

Professional knowledge standards for physics teacher educators: Recommendations from the CeMaST Commission on NIPTE

Carl J. Wenning (wenning@phy.ilstu.edu), Illinois State University, Chair; Kenneth Wester, Illinois State University, Co-chair; Nancy Donaldson, Rockhurst University; Steven Henning, Concordia College (NY); Thomas Holbrook, University High School (IL); Michael Jabot, State University of New York Fredonia; Dan MacIsaac, Buffalo State College, SUNY; Duane Merrell, Brigham Young University; Diane Riendeau, Deerfield High School (IL); and John Truedson, Bemidji State University.*

The CeMaST Commission on NIPTE consists of a team of ten physics teacher educators, in-service high school physics teachers, and physics teaching resource agents from across the USA. This Commission gathered at Illinois State University January 8-10, 2010, using funding provided by the University's Center for Mathematics, Science, and Technology (CeMaST). The Commission developed initial recommendations for the creation of National Institutes for Physics Teacher Educators (NIPTE) to be held each summer over the course of several years if funding can be secured. This article represents an initial effort by the Commission to define what physics teacher educators should know and be able to do.

According to the American Association for Employment in Education (AAEE, 2008), physics teacher positions are the second most difficult to fill at the high school level following only special education. A recent survey by the American Institute of Physics' Statistical Research Center (2010) showed that of some 500 recently-surveyed physics departments across the USA, approximately 70% had no physics teacher education majors graduate within the past two years. The physics community has made clear the growing need for and importance of more high school physics teachers and pointed to both failures and successes associated with their preparation (Hodapp, Hehn, & Hein, 2009).

America's universities clearly are not graduating adequate numbers of new high school physics teachers to meet the growing needs of public school systems that have historically faced a critical shortage in this area. This shortage stems in part from the fact that there are few physics teacher education (PTE) programs of sufficient quality to attract and retain adequate numbers of undergraduate majors. PTE programs with highly qualified personnel *are* attracting and graduating comparatively large numbers of majors, but such programs are relatively rare due to the general unavailability of well prepared physics teacher educators. While university programs do exist for the general preparation of teacher educators, there are very few, if any, programs currently available designed specifically to prepare physics teacher educators. In order to increase the number of high school physics teachers, our nation first needs a program to address the critical shortage

of physics teacher educators. National Institutes for Physics Teacher Educators (NIPTE) is being designed to prepare educational leaders for high school physics teacher education programs.

The goal of NIPTE is to provide professional development for physics faculty interested in improving the pre-college physics teacher preparation programs associated with their departments. Without improved physics teacher preparation programs, many high school students will continue to learn physics under the tutelage of under-qualified and under-prepared science teachers who are being used to bridge the gap.

Many PTE programs exist around the United States that graduate small numbers of new high school physics teachers annually. Their instructors are often junior faculty who have little or no formal preparation to teach others in ways that align with the science education reform movement as outlined in the *National Science Education Standards* and *Project 2061*. Graduates of such programs often teach using the folk theory of physics teaching sometimes referred to as the "college model" – teaching by telling – that has been shown by research to be relatively ineffective when compared to inquiry-oriented instruction (Duit, 2009; Lasry et al., 2009; Dykstra, 2005; NRC, 2000; NRC, 1999).

It is the CeMaST Commission's belief that NIPTE can improve the current situation of too few authentically qualified high school physics teachers by bringing together the best people and resources to develop a national program that would not only improve the programs of participants, but the very programs that will serve as models.

National funding soon will be requested to support the NIPTE initiative. The proposal will be for a five-year multi-million dollar targeted MSP grant that will, if funded, partner faculty of successful PTE programs – as well as master high school physics teachers and recent

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graduates of exemplary PTE programs – with less well prepared physics teacher educators whose universities’ PTE programs show commitment to and potential for programmatic change and growth. The measurable outcomes will be to: 1) significantly increase the ability of 120 physics teacher educators (5 cohorts of 24) to develop, administer, and teach within their PTE programs, 2) build both quality and quantity of their PTE courses in comparison to specified indicators, 3) significantly improve high school physics teacher candidate performance as measured on a variety of assessments, and 4) significantly increase enrollments in those programs – all within the lifetime of the grant.

Many of these less-well-prepared physics teacher educators who will be involved in NIPTE summer programs probably will have taught physics for a number of years – being good teachers themselves – but they might never have had formal training in how to effectively pass on their physics and physics-related teaching knowledge to teacher candidates. Summer institute participants will profit from a course that addresses pedagogical knowledge and pedagogical content knowledge: learning about education theory and practice, reviewing the findings of basic science education research, practicing non-traditional teaching and learning strategies, learning about the needs and challenges of middle and high school teachers, examining successful physics teacher education programs, and so on. NIPTE also will provide participating university physics faculty members with further insights into how to reform their own university-level physics teaching to make it more compliant with the *National Science Teaching Standards* as well as state and national accrediting agencies for teacher education.

The short-term goal of NIPTE is to educate five cohorts of physics teacher educators that can result in each state having on average two physics teacher education centers offering programs of excellence that work hand-in-hand with the associated schools or colleges of education. The idea is to help university-level physics teacher educators work within their own institutions and organizational structures to create top quality high school physics teacher education programs using other successful programs as both guides and resources.

A long-term goal of NIPTE is to help participating teacher educators better recruit, retain, prepare, and support teacher candidates, and provide transitional mentoring for recent graduates and professional development for all high school physics teachers. To this end a national network of physics teacher educators will be developed and actively encouraged to contribute to preparing and sharing resources suitable for use by physics teacher educators everywhere.

Another long-term goal is to create one or more permanent courses for physics teacher educators housed in graduate-level programs whose institutions host a NIPTE summer institute. The course(s) will be associated with a program of study leading to an MS Ed., Ed.D. or Ph.D. degree for science teacher educators. The aim of the

course(s) would be the preparation of physics teacher educators who would teach in universities with PTE programs. Other non-physics science teacher educators, classroom teachers, and school administrators also might find the course(s) to be of value in their professional preparation/development.

It is not a goal of NIPTE to create cookie-cutter copies of successful physics teacher education programs. Rather, the plan is to assist physics teacher educators develop programs that meet the needs of teacher candidates while working within the constraints and conditions prevailing in their home institutions. NIPTE will provide information and support for doing so.

In order to help achieve the goals of NIPTE, the CeMaST Commission has developed recommendations for the professional knowledge base of physics teacher educators. These recommendations indicate what physics teacher educators should know and be able to do.

For the purposes set forth in this document, physics teacher educators are defined as university or community college faculty or staff, along with teachers in residence, whose appointments include a significant time allocation dealing directly with the preparation of future high school physics teachers. This time allocation does not include teaching of content courses but ideally will include the teaching of one or more physics or science methods course(s), supervision of student teachers, and advisement of physics teacher candidates. This definition also includes teacher leaders who provide professional development opportunities such as workshops for in-service high school physics teachers.

Professional Knowledge Standards for Physics Teacher Educators

The Association for Science Teacher Education (ASTE, 1997) prepared a policy statement that has in some ways served as an inspiration for NIPTE and the current effort. That policy statement, *Professional Knowledge Standards for Science Teacher Educators*, provided a very limited set of generic standards for all science teacher educators. The CeMaST Commission on NIPTE adapted and expanded that effort making a greater number of more detailed recommendations for professional qualifications of physics teacher educators.

These recommendations – enunciated as a set of professional knowledge standards for all physics teacher educators – fall into three general categories: content knowledge, pedagogical knowledge, and pedagogical content knowledge. These standards will help chart the course for efforts of NIPTE and, during the interim, provide guidance for professional development to others.

Content Knowledge Recommendations

The CeMaST Commission on NIPTE recommends that physics teacher educators possess:

- *an understanding of physics subject matter as well as research experiences within the discipline.* While chemistry is an experimental science, what is happening at the microscope level is frequently inferred from macroscopic observations. Biology employs observations that are often conducted over a time span of days or weeks. Astronomy is mostly an observational science and conclusions will be derived mostly from data collected by others. Earth science often deals with systems that are too large to bring into the classroom. These “limitations” make physics the discipline best suited to provide opportunities for experiential learning and controlled studies at the high school level. Because physics is more conducive to classroom-based inquiry, it is best that someone well versed in its practices serve as physics teacher educator.
- *a knowledge of science in general and of mathematics.* While the need for physics teacher educators to have a substantial knowledge of physics is clearly evident, physics teacher educators should have a strong general knowledge across several scientific disciplines such as astronomy, biology, chemistry, earth science, and environmental science to help students better understand the unifying concepts and nature of science. The level of this content knowledge should exceed that specified in such science education reform documents as the *National Science Education Standards* or *Project 2061*, and most certainly should exceed content knowledge requirements for teacher licensure in a given state. Physics teacher educators also should have an understanding of mathematics through calculus as well as specialized understanding of those mathematical procedures most closely aligned with laboratory research.
- *an understanding of the nature of science, including its history, philosophy, and epistemology at levels that exceed those specified in science education reform documents.* This includes an understanding and demonstration of appropriate scientific and philosophical dispositions, the relationships between science and technology, the societal implications of science and the surrounding issues, and a readiness to provide explicit instruction on the nature of science.

Pedagogical Knowledge Recommendations

The CeMaST Commission on NIPTE recommends that physics teacher educators possess:

- *experience in teaching at high school level and ideally formal teaching credentials for their state.* Without these qualifications, it is still possible for a physicist to be qualified if effort is made to understand and work with students using the many and various inquiry-oriented educational techniques described in the educational reform literature. Theoretical knowledge of such practices is inadequate background for

teaching them effectively. It will benefit both the physics teacher educator and the associated program if effort is made to pursue opportunities to build the necessary pedagogical knowledge base. This might include working as an instructional aide in a high school setting with a master physics teacher until such time as the requisite skills are clearly demonstrated.

- *an understanding of and experience with age-appropriate inquiry-oriented teaching practices.* Teacher educators should be familiar with the full spectrum of inquiry practices such as discovery learning, interactive demonstrations, inquiry lessons, inquiry labs, and hypothetical inquiry, and have an understanding of the intellectual process skills most closely associated with them (Wenning, 2005, 2010). This includes problem-based learning, project-based learning, and the use of whiteboarding and Socratic dialogues. They should know how to help students construct knowledge from appropriate hands-on, minds-on experiences. They should be familiar with the relationship between inquiry and the *National Science Education Standards* (see NRC, 2000).
- *both knowledge of and skill in teaching with the use of effective inquiry practices.* They should be well versed in the use of active and engaged learning that incorporates effective questioning strategies and appropriate listening techniques. They should understand how to convert traditional lectures and cookbook labs into active and engaging inquiry.
- *an understanding of how to establish and maintain effective classroom atmospheres that serve to motivate student learning.* Such classrooms will be knowledge centered, student centered, assessment centered, and community centered (NRC, 1999). This includes methods of responsive teaching and differentiated instruction, appropriate classroom management skills, and dealing effectively with resistance to reformed teaching when confronted by students, staff, parents, administration, and peer teachers. Teacher educators need to be thoroughly aware of the context within which physics teaching takes place including how to overcome student cultural and psychological barriers to learning science.
- *a theoretical background and practical experiences with curriculum, instruction, and assessment, including their development, implementation, and alignment.* Physics teacher educators should have a demonstrable understanding of how to conduct long- and short-term planning including such things as syllabus development, and unit and lesson planning. Physics teacher educators should understand how teaching and assessment practices relate to deep and surface learning as well as to the development of conceptual understanding. Experience with various approaches to assessment, formal and informal, formative and summative, as well as traditional and alternative, is recommended.

- *a knowledge of student learning and cognition.* An understanding of the findings of cognitive science and its connection to student learning in general and science learning in particular is essential. This includes a broad familiarity with learning theories and the educational community's views on the relationship between teaching and learning.
- *a knowledge of students' learning difficulties, and an empathy toward students' inability to understand physics.* This includes an understanding of alternative conceptions and how to deal with them effectively, student metacognition and self-regulation, reflective practice, and differentiated instruction. They are able to conduct discourse analysis as required.
- *an understanding of the utility of and experience with appropriately using teaching and learning technologies.* This includes but is not limited to demonstration materials and lab equipment, calculator- and microcomputer-based lab sensors, online platforms for managing courses and student learning, simulations, spreadsheets, and so on. This standard includes an understanding of the relationship between the use of technology and student learning.
- *an understanding of the need of and resources for reflective practice, self-assessment, and ongoing professional development.* Physics teacher educators need to understand that the preparation of teacher candidates is a recursive process in which students continue to grow as the result of supervised practice and corrective feedback.
- *an understanding of the state's school law as well as the teaching profession's ethical code of conduct.* Teaching candidates need to be fully informed of the limits on behaviors that can result in violations of civil mandates or ethical standards of the teaching profession.

Pedagogical Content Knowledge Recommendations

The CeMaST Commission on NIPTE recommends that physics teacher educators possess:

- *an understanding of the main goal of science education, and an understanding of what it means to be scientifically literate.* It is sometimes noted that the main goal of science education is the development of scientific literacy (NRC, 1996, 1999, 2000; AAAS, 1990). Without the teacher having a clear understanding of the goal of science education, it is unlikely that students will achieve it. Physics teacher educators need to be aware that the definitions of science literacy are many and varied and must be prepared to promote the type best suited to students at different stages of their intellectual development.
- *an understanding of the authentic best practices of physics teaching.* They should possess the knowledge and skills required to teach not only physics content, but know how to teach the next generation how best to

teach it. This requires both an understanding of effective practices of both physics teaching and science teacher preparation. They should have a good understanding of the basic principles of effective physics teaching as outlined in publications such as *Five Easy Lessons* (Knight, 2004).

- *an understanding of the various approaches and practices associated with exemplary and successful physics teacher education programs.* They should have a good understanding of the structures, content, and practices of successful physics teacher education programs, and know how to take advantage of these as resources. They should understand the need to learn from the ideas, successes, and failures of others. They should possess an understanding of the differences between basic, intermediate, and advanced physics teacher education programs.
- *an understanding of how best to prepare future physics teachers.* They themselves should be teachers of excellence – capable of effectively modeling authentic types of practices that pre-service teachers are expected to learn. They should have a thorough understanding of the content and processes of effective teacher preparation, and should be well versed in its literature and resources.
- *an understanding of the basic findings of science education research, but especially that of physics.* This understanding can be obtained by extensive reading and augmented by being professionally active in local, regional, and national meetings where this subject matter is presented and discussed as a means of ongoing professional development.
- *an understanding of how best to recruit and retain high school physics teacher candidates.* This includes using promotional printed materials and web sites, campus visits and follow-up activities, working with in-service teachers and school counselors, working with community colleges and professional teaching organizations, using detailed and timely advisement practices, and employing approaches such as Teachers in Residence and Learning Assistants.
- *an understanding of safe teaching practices as outlined by the American Association of Physics Teachers and other competent authorities.* This includes knowledge of the six major hazard areas associated with physics teaching (AAPT, 1979), and how to conduct a cost-to-benefit analysis.
- *a knowledge of effective high school curricula that can serve as teaching resources.* Physics teacher educators should have had exposure to or experience with multiple physics curricula that employ reformed approaches to teaching that are experience-based and/or research-based (e.g., CPU, PET, C3P, ISLE, PUM, PBI, PIPS, PRISMS, Modeling, CASTLE, Active Physics, and Workshop Physics). Information about these curricula shared with teacher candidates will help them avoid having to develop their lesson and unit plans from the ground up, which wastes

valuable planning time and ignores the expertise and advice of experienced teachers who have come before them.

- *an understanding of how best to formatively and summatively assess the performance of pre-service physics teacher candidates.* Physics teacher educators should be able to make effective use of public standards and objective data from work sample methods, RTOP (MacIsaac & Falconer, 2002), university supervisor evaluations, cooperating teacher evaluations, and student teacher effectiveness reporting systems to assess, evaluate, and improve the practice of teacher candidates in classroom performances, clinical experiences, and student teaching.
- *an understanding of the role of clinical experiences, their role in teacher preparation, and the effect of clinical placements of teacher candidates.* This includes early, multiple, and varied classroom experiences with a variety of in-service teachers, as well as experiences as a tutor, teaching and/or learning assistant at the college level. Physics teacher educators should know how to provide meaningful professional experiences for pre-service teachers, and know how to select, prepare, and work with cooperating in-service teachers to benefit candidates during student teaching practica.
- *an understanding of how best to provide transitional, mentoring, and professional development experiences for pre-student teachers as they move toward and work at their student teaching sites, and as first-year teachers.* They should know how to promote, establish, and maintain – and even participate in – school-based transition and mentoring relationships for program graduates. This includes involvement with high schools, colleges or schools of education, and professional organizations.
- *an understanding of the need for and an ability to work with the university's and educational program's accrediting agencies.* This will include such accrediting agencies as the state board of education and the National Council for the Accreditation of Teacher Education (NCATE).

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While it is unlikely that any one physics teacher educator – no matter how experienced – will possess all these understandings and have possession of the entire knowledge base, they do constitute goals toward which all physics teacher educators should strive. Ideally, two or more physics teacher educators working cooperatively in the same institution will meet all these standards.

These knowledge standards provide guidance to those working in isolation, and serve to assist with the work of NIPTE and others involved in the professional development of all physics teacher educators. The standards can serve as guidelines for the content of physics

teacher education program. Additionally, these standards might be of use to those responsible for recruiting, hiring, and evaluating physics teacher educators.

The Merit and Potential Impact of NIPTE

These recommendations will serve as the basis for the work of a larger working group to gather during the summer of 2011 if funding can be obtained. As an outcome of that meeting, these recommendations will be more fully described in a *Handbook on High School Physics Teacher Preparation* that will include numerous examples and additional details. This publication will then serve as the basis for National Institutes for Physics Teacher Educators if additional funding can be obtained.

NIPTE will be informed by both research and the real-world experiences of successful physics teacher educators and master and other exemplary high school physics teachers working in concert with successful physics teacher educators. The wider project will take into consideration the backgrounds, preparation, and experiences of summer institute participants. The project will be led by some of the most successful physics teacher educators in the country with the assistance of master high school physics teachers, and exemplary recent graduates from physics teacher education programs of note.

If funded, the larger NIPTE project will support the creation of specialized physics teacher preparation centers in various states where teacher candidates, faculty with expertise, and education resources can be concentrated. Physics teaching candidates from NIPTE-affiliated physics teacher preparation centers will be much more capable of teaching in the wide variety of ways that align with the current science education reform movement. This will positively impact the quality and quantity of high school student learning and positively influence students to become involved in STEM-related careers. Project leadership will conduct original research in relation to the needs and preparation of physics teacher educators on a nationwide basis prior to the special topics meeting. Selected individuals from the special topics meeting will be charged with the preparation of resources for use by participants in NIPTE summer institutes – primarily through the *Handbook for Physics Teacher Educators*. This entire project and its various products will serve as both model and guide for improvement in other science teacher educator programs – astronomy, biology, chemistry, earth science, and environmental science – on a nationwide basis.

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