is also referenced for the description of self efficacy.These teachers who were instructing Physics courses were given professional development in physics content and pedagogy via modeling professional development workshops. According to Hodapp Henn & Hein (2009), Advancing STEM education requires effective, continuous, and dynamic training to enhance and refine classroom practice. Their traditional pedagogy had relied heavily on textbooks and lecture-type methods of teaching, denying students meaningful learning experiences. Qualitative and quantitative data were collected from classroom observations, teacher surveys, teacher interviews, and observer field notes. Results indicate a large treatment effect size difference in their instructional practice, improved self-efficacy and improvement in content knowledge. The lack of ongoing professional development leads to teacher resistance to change.

One ongoing professional development program in Alabama for high school physics teachers is APEX (Alliance for Physics Excellence). This professional development program targets physics training designed to deepen pedagogical knowledge and content knowledge. Participants build confidence and new skills through active participation in collaborative model building activities. The APEX model provides a model for continuing training for out-of-field physics teachers.

Otero, V., Pollock, S, Finkelstein, N., (2010), A physics department's role in preparing physics teachers: The Colorado learning assistant model, American Journal of Physics, Journal 78, no. 11., pp. 1218-1224.

Substantial evidence suggests that many U.S. students are inadequately prepared in science and mathematics. A model for reform in preparation of future physics teachers has been developed at the University of Colorado. The adaptable model is designed to improve the education of all students in introductory physics and increases the numbers of talented physics majors becoming certified to teach physics. The Colorado Learning Assistant model is presented and its effectiveness discussed. Since 2003 when LA program started, an increase in the pool of well-qualified K–12 physics teachers by a factor of approximately three has been recorded. The program demonstrated success at the recruiting and preparation of future teachers, and improved the introductory physics sequence so that students' learning gains are typically double the traditional average.

Otero, V. K., Meltzer, D.E., (2017), The past and future of physics education reform, Physics today, Vol. 70, No. 5., pp. 50-56.

This resource provided an excellent context for the development of physics instructional reform. The authors present a chronological explanation of ongoing reform efforts beginning in the late 1800s and continuing to the present. The recurrent theme of the inductive method, or scientific inquiry and nature of science tie teachers and physicists together in a drama that is still unfolding. As traditionally favored pedagogical methods of delivery in "silos" of specific areas of academic disciplines compete with schools of education for hours of university training, reformers are setting out unique compromises that favor the holistic preparation of future physics educators.

Wells, M., Hestenes, D., Swackhamer, G., (1995), A modeling method for high school physics, American Journal of Physics, vol. 63, pp. 606-619.

Dr. Malcolm Wells was part of the great generation of physicists that worked together to launch mankind into space. He became a classroom teacher who collaborated with his peers to found the modeling instructional method, an alternative to traditional physics instruction. Through his dedication, he elevated the craft of physics instruction. His physics courses were structured around basic models and modeling cycles.

Malcom developed a plan to extend the successful modeling pedagogy by developing university and continuing education workshops. The workshops allowed teachers to role play as students and teachers, practicing cooperative inquiry within the modeling method of instruction. His success underscored the need for permanent institutional mechanisms to support teacher interteraction and professional development. Malcom understood that. standard teacher preparation and in-service training alone cannot result in the high level of expertise required in modeling instruction, but the workshops would provide a starting place.The growth of modeling instructional skills depends on years of personal interactions and practice in a classroom.

Malcom was among the first physics teachers to use computers in the classroom. He wrote his own programs to support activities that he designed for his lab. He was among the first to establish the sound principles for use of computers in the physics classroom.

Working with Ibrahim Halouun, he helped to design the FCI (Force Concept Inventory) that has become an internationally accepted measure of student understanding of basic Newtonian concepts and growth. He was also among the first to practice the Modeling Theory, developed at Arizona State University by Dr, David Hestenes. His work with learning cycles based on the research of Robert Karplus lead to the modelling cycle. His vision lives on through the dedicated work of Ibrahim Halloun, Larry Dykerich, Jane Jackson, and Colleen MeGowan and the American Modeling Teachers Association.

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