Overview of U.S. Science Teacher Preparation Programs and a Model Research-Guided Program in Ohio

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Due to the rising importance of a scientifically literate citizenry, the reform of science education in Kindergarten through grade 12 has become a national focus and such reform depends heavily on appropriate teacher preparation. This article provides an overview of teacher preparation in the United States and describes how state requirements differ. This leads to variations in the nature and quality of teacher preparation programs across the country. A model research-guided teacher preparation program in Ohio is presented along with a description of how action research can be employed to assess program weaknesses and drive curricular modifications. Links to various websites and resources are provided regarding specific state teacher licensure requirements as well as links to all U.S. Colleges of Education.

I. INTRODUCTION

Science and mathematics education is emphasized worldwide. Reports from large-scale international studies such as TIMSS and PISA continually rank U.S. students behind many other nations. As a result, the U.S. has increased its emphasis on the implementation of a more extensive curriculum in Kindergarten through grade 12 in science, technology, engineering, and mathematics (STEM). Educational reforms stress the need for a prepared 21st century workforce, which translates into students learning science content while acquiring advanced transferable reasoning skills (Bybee & Fuchs, 2006). Strong preparation in science and mathematics will better enable students to handle open-ended novel situations and design their own investigations to solve scientific, engineering, and social problems as well as successfully handle real-world tasks in future careers (National Research Council, 2002; Singer, Hilton, & Schweingruber, 2005). This is especially important in a time when society strives to create a sustainable edge in science and technology in a fast evolving global environment where crises and opportunities emerge and change rapidly. This emphasizes the need for not only K-12 students to develop a solid foundation of appropriate content knowledge in science and mathematics, but implies that teacher preparation programs must produce teachers also competent in these areas along with an understanding of the instructional practices that develop such knowledge in students.

II. OVERVIEW OF U.S. TEACHER PREPARATION PROGRAMS

There are large differences in teacher preparation programs across the U.S. which is due to differences in the teacher credentialing and licensing regulations among the 50 states[1]. Over 1200 public and private higher education institutions offer teacher education programs and approximately 500,000 students are enrolled in such programs at any one time (Doyle, 1990). The U.S. Department of Education estimates that 220,000 certified teachers complete these programs each year[2].

Although each state establishes the requirements for pre-Kindergarten through grade 12 educator preparation and licensing, national organizations such as the National Research Council (NRC) and American Association for the Advancement of Science (AAAS) have to a large extent been influential in setting minimum levels of competence while attempting to standardize the teacher training process. Unfortunately, even with such standards in place large differences in the requirements and quality of teacher preparation programs exist. In addition, a teaching license granted in one state is not necessarily transferable to another. Although over 40 states have reciprocity agreements allowing teachers to transfer licenses, some consider this transfer only provisional and require additional coursework to earn the new state's license.

A. Nature of Teacher Preparation Programs

The content of undergraduate and graduate teacher education programs is largely driven by laws and regulations at the state level[3,4]. However, most undergraduate programs begin with 1-2 years of general education requirements for the purpose of providing teacher candidates with breadth of knowledge. This is followed by 2-3 years of specific subject matter and professional education coursework. While students pursuing secondary (high school) licensure take a large number of courses in the subject area(s) they have chosen to teach, and subsequently earn an undergraduate degree in this content area (i.e. bachelors degree in physics), students pursuing elementary licensure take a much broader spectrum of subject matter coursework including English, mathematics, science, humanities, and fine arts. The professional education courses are typically placed at the end of the program and consist of coursework on classroom management, school law, teaching methods for particular subject concentrations, instructional technology, human development, and multicultural education. Field experiences and student teaching are also included to enable students to apply theoretical knowledge to classroom practice.

The structure of teacher preparation programs varies amongst institutions and may include a 4-year undergraduate program, a 5-year program with or without a masters degree, and an alternative licensure program. The 4-year undergraduate program leads to a bachelors degree and combines the general education, subject concentration, and professional education courses described earlier. This type of program is more cost-effective than the 5-year programs but does not necessarily allow enough time for teacher candidates to develop adequate subject matter knowledge particularly in science and mathematics. The 5-year programs which do not lead to masters degrees enable more time to develop strong subject matter knowledge but are obviously not as attractive to students nor are they as cost effective. The 5-year programs that lead to masters degrees require students to first earn a bachelors degree in an academic major (i.e. education, child development, liberal arts, biology, and so on). Students then spend one or more years completing graduate level professional education courses and student teaching. This latter coursework can be applied to a masters degree in education. Although this type of program increases the professionalism of the teaching field and directly benefits students who earn the advanced degree, the separation of subject matter courses from professional education courses and field experiences may reduce the effectiveness of these teachers in their future classrooms.

Alternative licensure programs typically exist in subject areas and for grade levels in which there is a shortage of teachers (i.e. secondary science and mathematics). The requirements for licensure under this special program are set at the state level and can vary between states, although in all cases candidates must hold a bachelors degree[5]. Typical coursework includes professional education courses and field experiences and often the candidate is placed in actual teaching positions before completing the program. Candidates must meet state requirements for subject content knowledge so additional undergraduate courses may be needed. Although alternative licensure programs can help fill teaching positions in which there is a high need, the program does not necessarily allow candidates enough time to develop teaching skills before being put in a classroom.

Regardless of the length or nature of teacher preparation programs, in all cases those who complete credentialing programs must then apply to their own state education department for an initial teaching certificate/license. Other state requirements may include passing an examination prescribed by the state board of education (i.e. the Praxis test[6]) as well as completing state and federal (FBI) background checks. Once an initial license is granted, it must periodically be renewed based on the timeline and criteria (typically additional coursework) set forth by the issuing state education department.

B. Reforms of Science Teacher Education Programs

Even with state standards in place, large differences in the quality of teacher preparation programs exist. Given the importance of education in the US, better preparation of teachers is essential particularly in key areas such as science and mathematics. Teacher preparation programs must not only prepare teachers to be effective in current K-12 settings, but must produce teachers who have the knowledge and tools to actually improve K-12 instruction and meet the changing needs of students in the 21st century.

As a resource guide for institutions of higher education, the National Science Teachers Association (NSTA) generated the Standards for Science Teacher[7] based upon a review of the professional literature in conjunction with the National Science Education Standards (NSES) (National Research Council, 1996). The NSES outlines what precollege students need to know, understand, and be able to do at different grade levels with the goal of promoting the development of scientifically literate citizens. Because the implementation of the NSES involves major changes in how science is taught in the U.S., the integration of these standards into teacher preparation programs is critical to its success. For example, the NSES promote science as an active process involving observations, inferences, and inquiry-oriented investigations. Students must combine scientific knowledge with reasoning and critical thinking skills to develop their own understanding of science rather than be provided a collection of scientific facts to memorize for a test. Because this method of instruction is so different from what teacher candidates will have likely been exposed during their own K-12 education, teacher preparation programs must provide specific training in these areas.

NSTA’s Standards for Science Teacher Preparation supports the vision of the NSES and acknowledges that students cannot achieve high levels of performance and scientific literacy without skilled professional teachers. These teachers must have strong science content knowledge as well as pedagogical content knowledge (Shulman, 1987); i.e. an understanding of how to teach specific subject content. Teachers must understand how to provide students the opportunity to learn science by doing science such as through the use of inquiry-based instruction, with or without the support of relevant technology (Dani & Koenig, 2008), along with an understanding of the nature of science.

III. TEACHER PREPARATION PROGRAMS AT WRIGHT STATE UNIVERSITY

At Wright State University, an open enrollment institution of roughly 17,500 students, the recommendations of NSTA and NSES have been incorporated into the science courses within its teacher preparation programs. The remainder of this paper provides an overview of these programs with specifics on how they are aligned with the recommendations of NSTA and NSES and include substantial coursework that focuses on strong science content knowledge, emphasizes pedagogical content knowledge, and models best teaching practices.

Wright State University offers three main teacher preparation programs that lead to licensure in Early Childhood (PreK-grade 3), Middle Childhood (grades 4-9), and Adolescent to Young Adult (grades 7-12). The Early Childhood program is the most popular and typically graduates between 135-155 students per year. The Middle Childhood program is smaller and graduates between 45-70 students per year with roughly 65%-80% of these students choosing concentrations in science and/or mathematics teaching. The Adolescent to Young Adult program is the smallest program with about 50 graduates per year with only a dozen pursuing science or mathematics licensure.

Wright State's teacher preparation programs are unique in that the science and mathematics portions of the Early and Middle Childhood programs are supported entirely by science and math educators who have dual appointments in both the College of Science and Mathematics (CoSM) and the College of Education and Human Services (CEHS) (with majority appointment typically in CoSM). The dual appointments resulted from a strong collaboration between the colleges and include: three full-time faculty in physics, three full-time faculty in biology, two full-time faculty in geology, four full-time faculty in math, and one chemistry and one math educator with full-time appointments in the chemistry and math departments. When possible, instructors with K-12 teaching experience are hired to teach courses not covered by the regular science and math education faculty.

A. Nature of Teacher Preparation Programs

Wright State's Early Childhood Education (ECE) program is a four year program offered through the education department that leads to a Bachelors of Science degree in Early Childhood Education. Students must complete 192 quarter hours including 57.5 quarter hours in general education, 47.5 quarter hours in curriculum content, and 87 quarter hours in professional education. The program was designed such that students develop theoretical and practical knowledge in the fields of the humanities, mathematics and technology, social sciences, biological and physical sciences, the arts and personal health and fitness. Courses that incorporate multi-cultural and global perspectives are included within the general education requirements.

Students complete most of the general education and content courses during the first two years of the program and the professional development courses and field experiences (i.e. structured time spent in local elementary schools) in the last two years of the program. Also included is one quarter of student teaching which occurs towards the end of the program. Once students have completed the licensure program and passed the appropriate Elementary Education Praxis exam[6], they are eligible for an Ohio provisional license for Early Childhood (Pre-K-3). This license qualifies a graduate for employment in daycares, preschools, Head Start programs[8], and primary/ elementary schools (grades K-3).

Wright State University offers a unique program in that students working towards this degree complete 4 science courses (one in each of biology, physical science, earth and environmental sciences, and physics) and 3 mathematics courses offered exclusively for this major. These courses were designed such that the content aligns closely with the NSES and Ohio academic content standards[9] for grades K-3 and models best teaching practices which emphasize inquiry-based, minds-on approaches to teaching and learning. The courses involve integrated lecture and laboratory experiences and stress the construction of knowledge through scientific inquiry. Age level pedagogical content knowledge is addressed through science content courses as well as science teaching methods courses. All science and math courses are offered through the College of Science and Mathematics rather than the College of Education and Human Services. All courses including the teaching methods courses are taught by science and math educators.

B. Reforms of Science Teacher Education Programs

The Middle Childhood Education (MCE) program with licensure is five years in length with candidates first earning a Bachelors of Science degree in Middle Childhood Education. This undergraduate program involves candidates completing two specialized concentrations of study (English/language arts, social studies, mathematics or science) accompanied by 15 hours of professional education coursework and field experiences in urban and suburban middle school settings. Once the BS degree is earned and students pass the two Praxis exams required by the state of Ohio for their chosen concentrations of study (i.e. Middle School English Language Arts, Middle School Mathematics, Middle School Science, and Middle School Social Studies), they enroll in five additional quarters of full-time graduate study and internship to complete licensure requirements. Students have the option of using these credits to complete a Masters of Education degree through the College of Education. Upon completion of the licensure portion of the program and successfully completing the Praxis exam in Principles of Learning and Teaching, candidates are eligible for an Ohio provisional middle childhood (grades 4-9) license in their two chosen concentrations of study.

Similar to the Early Childhood program, all science and mathematics courses within the Middle Childhood program were specifically designed for this program and are offered exclusively to Middle Childhood students. All middle childhood majors take 3 specialized math courses and 5 inquiry-based science courses (a foundations course in scientific literacy and one course each in biology, chemistry, earth and environmental sciences, and physics). Students choosing a science teaching concentration take 6 additional science courses and students choosing a mathematics teaching concentration take 6 additional math courses. All courses align with the NSES and Ohio academic content standards for grades 4-9 and model best teaching practices which emphasize inquiry-based, minds-on instruction. All courses are similar in nature to those offered under the Early Childhood licensure program; however, more technology is integrated into the teaching and learning within several of the courses in the Middle Childhood program (i.e. through the use of graphing calculators and Vernier probeware[10]). These courses are offered through the College of Science and Mathematics rather than the College of Education and Human Services and are taught by our team of science and math educators.

C. Adolescent to Young Adult Education Licensure Program

The Adolescent to Young Adult (AYA) Education licensure program involves candidates first earning a Bachelor in Science degree in their choice of major. Candidates then complete five-quarters of full-time graduate coursework and internship to satisfy Ohio licensure requirements with the option of completing a Masters in Education degree. Courses include professional education and field experiences in urban and suburban school settings. Students must pass the Praxis exam in their chosen content area along with the Praxis exam in the Principles of Learning and Teaching. Once students have fulfilled all requirements, they are eligible for a provisional Adolescent to Young Adult Education license (grades 7-12) in their specific content area which includes English/Language Arts, Mathematics, Social Studies, Science (various), or Integrated Business and Marketing.

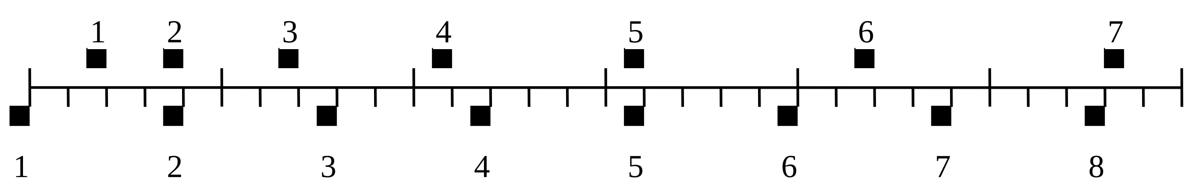
Unlike the Early and Middle Childhood programs, all science and math courses in the AYA program are the same courses offered to STEM majors. This is the result of having a dozen or less students in the science or math AYA program each year. Therefore the science and mathematics courses are typically taught in a traditional format by regular department faculty in large lecture settings. Although the students do not necessarily have best teaching practices modeled in these courses, each licensure candidate takes two graduate courses in science or math methods with strong emphasis on pedagogical content knowledge. For example, the first science methods course provides an understanding of instructional strategies that encourage critical thinking, problem solving, and performance skills. Prospective teachers learn how to plan instruction based on knowledge of the nature of science, how students learn and develop, and how to accommodate different approaches to learning. The second science methods course focuses on strategies that evoke more mature mental structures, decision-making abilities, and higher-order thinking skills such that students become more scientifically literate citizens. Knowledge of present and emerging issues in science and technology is emphasized and in both methods courses students apply what they've learned to projects/lessons within their own chosen teaching area (i.e. physics). The methods courses are taught exclusively by science or math educators.

IV. USING ACTION RESEARCH TO GUIDE CURRICULUM

A. Specialized Science and Mathematics Courses

Both the Early and Middle Childhood programs involve science and mathematics courses designed by a team of science and math educators and based on the National Science Education Standards (NSES), the AAAS Benchmarks, and recommendations of the National Council of Teachers of Mathematics (NCTM) and Mathematical Association of America (MAA) (Mathews, Basista, Farrell, & Tomlin, 2003). Each course is subsequently aligned with the Ohio Academic Content Standards which identify learning outcomes for K-12 students for subjects including writing, reading, math, social studies, science, and technology[11]. The science standards include by grade level separate criteria for earth and space sciences, life sciences, physical sciences, science and technology, scientific inquiry, and scientific ways of knowing. The mathematics standards are also divided by grade level into categories including number sense and operations, measurement, geometry and spatial sense, patterns, functions and algebra, data analysis and probability, and mathematical process.

The positions of two blocks at successive equal time intervals are represented by the numbered squares in the diagram below. For instance, at the end of the first time interval, the positions of the blocks are indicated by the "1", at the end of the second time interval, the positions are indicated by the "2".



a) Describe the motion of the top and bottom blocks as completely as you can.

b) Do the blocks ever have the same speed? Explain your reasoning.

Figure 1. Assessment question designed to assess physical science learning outcomes of Ohio Academic Content Standards for grade 3.

Most science and math courses in the Early and Middle Childhood teacher education programs are taught in an integrated lecture/lab format and model best teaching practices through the use of inquiry-based instruction and/or the integration of technology. Class sizes are limited to 24-28 students and students work in cooperative learning groups of 3-4 students. Courses typically meet twice a week for 120-170 minutes each

In alignment with NSTA's Standards for Teacher Preparation, these courses were designed to provide teacher candidates strong and appropriate content knowledge while modeling best teaching practices. As a result, a research approach was employed during course development, and content pre- and post-tests were used to guide curricular modifications of most program science courses. Due to the similarity of this approach across multiple program courses as well as the common instructional approach of the courses themselves, the specific details surrounding a single selected course are presented in the next section.

B. Concepts in Physics: A course for Early Childhood Education Majors

"Concepts in Physics" is a 4.5 quarter hour physics course designed and taught exclusively for early childhood majors. The class of approximately 24 students meets twice a week in two 170 minute blocks. The course includes a small number of introductory physics topics aligned with the NSES and Ohio academic content standards for Kindergarten through grade 3. The topics of force and motion, energy, electric circuits, and optics are covered in depth, while addressing student misconceptions and developing those reasoning skills necessary to perform scientific inquiry. The Physics of Everyday Phenomena (Griffith, 2004) is used in the course along with a custom lab manual similar in nature to Physics by Inquiry (McDermott, 1996). The course models best teaching practices through inquiry-based instruction and assessment along with the use of cooperative learning groups. Student knowledge is constructed through scientific inquiry as students engage in asking appropriate questions, designing and conducting investigations, using appropriate tools to gather data, using critical thinking skills to reason out solutions and explanations from evidence, generating alternative explanations, engaging in argumentation and debate, and communicating scientific results.

In order to ensure our early childhood majors were acquiring targeted content knowledge in the Concepts in Physics course, a concept pre-test was administered on the first day of class and an identical post-test was administered at the end of the course. For the topics of force and motion, the test questions were written by one of our physics educators using portions of the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhammer, 1992) and Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998) in conjunction with a series of open response questions. The questions were selected and written to align with the targeted grade level learning outcomes of the Ohio academic content standards. For the force and motion assessment administered to three groups across 3 quarters, students scored on average 25% on the pre-test and 74% on the post-test (sample size is 65 students). Although these scores represent a respectable content gain, curricular modifications were deemed necessary after analyzing the pre-post-test scores for individual questions or sub-topics.

The steps involved in this process are provided here to demonstrate how action research can be used to guide curriculum. As an example, according to the Ohio academic content standards, grade 3 students should be able to "describe an object's position by locating it relative to another object or the background" and "describe an object's motion by tracing and measuring its position over time". The pre- and post-test question in Figure 1, adapted from a question on the FCI, assessed this specific learning outcome for the teacher candidates enrolled in the course.

Due to the open-ended nature of this question, the same grading criteria were used in scoring student responses on both the pre- and post-test. On the pre-test, 36% of the students provided acceptable and complete answers (no point deductions) to part (a) and likewise 24% for part (b). On the post-test these averages were 88% and 65% respectively. Although this represents an acceptable gain, the students had undergone six hours of inquiry-based instruction involving position and changes in position on a number line, rolling a ball along a track and developing an operational definition for uniform motion, and analyzing and comparing instructor provided ticker-tapes of both uniform and non-uniform motion. In addition, the students had undergone another 6 hours of instruction which involved constructing and interpreting position versus time graphs of uniform and non-uniform motion and developing an understanding for the slope of the curve at various points. Students were also assigned multiple homework problems with one closely related to the pre- and post-test question presented here.

A closer look at student pre-test responses for the question in part (a) indicated that students were in general not familiar with this form of representation of motion. Some students interpreted the situation to involve seven blocks (numbered 1-7) moving above the line and 8 blocks (numbered 1-8) moving beneath the line. These students described how each block moved relative to the block right before or after it and some indicated that the bottom row of blocks all moved together at the same rate. Other students interpreted the bottom line of blocks to be a reference frame of sorts and indicated how the top row of blocks moved along in comparison. For example, one student wrote "Block 1 is moving faster than its time interval, block 2 is moving equally with its time interval, block 3 is moving faster than its time interval…." and so on. Some interpreted the larger spacing between the top blocks to indicate more time had transpired, rather than a greater distance had been covered in an equal time interval, and therefore these students claimed that the top block slowed down as it moved to the right.

Although only 36% gave correct and acceptable answers on the pre-test for question (a), the course curriculum apparently provided the students adequate experience in representing motion on a number line as 88% gave acceptable and complete answers on the post-test. A closer look at incorrect post-test responses revealed continued confusion for some students between distance and time on the diagram. A representative student written response is "the blocks in the top line are slowing down because there is more time interval between each block. The bottom blocks are moving at a constant speed because they have an equal time interval throughout." In the original course activities the students did not create their own ticker-tapes but rather analyzed those provided to them. A curricular modification that resulted from this particular pre- and post-assessment is that students are now directed to create their own ticker-tapes and actually pull the tapes through the timer with their hands rather than attach them to a rolling cart or other object or use tapes provided by the instructor. Students are also directed to engage in more exploratory activities to investigate how the motion of their hands impacts the spacing between the dots on the ticker-tape. In this way students can experience firsthand the motion as it is being recorded and hopefully come to a better understanding of what the spacing between dots actually represents.

A much larger proportion of students had difficulty in answering part (b) on both the pre- and post-test. The expected correct answer was that the blocks have the same speed during the 4th time interval (between the blocks labeled 3 and 4) due to the blocks covering the same amount of distance in this same time interval. The most common incorrect response on both the pre- and post-test was that the blocks have the same speed at points 2 and 5. Students have difficulty understanding speed as a change in position for a change in time. This was evidenced by explanations such as "at points 2 and 5 the blocks has the same speed because they are at the same position." Others, particularly those who missed the question on the post-test, cited the equation for speed and wrote "the blocks have the same speed at the end of the second time interval because the blocks have traveled the same distance in the same time. This is also true of block 5." A handful of others indicated on the pre-test that the blocks never had the same speed because "if they did then at two points in a row they would be at the same place and that never happens." Interestingly, this response was not seen on the post-test.

The post-test results indicate students have a better understanding of this particular representation of motion but still have difficulties with the concept of instantaneous speed. As a result, the curriculum has been further modified and students are now provided more direct instruction on instantaneous speed and how it can be measured using the multiple ticker-tapes the students made themselves in class. Additional homework questions have also been added using different contexts such as a car dripping oil as it moves along a road. The post-test results of the modified curriculum for the Concepts in Physics course are forthcoming in a future paper.

V. SUMMARY

As the need for scientifically literate citizens and a prepared 21st century workforce continues to dominate U.S. headlines, the call for the reform of K-12 science education remains high. Teacher preparation programs play a critical role in this reform and due to the large variations in state requirements for teacher preparation and licensing, national organizations such as the NRC and NSTA have been influential in setting minimum levels of competence while attempting to standardize the teacher training process. Even with standards and recommendations in place, the nature and quality of science teacher preparation programs continue to exist. This article provided an overview of such programs in the US, while describing some of the program differences, and included links to various websites and resources to provide the reader access to information about individual state requirements as well as links to all U.S. Colleges of Education[11] (Doyle, 1990).

A description of a model teacher preparation program in Ohio was provided to demonstrate how programs can be designed to meet the call for science education reform; i.e. how programs can be constructed to align with NSTA's Standards for Teacher Preparation and the National Science Education Standards. Details demonstrating the use of action research to guide curricular modifications were also provided to serve as a model for other programs undergoing revision. Although assessing program effectiveness with current students is an important step in the development of any program, more research is needed to determine how our teacher graduates actually perform out in the field when working their own students.

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