A Brief Review of the Preparation of Kentucky Mathematics and Science Teachers

Prepared for the
Kentucky Education Professional Standards Board

By
Terry Hibpshman

August 27, 2007

Executive Summary

Education in the STEM disciplines (Science, Technology, Engineering, and Mathematics[1]) has become a recent emphasis nationally and in Kentucky. Results of the Trends in International Mathematics and Science Study (TIMSS) have consistently shown that achievement in science and mathematics for U.S. public school students lags behind that of their counterparts in other industrialized countries, a fact perceived to place the United States at risk in an increasingly competitive world economy. Additionally, commentators in this area note that the United States currently ranks 14th internationally in the number of persons obtaining mathematics and science degrees, a statistic that bodes ill given the importance of research and development to economic success in the modern world.

In Kentucky two trends have caused concern about preparation in the STEM disciplines. Comparison of Kentucky students with those from other states on the NAEP assessments shows that although Kentucky's 4th and 8th grade students have made significant progress in recent years, and although Kentucky students compare favorably with those of other states in science, Kentucky students continue to lag behind the national average in mathematics at both the 4th and 8th grade levels. Estimates by the Kentucky Council on Postsecondary Education of the proportion of entering freshmen requiring developmental mathematics at Kentucky institutions of higher education indicate that 41% of all entering students -- and 35% of recent high school graduates -- required these services, a figure deemed unacceptably high by CPE.

These difficulties are probably the consequence of a number of underlying social and educational factors, not all easily amenable to solution. Commentators in the area have focused primarily in recent years on the one factor most accessible to policy change, the preparation of elementary and secondary teachers who teach science and mathematics. A substantial literature has developed indicating that teachers in these subjects are poorly prepared, and a number of standards-setting groups have developed statements about the necessary minimum preparation in math and science for teachers at all levels. Additionally, the National Science Foundation, the Institute of Educational Sciences of the U.S. Department of Education, and the Kentucky General Assembly have made funding available in Kentucky and elsewhere for the purpose of upgrading the math and science skills of elementary and secondary teachers.

Studies conducted in Kentucky by the Education Professional Standard Board and others provide a more nuanced view. These studies make it clear that – at least insofar as graduate and undergraduate hours earned during teacher preparation are indicators of adequacy – mathematics and science teachers at the middle and high school levels are adequately prepared. Elementary teachers, on the other hand, are generally ill-prepared to teach mathematics, and although they have an adequate number of hours in the

[1] Technology in the P-12 world is taught as a part of the science curriculum, and engineering is rarely taught as a separate discipline. For these reasons, STEM in the P-12 context is normally confined to the teaching of science and mathematics.

sciences, there may be reason to be concerned about the distribution of these hours across the different scientific disciplines.

Based on the above considerations the present paper recommends a multilevel strategy. Preparation appears to be a problem at the elementary level, especially in mathematics, and Kentucky should investigate a more rigorous model for the training of these teachers in mathematics and science.[2] Problems with mathematics and science achievement at the middle and high school levels appears to be a consequence of two factors, residual effects of poor preparation at the elementary level and an undemanding set of requirements for middle and high school math and science achievement. Changes in minimum high school graduation requirements to overcome these undemanding standards (including acceleration of the recent KBE requirement for a fourth year of high school mathematics, to be implemented before 2012) and the requirement that all college-bound high school graduates take four years of science, to include physics, would do much to resolve the problem. In addition, ongoing professional development activities in mathematics and science should be extended to improve the content knowledge and skills of as many of the existing elementary teachers and mathematics and science teachers at the middle and high school levels as needed. To operationalize these recommendations, the present paper recommends that that the EPSB convene a task force charged with the development of a comprehensive strategy on the preparation and support of math and science teachers.

[2] "Rigorous" in this context means that the preparation of elementary teachers should focus on a thorough conceptual understanding of the mathematical or scientific principles involved in the material they teach, and that preparation should assure that the all of the mathematical or scientific knowledge recommended by the various standards groups be represented in their preparation curriculum. This is in distinction to a preparation approach criticized later in this paper that emphasizes algorithms and methods over strong conceptual understanding.

Introduction

The preparation of American elementary and secondary public school students in mathematics and science has become a major issue both nationally and in Kentucky. Recent studies of the achievement of American students in these areas have raised alarm at what is seen as a threat to the nation's long-term economic competitiveness.

Results of the Trends in International Mathematics and Science Study (National Center for Education Statistics, 2004) in recent years have consistently shown the United States to rank below other industrialized nations in mathematics and science, particularly at the 8th grade level. In the 2003 results, 4th grade American children ranked 12th of the 25 nations in the math sample and 6th of the 24 nations in the science sample; at the 8th grade level, American students ranked 15th of the 45 nations in the mathematics sample and 10th of the 44 nations in the science sample. Nations that consistently rank above the United States on these assessments, such as Japan, Singapore, and Korea, are significant international economic competitors of the United States[3], and commentators frequently assess these rankings as indicators that the United States will have difficulty competing in a world economy where technological innovation, fueled by expertise in science, mathematics, and engineering, is a key element in competitiveness.

Other commentators have noted that poor performance in these areas has resulted in the United States falling behind in the number of scientists and engineers graduated from institutions of higher education. The United States ranks 14th in the number of 24-year-olds with degrees in science, technology, engineering, and mathematics (STEM) disciplines, down from 3rd 25 years ago (Symonds, 2004). This phenomenon is not due to a decrease in the proportion of college graduates who are awarded degrees in these fields - which has remained steady at about 17% for some time - but is rather due to an increase in STEM degrees awarded in other countries (Kuenzi, Matthews, and Mangan, 2006). Among STEM degrees awarded, the proportion of degrees awarded in computer science has increased, while the proportion of degrees awarded in the biological sciences has remained relatively steady, and the proportion of degrees awarded in all other STEM fields has declined. Additionally, a large proportion of the STEM advanced degrees awarded by U.S. institutions in recent years has been to foreign students.

Kentucky mirrors the national situation. In late 2006, The Kentucky Council on Postsecondary Education empanelled a task force of representatives from numerous public agencies, institutions of higher education, and private entities for the purpose of developing a strategy for improving the achievement of Kentucky P-12 students in science and mathematics, and for improving the state's competitiveness by increasing the number of students earning degrees in these fields (Lexington Herald-Leader, 2007). This task force has completed eight recommendations for improving the state's performance in these areas.

---

[3] Some significant competitors, such as China and India, did not participate in the most recent TIMMS study. Given that these nations' children have consistently ranked above those of the United States, it is probable that had they participated in the most recent study, the U.S. position would have been lower.

An independent assessment of the status of mathematics and science achievement of Kentucky students was conducted by evaluating information from three sources: CATS test results, NAEP assessments, and published data by CPE.

Charts 1-4 illustrate graphically the levels of achievement for Kentucky children over the available time horizon, as measured by the CATS (1999-2006) and NAEP (1992-2005) assessments. Reading and overall academic indexes are given for the CATS tests for comparison purposes.

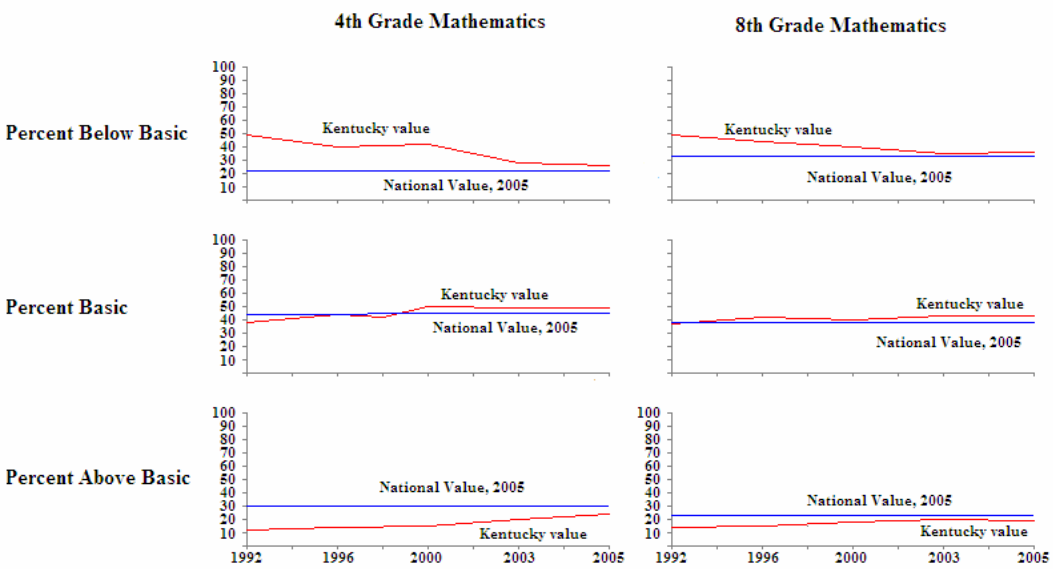
Mathematics achievement for elementary subjects on the CATS tests shows a generally rising trend over the period from 1999-2006, with a shallower rise for middle and high school students. Science at the elementary level shows a rising trend similar to that for mathematics, with an almost flat trend for middle and high school students. The science indexes at all three levels begin at a higher value in 1999 than for mathematics, but because of the shallower trend are at about the same level as mathematics at the end of the horizon in 2006. By comparison, reading values begin and end at higher levels than for either mathematics or science, and show a generally rising trend at all three grade levels. The overall academic index has a trend similar to that of the reading index. Overall, the index scores show substantial improvement in mathematics and similar improvement in science, with both mathematics and science showing less improvement than the reading and academic indexes.[4]

Chart 1
Statewide CATS Index Scores for Mathematics, Science, Reading, and Academic Index
School Years 19981999 – 20052006

[4] The Kentucky Performance Report for 2006 (Kentucky Department of Education, 2006a) estimates that the mathematics index for elementary students in 2014 will be at 105, for middle school students at 85, and for high school students at 84.

NAEP results (National Center for Education Statistics, 2005) show considerable improvement over the limited available time horizon for Kentucky 4th and 8th graders relative to the national sample. Chart 2 demonstrates that while the achievement of Kentucky students in mathematics continues to lag somewhat relative to the national sample, considerable improvement has occurred over time, and the Kentucky value is approaching the 2005 national value. It is important to remember, however, that the proportion of Kentucky 4th and 8th graders below basic on the NAEP assessments in 2005 was 25 and 36 percent respectively. Note as well that the proportion of Kentucky 4th graders at or above proficiency in mathematics in 2005[5] was 27%, and the proportion of 8th graders at or above proficiency was 22%. These numbers are considerably below the point where a typical student would be proficient.

Chart 2
NAEP Mathematics Values, 1992-2005



Charts 3 and 4 were copied directly[6] from the NAEP report, because the very small number of data points made it inadvisable to retable the data as in Chart 2. Chart 3 shows the values for Kentucky 4th grade students in science for the two years 2000 and 2005. With 76% of Kentucky subjects at or above the basic level in 2005, compared to 66% for the national sample, Kentucky students appear to be performing well compared to students nationally. Note, however, that only 36% of Kentucky students were at or above proficiency in science.

[5] Corresponding roughly to the proficient and distinguished levels on the CATS tests.
[6] With minor modification to eliminate confusion.

Chart 3
NAEP 4th Grade Science, 2000-2005

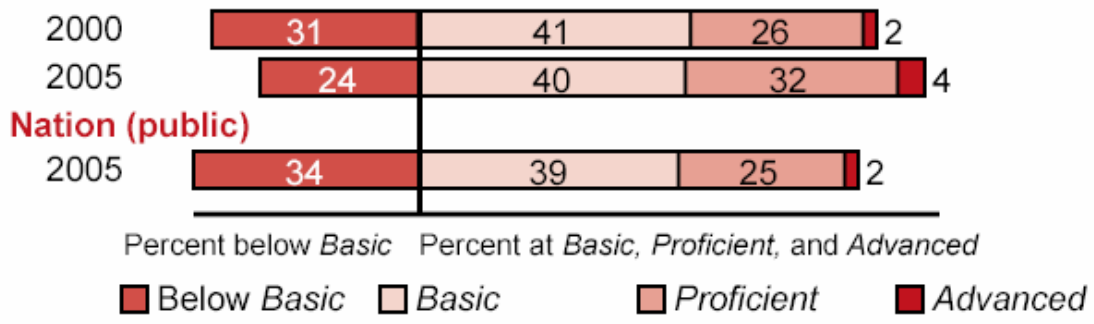
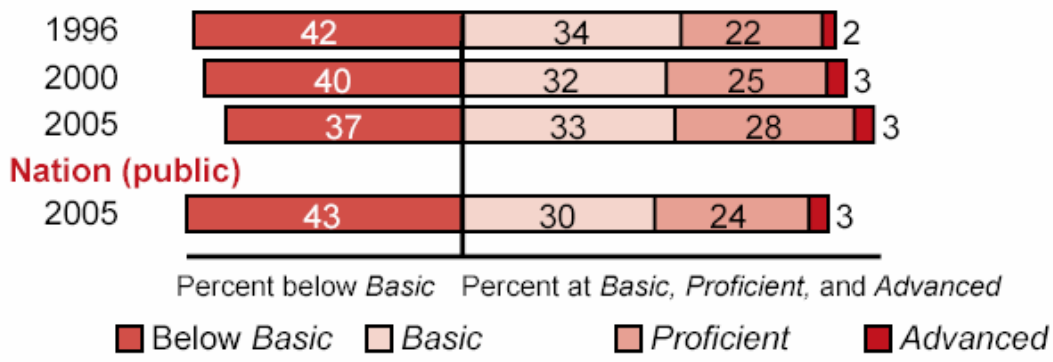


Chart 4 shows the values for Kentucky 8th graders in science for the school years 1996, 2000, and 2005. There appears to be a rising trend, and 67% of Kentucky subjects in 2005 were at or above the basic level, compared to 57% for the national sample. Still, only 31% of Kentucky students were at or above proficiency in science.

Chart 4
NAEP 8th Grade Science, 1996-2005



Although both mathematics and science show improvement in the CATS and NAEP data, the results should leave us with some concern. The CATS results are framed in terms of an index where a value of 100 would indicate "proficiency," i.e., that an average student is performing at a minimally acceptable level. Despite the general improvement in index values, considerable additional improvement will have to occur before Kentucky students as a group at any grade level achieve proficiency.

The NAEP values tell a similar story. Considerable improvement has occurred in recent years for Kentucky students compared to the national sample, but a substantial proportion of Kentucky students at both the 4th and 8th grade levels continue to score below the basic level, and more than two thirds score below proficiency.

A recent study by Heidi Hiemstra at the Kentucky Council for Postsecondary Education (Hiemstra, 2005) noted that entering college freshmen are less well-prepared than is desirable. She noted that 41 % of all entering students and 35% of recent high school

graduates required developmental mathematics on entering a four-year institution.[7] Given that students who require developmental courses are less likely to persist in higher education, and given the importance of mathematical competence to the achievement of a degree in any science, engineering, or technology field, the existence of large numbers of entering students with deficiencies in mathematics restricts the ability of the state to produce the numbers of graduates in these fields needed for national and international competitiveness.[8]

Kentucky students at the P-12 level have made considerable gains in mathematics and science in recent years, but it is apparent that much additional improvement is needed. Kentucky students still lag behind their American counterparts in mathematics, and because they are just above the national level in science, Kentucky shares with the rest of the nation the risks attendant with the United States' poor position in the STEM disciplines.[9] This paper is intended to suggest a strategy for improving the relative position of Kentucky in the achievement of its students in the STEM disciplines by addressing identified deficiencies in the preparation of teachers in these areas and in the course-taking behavior of students. To this end, the paper is organized into three sections:

In section 1, the relationship between teacher training in mathematics and science, and student achievement is evaluated.

In section 2, the typical preparation in mathematics and science of Kentucky teachers at the elementary and secondary levels is explored, and the likely consequences given what is known about the relationship between teacher preparation and student achievement are evaluated.

In section 3, ideas for improvement in the STEM disciplines are offered – with especial attention to the problem of low achievement in mathematics – based on the information in sections 1 and 2.

---

[7] There are no corresponding values for science, since developmental science is not generally taught at institutions of higher education (IHEs).

[8] Because the proportion of students who require developmental courses was not tracked in the past, the CPE study could not establish whether this large proportion of students requiring developmental courses represents a decline in the typical preparation of entering students. It is true, however, that the average ACT scores of entering students have declined, and this would probably indicate that entering students are less well-prepared than they have been in the past. Some caution is due in interpreting this assertion, since a greater proportion of high school graduates than ever before are attending college, so that the population of entering students today may not be comparable to those who have entered in the past.

[9] The discrepancy between the better performance of Kentucky elementary students and the poor performance of middle and high school students requires comment. This seems incongruous in light of the fact, noted later, that elementary teachers are typically poorly prepared to teach mathematics, while middle and high school teachers are amply prepared. This discrepancy can best be explained, we think, by noting that despite the better performance of elementary students on the CATS and NAEP tests, they seem not to be well-prepared for performance in the secondary mathematics curriculum (Newman, 2007). This would be true if the elementary curriculum focused principally on computational skills but did not prepare students for the more conceptually oriented nature of the secondary curriculum.

Section 1: Teacher training and student achievement

A number of investigators have conducted research over the past two decades with regard to the relationship between teacher preparation in mathematics and science and student achievement. This work resulted from two events, the failure of the economics production literature to identify reliable predictors of student achievement based on global measures of teacher qualifications (Hill, Bowan, & Ball, 2005); and the seminal article by Lee S. Shulman (Shulman, 1986) about the components of knowledge necessary for teachers to perform successfully. It became apparent to researchers as a result of these two strands that what was known about teacher competencies was insufficient to explain student achievement, and researchers embarked on a program to identify components of teacher knowledge and practice necessary to produce student performance. As results have accumulated, various organizations, including most importantly the National Council of Teachers of Mathematics (NCTM), the National Research Council, the National Science Teachers' Association, and the Conference Board of the Mathematical Sciences (CBMS) have published recommended guidelines for the preparation of mathematics and science teachers.[10] These publications have been influential in guiding the thinking of educator preparation program staff and state policy makers on the preparation and certification of both elementary teachers and secondary STEM teachers.

Two essential questions have emerged from these studies - the strength of the relationship between teacher content knowledge and student achievement, and the specific representations of knowledge that are most conducive to effective teaching.

That the overall level of content knowledge of teachers is related to student achievement has been amply demonstrated. Monk (Monk, 1994) used the Longitudinal Survey of American Youth to determine whether teacher knowledge in mathematics and science is associated with student achievement and found that how much a teacher knows about his subject has a positive effect on students' learning gains. He found that for high school juniors, an increase of one mathematics course for a teacher with modest mathematical training was associated with a 1.2% increase in student achievement but that the addition of further courses beyond five had a diminishing effect; and that the number of courses in a teacher's background had a positive effect on students' achievement in AP courses but not in remedial courses. Teacher undergraduate preparation in the life sciences had no discernible effect on student science achievement, but there were significant effects for teacher preparation in the physical sciences. Hill, Bowan, and Ball (2005) found roughly 1/2 to 2/3 of a month of additional growth in student achievement per standard deviation difference on their measure of teacher content knowledge. Goulding and Rowland (Goulding and Rowland 2002) found in Britain that teachers' measured content knowledge was associated with performance as mathematics instructors. Goldhaber and Brewer (Goldhaber and Brewer, 1997), using data from NELS:88, determined that a master's degree in mathematics had an effect on student achievement, and found in a

[10] These are by no means the only groups publishing recommended standards in this area. William Bush of the University of Louisville (Bush, in press) identified a total of 13 standard-setting groups just in the mathematics area.

second study (Goldhaber and Brewer, 1998) that earning a subject-specific degree had a positive effect on student achievement in both mathematics and science. Rowan, Chiang, and Miller (Rowan, Chiang, and Miller, 1997), also using NELS:88 data, found that a major in mathematics at the graduate or undergraduate level was associated with student achievement in the 10th grade.

The studies cited above deal principally with the relationship between mathematics and science content knowledge of secondary teachers and student achievement and make it clear that teacher content preparation is essential to student achievement in these subjects. The content knowledge of elementary teachers, who teach mathematics and science as well as other content, is the subject of a more detailed research literature. This literature concerns itself with a number of additional issues that arise as a consequence of particular features of the training of elementary teachers and of elementary classroom practices.

Elementary teachers, unlike secondary teachers, are generalists. As a result, they must be prepared to teach a variety of content, some of which is acquired in the course of their general college studies prior to admission to teacher training. Their content preparation in the elements of the elementary curriculum is thus subject to the general requirements of the institution where they train and to the specific requirements of the teacher training program that prepares them to teach.

One thing that emerges from the research on elementary teacher preparation is that in general, elementary teachers are math averse. A number of authors, such as Cornell (Cornell, 1999), have documented that elementary candidates are unsure of themselves when it comes to understanding and teaching mathematics, and avoid taking mathematics undergraduate courses. Prior to admission to teacher training, elementary candidates bring with them an educational history that may involve previous deficiencies in and bad experiences with mathematics learning (Weitman and Colbert, 2003). Elementary candidates often feel that they are not good at math and try to avoid it (Ball, 1990a).

Other researchers have addressed the question of what specific knowledge is needed by elementary teachers. One might naively assume that because the mathematics content taught by elementary teachers is very basic, little mathematics preparation is needed to enable elementary teachers to effectively deliver the content (Friedberg, 2005). In fact, teaching mathematics to students in the earliest grades is a demanding process that requires surprisingly high levels of mathematical knowledge. Elementary teachers must impart mathematical knowledge to children who may have difficulty understanding the content regardless of how it is delivered, and teachers need to have sufficiently broad understanding of the content to be able to represent it in multiple ways (Ball, 1990a). Elementary teachers must be prepared to impart mathematical knowledge ranging from simple counting to algebraic thinking (Franke, 1999). Further, student achievement in mathematics – and subsequent achievement in science as well – requires that students understand math concepts in depth, and elementary teachers with poor math backgrounds tend to teach an algorithmic approach that is not likely to produce the necessary conceptual understanding (Ball, 1990a; Taylor, 2002). Some researchers have discovered that elementary teachers tend to have the same misconceptions about elementary mathematical operations as the children they teach (Graeber, Tirosh and Glover, 1989),

and thus are unable to assist their students in developing the type of thorough understanding of mathematic concepts that is optimal. Milgram (Milgram, 2006) listed elementary number theory, geometry and measurement, and combinatorics, probability, and statistics as necessary mathematics competencies for elementary teachers. Clearly, these competencies are much more demanding than might be expected from a naïve view.

Several studies have evaluated specific deficits in elementary teachers' ability to meet this requirement for deep understanding of mathematical principles and flexibility in presentation. The CBMS (Conference Board of the Mathematical Sciences, 2001) recommendations for mathematics teacher preparation noted that

> *. . .teachers must have the patience to listen for, as well as the ability to hear, the sense---the logic---in children's mathematical ideas. They need to see the topics they teach as embedded in rich networks of interrelated concepts, know where, within those networks, to situate the tasks they set their students and the ideas these tasks elicit. In preparing a lesson, they must be able to appraise and select appropriate activities, and choose representations that will bring into focus the mathematics on the agenda. Then, in the flow of the lesson, they must instantly decide which among the alternative courses of action open to them will best sustain productive discussion.*

The CBMS recommendations, in order to operationalize these requirements, recommended that elementary teachers have at least 9 hours of formal mathematics training[11], covering specifically algebra, geometry, and statistics.

Friedberg (Friedberg, 2005) commented that the teacher preparation community has responded to this requirement by organizing courses on mathematics methods for elementary teachers, but asserts that this is not sufficient to meet the requirement, because what elementary teachers require is mathematics beyond that taught in high school, in order to achieve the depth of knowledge necessary to effectively teach the content. Wu (Wu, 2005) suggests that elementary teachers must teach serious mathematics, by which he means, ". . . mathematics that puts a heavy emphasis on precision, skills, conceptual development and reasoning, regardless of how elementary the material may be."

A number of authors have noted that elementary teachers often have deficiencies in understanding of fairly simple mathematical concepts. Rule and Hallagan (Rule and Hallagan, 2006) conducted a study of difficulties preservice elementary teachers had in understanding algebraic concepts, finding that the preservice teachers in their sample had difficulty defining variables and identifying patterns in order to solve simple algebra problems using object boxes. Lewis and others (Lewis, Alacaci, O'Brien, and Jiang 2002) found in their study of preservice elementary teachers that their subjects had difficulty integrating mathematical concepts into science lessons and had difficulty handling simple statistics problems. Ball (Ball, 1990a) found that her subjects had a

[11] As does NCTM, although NCTM does not recommend specific courses as does CBMS.

problem with confounding everyday language with mathematical language and had difficulty explaining their reasoning as they solved problems. She found in a different study (Ball, 1990b) that preservice teachers' understanding of division by fractions was unattached to other ideas about division, and that they used an algorithmic approach with little understanding of the underlying principle. Graeber, Tirosh, and Glover (Graeber, Tirosh, and Glover, 1989) found that a large proportion of the preservice teachers in their sample answered a large number of sample multiplication or division problems incorrectly, principally because they were influenced by primitive notions of multiplication and division that otherwise characterize 10- to 15-year-old children.

It seems clear from the available evidence that there is a relationship between teacher content preparation in mathematics and science and student achievement, and that this relationship is operative at all levels of the P-12 enterprise.[12] As demonstrated by the studies cited above, the effect sizes are small year-to-year, and it is apparent that other factors also play a prominent part in student achievement in these subjects. These other factors – family effects, socioeconomic factors, community factors, school and district effects, and individual child behaviors – have been the focus of other studies, but they have the distinction (as opposed to teacher preparation and teacher content knowledge) of not being easily amenable to policy manipulation. The present paper restricts itself to those factors than can be affected by EPSB and other education agencies and institutions and is confined primarily to teacher preparation and curriculum requirements.

The studies cited above were conducted outside of Kentucky, and one may well ask whether the content preparation and content knowledge of Kentucky teachers are similar to those of elementary and secondary teachers elsewhere. Although there are no Kentucky-specific studies of the representation of content knowledge similar to those conduced by Ball and others, some recent research has been conducted relevant to the content preparation of STEM teachers in Kentucky. To the extent that teacher preparation in Kentucky is similar to that of the teachers involved in the studies cited above, it is reasonable to believe that the effects will be the same. Section 2 will evaluate these studies.

[12] It is interesting that no similar research program has developed in the case of the other two subjects in the core elementary curriculum, language arts and social studies. The available literature in these subjects is much more characteristic of the situation two decades ago, when the research program in mathematics and science had its beginning. This may be due to the emphasis on mathematics and science since 1957 as generators of economic competitiveness and national security, but it may also have much to do with the fact that mathematics is the only subject in the public school curriculum that is consistently measured across all grade levels.

Section 2: The mathematics and science preparation of Kentucky teachers

EPSB has conducted three studies since 2004 that shed light on the preparation of STEM teachers in Kentucky. Collectively, these studies provide information about the preparation of teachers at the elementary, middle, and high school levels. Additionally, other researchers in Kentucky have contributed significant results in this area.

The most recent study, conducted in 2007 in support of the present paper, investigated the preparation of elementary teachers in mathematics and science. Transcripts of a sample of 50 completers of Kentucky-approved elementary education programs who were first certified in school years 2005-2006 and 2006-2007 were drawn from the EPSB imaging system. Hours attempted and completed were collected from the transcripts and then summarized in tables 1-5.

Table 1 displays the results for "arts and sciences" courses taken by teacher candidates, i.e., courses organized for students by the relevant college or university academic department without regard to the individual's status as a teacher candidate. It is notable that of the subjects in the core curriculum[13], the average number of semester hours of mathematics completed for credit, at 6.5, was markedly less than the average hours for the other subjects. By contrast, candidates completed for credit on average 10.42 semester hours in the sciences, 11.62 hours in language arts, and 27.16 hours in social studies[14]. Courses "completed" were those the candidate completed regardless of grade, and courses "completed for credit" were those courses where the candidate received a grade of "C" or better, or in the case of ungraded courses, received a "Pass" or its equivalent.

Table 1.
Semester Hours Attempted and Completed by Elementary Candidates, Arts and Sciences Courses

Content type	Attempted	Completed	Completed for Credit
Arts	6.12	5.78	5.72
English/Theater	12.76	11.86	11.62
Foreign Language	1.68	1.56	1.5
Geography	2.34	2.1	2.1
History	8.32	7.52	6.86
Humanities	5.74	5.32	5.26
Mathematics	8.26	6.94	6.5
Sciences	12.96	11.4	10.42
Social Sciences	14.6	13.64	12.92

[13] Mathematics, science, social studies, and language arts
[14] This includes history, humanities, geography, and social sciences.

Table 2 displays the average number of hours attempted and completed in "for teachers" courses. These courses are organized specifically for teacher candidates and are often taught by the relevant arts and sciences faculty. Note that the average number of hours earned for mathematics, at 5.46, is much greater than the number of hours earned for science (0.96), social studies (.12)[15], and language arts (.36).

Table 2.
"For Teachers" Hours Attempted and Completed by Elementary Candidates

Content	Attempted	Completed	Completed for Credit
Arts for teachers (Includes both art and music)	1.22	1.16	1.16
Geography for teachers	0.06	0.06	0.06
Language arts for teachers	0.36	0.36	0.36
Math for teachers	6.18	5.76	5.46
Science for teachers	0.96	0.96	0.96
Social Studies for teachers	0.06	0.06	0.06
Health/physical education for teachers	0.16	0.16	0.16

Table 3 displays the average number of hours attempted and completed in "methods" courses. These courses, typically taught in the education department, are intended to train candidates in methods of delivering the respective content. Note that the number of hours completed for social studies (2.94), science (2.52), mathematics (2.42) and language arts (2.1)[16] is roughly the same.

Table 3.
Methods Course Hours Attempted and Completed by Elementary Candidates

Content Type	Attempted	Completed	Completed for Credit
Arts methods	2.16	2.04	2.04
Health/physical education methods	0.12	0.12	0.12
Language arts methods	2.1	2.1	2.1
Math and science methods	0.12	0.12	0.12
Math methods	2.42	2.42	2.42
Science methods	2.52	2.52	2.52
Social studies methods	2.94	2.94	2.94

[15] This includes geography and social studies

[16] The number for language arts is somewhat artificially low, because in some programs language arts methods and reading methods are included in the same course. In those cases the course was counted as a reading methods course.

Table 4 displays the total number of hours earned by course type for each of the core subject areas and displays the proportion of hours taken as non-teacher content courses in the arts and sciences departments. Note that the proportion of arts and sciences courses in mathematics (.40) was very much less than that for science (.76), language arts (.83), and social studies (.90). Mathematics is the only core content subject where the majority of hours were earned outside the arts and sciences departments.

It is important to note here that the intent of preparation programs in organizing "for teachers" courses is to provide content, not methods. But as William Bush noted in his research – to be described later in this paper – the coverage of these courses varies considerably from one institution to another, with some institutions providing courses that meet the above definition of rigorous content, and others providing what are essentially methods courses. The two types of courses were combined to make a point: mathematics preparation, more than any other core subject, is conducted principally in courses organized specifically for teacher candidates. To the extent that these courses cover all of the content recommended by NCTM and CBMS and are rigorous by the definition above, there can be no objection in principle to this model of teacher training. The suggestion later in the present paper for nine hours of training in arts and sciences mathematics is meant to emphasize the value that should be placed on rigor and coverage of the recommended content, and should not be seen as precluding the possibility that institutions might develop "for teachers" courses that would meet all of the requirements for rigor. A recommendation is also made about the process of assuring that these courses are indeed as rigorous as is desired.

Table 4.
Total Hours Attempted and Completed by Elementary Candidates

Total by subject area	**Total hours**	**Proportion "for teachers" courses**	**Proportion methods courses**	**Proportion "for teachers" and methods courses**	**Proportion Content Courses**
Math-related	14.38	0.43	0.17	0.60	0.40
Science-related	14.32	0.07	0.18	0.24	0.76
Language Arts-related	14.08	0.03	0.15	0.17	0.83
Social Studies-related	30.20	0.0	0.10	0.10	0.90

Table 5 displays the breakdown of science hours attempted and completed by scientific discipline. Note that half of the hours earned were in biology, and more than 80% were earned in biology, chemistry, and earth science combined. The relatively large proportion of hours earned in chemistry was due to the presence in the dataset of a few individuals who had begun their college careers as nursing or allied health majors but later switched to elementary education. Typically, the elementary education candidates in the sample took only biology as a science.

Table 5.
Science Hours Attempted and Completed by Discipline

Science	Attempted	Completed	Completed for Credit
Astronomy	0.98	0.92	0.92
Biology	6.74	5.8	5.18
Chemistry	2.3	2.18	2.1
Environmental studies	0.08	0.08	0.08
General science	0.1	0.1	0.1
Geology/earth science	1.62	1.3	1.12
Meteorology	0.06		
Physical science	0.48	0.48	0.4
Physics	0.54	0.48	0.46

In addition to evaluating the actual course-taking behavior of elementary candidates, preparation requirements as reflected in guide sheets[17] provided by teacher preparation programs to the Division of Educator Preparation of EPSB were also evaluated. Scorable guide sheets were available for 25 of the state's 29 approved educator preparation programs. Examination of the guide sheets revealed that institutions typically require one undergraduate arts and sciences mathematics course, two or three mathematics for teachers courses, and one mathematics methods course. Two programs require 3 arts and sciences mathematics courses, and 4 require none[18]. The programs require on average 7 arts and sciences hours in the sciences and one science methods course. Some institutions require specific science courses, principally biology and physical science, but most allow students to select science courses from a menu that includes any of the natural sciences.

In a study of high school STEM teacher transcripts in December, 2006, the author (Hibpshman, 2007) evaluated the academic records of a sample of 400 mathematics and science teachers who were teaching math or science content in the 2006-2007 school year. The results showed that mathematics teachers had an average of 30 undergraduate hours in mathematics, and science teachers had an average of more than 30 undergraduate hours in combined science courses. Less than 2% of mathematics teachers lacked a major, minor or its equivalent in mathematics, and less than 4% of science teachers lacked a major, minor, or equivalent in some scientific discipline. Biology and physical science teachers had on average enough hours in the relevant disciplines to constitute a major, and chemistry teachers had enough hours on average to constitute at least a minor. Physics and earth science teachers had on average more than 40 hours in combined sciences but often did not have enough hours in the relevant discipline to constitute either a major or minor. The apparent deficiency in physics and earth science

[17] In most cases these were curriculum contracts signed by elementary candidates when they are admitted to teacher training.

[18] The number of required arts and sciences math courses for two programs could not be reliably determined from the guide sheets.

was explained by recent changes in the state science certification regime, from certification in physical science to certification in specific physical sciences. Persons with permission to teach physical science under the old model also had permission to teach chemistry, physics, or earth science, and these privileges cannot be revoked once granted.

In a study of middle and high school teachers in all disciplines in 2004 (Hibpshman, 2004), the author found that content teachers in all subjects at the middle and high school levels typically had a major, minor, or equivalent in the subject taught. 4.5% of teachers at the high school level lacked a major or minor, and these were accounted for by persons teaching with emergency certificates and persons teaching illegally[19]. 18% of middle school teachers lacked a major, minor, or equivalent, and most of these were persons with old "K-8" certificates. A recent study in 2006 found that this group of teachers now represents 12% of the middle school teaching force.

In addition to these three studies, other analysis conducted by EPSB and others shed some light on this subject. A study begun in 2003 by EPSB and currently ongoing was developed specifically to test whether arts and sciences mathematics courses are more effective in promoting student achievement than are mathematics for teachers and methods courses collectively. CATS scores were collected for all students of elementary teachers and middle school mathematics teachers in a district that agreed to be a part of the study, and transcript data were collected for the sample of teachers. Mathematics courses were coded as either arts and sciences courses or math for teachers/math methods courses. The results of the study (Toma, 2005), using a value-added methodology, demonstrated that the number of hours of arts and sciences mathematics was positively related to student achievement in elementary and middle school, but that the number of hours in math for teachers/math methods courses was negatively related to student achievement, once arts and science course effects had been accounted for.

A study by William Bush of the University of Louisville (Bush, in press), conducted as part of the EPSB Title II grant in 2005, investigated the content of mathematics courses taken by middle school candidates at six Kentucky public universities. Dr. Bush's study used an ingenious method: instead of examining syllabi alone, he and his collaborators used instructors' tests as a measure of what was actually taught in the courses. Course content was compared to a list of high, low, and no priority content elements drawn from a review of 13 mathematics standards documents. Dr. Bush found considerable variation in the coverage of essential content by math for teachers courses at the different universities, concluding that alignment of courses with national standards and expectations was mediocre. He developed a theoretical "best 24 semester hour" program combining courses from across universities, finding that such a program would focus on high priority content 88 percent of the time.

[19] Kentucky strictly prohibits out of field teaching and applies sanctions when an individual is found to be teaching illegally. Prior to the 2006-2007 school year, teacher assignments were collected only at the beginning of the year, and districts were required to correct any identified illegal assignments. These estimates therefore reflect only what was true at the beginning of the 2003-2004 school year.

On the basis of the above studies the following may be concluded:

1. Having under-qualified teachers at the middle and high school level is a problem only with regard to the 12% of middle school teachers who are teaching with K-8 certificates. Since these certificates were last issued in 1986, all of these teachers are currently late in their careers and can be expected to retire in the next few years. Otherwise, high school and middle school teachers are generally well qualified.

2. Teachers of physics and earth science at the high school level present a problem because of the shift from physical science certification to certification in a differentiated science curriculum. A large proportion of persons teaching these subjects have less than a major or minor in the specific discipline taught, but generally these persons have many more than 30 hours on average in the physical sciences combined. This problem should be substantially ameliorated as new teachers are produced with specific training in chemistry, physics, and earth science.

3. There are two problems with elementary teacher preparation:

    - Most of the mathematics hours completed by elementary candidates are in either "math for teachers" or math methods courses, a pattern that is not paralleled in any other core subject area. These courses serve a useful purpose, but as noted above, elementary teachers need a firm grounding in mathematics, and it is unlikely that this pattern provides them with sufficient depth of knowledge to provide the quality of instruction needed, unless special care is taken in the design of these courses. Additionally, the Toma transcript study demonstrated that these courses are associated with less student achievement than is the case with arts and sciences courses.

    - Most of the science hours completed by elementary teachers are in biology. It would be highly desirable for elementary teachers to have a broader understanding of the sciences than is likely to be produced by this pattern.

Section 3: A strategy for improvement of STEM achievement by Kentucky P-12 students

One additional recent study conducted in 2007 as part of the present effort will shed light on the course-taking patterns of high school students. As noted above, STEM teachers at the secondary level are generally well-qualified in their content areas. Student enrollments in high school science courses were computed from LEAD[20] for the past three available school years and are displayed in Table 6. The numbers displayed in the table are the sum of enrollments by content type divided by the reported enrollment for the school for that year. Because the course enrollments and total school enrollments come from different datasets collected with slightly different methodologies, the numbers cannot be viewed as proportions, but they represent an index of the relative course-taking behavior of high school students statewide. Note that chemistry has the highest enrollment index of all the sciences, and physics the lowest enrollment index. These results are significant when considered in light of a recent report by ACT (ACT, 2007). ACT conducted a study of the likely college success of students depending on the specific mathematics and science courses they took in high school, and found that students who took biology, chemistry, and physics were 80% likely to persist beyond the first year of college, while those who took biology and chemistry were 74% likely to persist, and those who took only biology were 64% likely to persist. Given the very low index in table 6 for physics, it is possible that an increase in the enrollment in physics courses statewide would have a positive effect on college success of Kentucky students.[21]

Table 6
High School Enrollments in the Sciences, 2003-2006

Discipline	2003-2004	2004-2005	2005-2006
Biology	.151	.204	.198
Chemistry	.226	.350	.334
Integrated Science	.102	.165	.179
Physical science	.036	.084	.082
Physics	.047	.052	.051

In addition to the brief study described above, it is important to mention recent developments in Kentucky with respect to high school graduation requirements. Current Kentucky regulation requires that high school students, in order to graduate, must take three units of mathematics (Kentucky Legislative Research Commission, 2007), including Algebra I, geometry, and an elective. In 2006, the Kentucky Board of Elementary and Secondary Education enacted a new regulation, to take effect in 2012

[20] LEAD is EPSB's annual collection of data about courses taught by teachers in public schools in Kentucky.

[21] Some care needs to be taken in interpreting these estimates. The ACT study is correlational, and as is always the case, the direction of causality cannot be determined from a correlational study. It might be that taking physics has a positive effect on college achievement independent of a student's general level of ability (as has been suggested elsewhere), or it might be that those students most likely to take physics are the same students who are most likely to succeed in college.

(Kentucky Department of Education, 2006b), that would require all high school students to take four years of mathematics, including Algebra I, geometry, Algebra II, and an elective beyond Algebra II. This is salutary in light of the results of the ACT study, which found that 73% of students who take Algebra I and II, geometry, and calculus persist in higher education, while 56% of students who take Algebra I and II, Geometry, and an advanced mathematics course other than calculus persist, and only 38% of students who take Algebra I and II and an unspecified elective persist. It seems clear from these results that the KBE regulation should have positive effects on the college success of Kentucky students, once it takes effect.

If one conclusion is to be drawn from the information summarized above, it is that an improvement in Kentucky's performance in the STEM areas, including an increase in STEM course taking at the college level and the award of additional degrees in the STEM disciplines, will require additional rigor throughout the P-12 system. At the elementary level, where teacher content preparation in mathematics and science is a problem, this will mean development of a more demanding curriculum for preservice elementary teachers. At the high school level, where teachers are well prepared but student enrollments in rigorous mathematics and science courses are less than optimal, it will mean developing mechanisms for encouraging students to take a more demanding curriculum. At the middle school level, where teachers generally have adequate content preparation in the STEM disciplines but a significant proportion continue to teach with the old K-8 certificate, additional efforts to improve the content knowledge of existing teachers via professional development may be fruitful.

There are potential hazards to requiring additional rigor. At the elementary level, requiring additional coursework in mathematics and science may have the effect of suppressing the production of teachers in two disciplines. As noted above, elementary candidates are math averse, and requiring additional and more rigorous mathematics courses may have the effect of reducing the number of elementary candidates. Elementary candidates represent the largest single number of persons enrolled in teacher preparation programs, and a reduction in the number of candidates would not by itself pose much of a problem, since many more elementary teachers are produced each year than can be employed in public school systems.

The potential difficulty arises because of a historic artifact of teacher preparation. There has never been a shortage of newly minted elementary teachers, but there has been a persistent shortage of special education teachers. In recent years, elementary education graduates who are unable to immediately get a job as elementary teachers have been retrained to serve as special education teachers. A reduction in the number of elementary education graduates could potentially exacerbate the persistent shortage of special education teachers.

Another consideration is the impact of changes on the institutions that train teachers. Elementary education candidates constitute half or more of the new teachers graduated each year by many institutions. If additional rigor in the elementary education curriculum causes a reduction in the number of elementary candidates, then institutional

enrollments could decrease as a consequence. This could have serious consequences for the teacher preparation programs.

A final consideration about elementary preparation has to do with the cumulative effect of adding requirements to the elementary curriculum. As preparation programs have struggled to respond to additional requirements for the elementary preparation curriculum over the past few years, the number of college hours required to complete the curriculum has expanded correspondingly, until it has become difficult to design an elementary preparation sequence that can be completed by an undergraduate in four years (Sandidge, 2007). If additional mathematics and science requirements are added, it will be difficult to do so without exacerbating this problem, if the rest of the elementary preparation program is not adjusted to accommodate the new requirements. Such an adjustment will be difficult. Elementary teachers are generalists who must teach all of the core subjects and by the nature of their practice must have a greater proportion of education courses than other teachers. One might resolve this problem by differentiating the elementary curriculum so that teachers would specialize in particular disciplines.[22] This would work well when teachers are prepared for large urban or suburban schools but would be a problem for small rural schools that lack enough teachers to guarantee a teacher in each specialty. One could also resolve the problem by not requiring that elementary candidates take methods courses in music, art, and physical education, relying instead on content teachers to provide those subjects. This again would work well for large urban and suburban schools but would be a problem for small rural schools where content specialists in music, art, and physical education are not as readily available.[23]

Increasing enrollments in rigorous mathematics and science courses at the high school level has a different set of potential consequences. Kentucky produces about 20 new physics teachers a year. This number is sufficient to meet the demand for physics teachers at the current low levels of demand, but a substantial increase in the number of student enrollments in physics would certainly cause a shortage of qualified physics teachers. Although there is reason to believe, based on an analysis of similar shortage problems in the past, that this shortage would be temporary, lasting about 3-5 years (Hibpshman, 2006), Kentucky would in the intervening time see an increase in the number of emergency certificates in physics and would suffer in its annual "Highly Qualified" report to the federal government.

These potential consequences are manageable with adequate planning and should not deter increasing the rigor of the system at all levels. To this end the following recommendations are offered for consideration:

1. Preservice elementary education teachers should be required to take a more rigorous curriculum in mathematics and science, including 9 hours of arts and sciences mathematics in addition to mathematics for teachers and math methods courses, at

[22] Most of the state's approved programs already provide for emphasis by elementary candidates in a particular subject. These emphases generally require that the teacher take from 21 to 24 hours in the specialty subject.

[23] And because art and music are highly favored by elementary teachers, would probably face strong opposition.

least one physical science course, and an earth science course. Elementary candidates should have mathematical training that assures a thorough conceptual understanding of algebra, geometry, and probability/statistics. Consideration should be taken prior to implementation of this requirement to ameliorating the possible consequences noted above.

2. High school students should be encouraged to take additional science content, including in particular physics. The most attractive approach to this requirement would be to require four years of science and make physics a requirement for college admission. Regardless of the mechanism used to increase high school enrollments in rigorous science, attention should be given to how we can best deal with the likely resulting shortage of physics teachers. Given that an immediate implementation of the 4th-year mathematics requirement would probably not cause a serious shortage of high school mathematics teachers, KBE might consider revisiting the 2006 regulation change, accelerating the implementation of this new requirement. This would prevent the problem of attempting to implement two major system changes in the STEM area at the same time.

3. Additional study of the content preparation and content knowledge of middle school teachers needs to be undertaken. A significant proportion of current middle school teachers have the obsolete "K-8" certificates, and we cannot revoke their rights to teach science and mathematics. Some of these individuals will have acquired additional content knowledge via professional development or other training programs over the years, but we lack any means of estimating what proportion is thereby adequately qualified to teach mathematics and science. Most of these persons will retire in the next few years, but the last group with these certificates will not be eligible to retire for a few years yet, so this will be an ongoing concern. In addition, Dr. Bush's investigation of mathematics for teachers courses indicates that the rigor of mathematics preparation of middle school teachers may be uneven, and some additional investigation of this question also needs to be undertaken.

4. An investigation of the content coverage of elementary math for teachers courses, similar to Dr. Bush's study, should be undertaken, and a model for adequate coverage in these courses should be developed.

<u>A comment on professional development</u>

One additional problem must be considered. Teachers in Kentucky as elsewhere typically teach for 30 years or more before they retire, and teacher preparation standards regularly change. As a result, the teacher workforce at any given time represents an amalgam of teacher cohorts prepared under different standards. This is particularly a problem in the case of middle school teachers who received K-8 certification until 1986, and a new requirement for more rigorous preparation of elementary teachers in science and mathematics will likely create a similar problem. Given the historic 7% yearly overall attrition rate for teachers, it would be about 11 years after implementation of any new requirements before more than half of the elementary teachers were trained under the new regime.

There has been a great deal of interest in recent years in using professional development to upgrade the skills of existing teachers in science and mathematics. The National Science Foundation has developed a grant program to provide services to improve teacher knowledge and skills in the STEM disciplines, and Kentucky is a participant in one of these programs, the Appalachian Math and Science Partnership (AMSP), which serves 38 Kentucky school districts. Additionally, the General Assembly in 2006 established the Kentucky Center for Mathematics at Northern Kentucky University, which provides a variety of professional development programs.

These are excellent programs, but they are voluntary and it is doubtful that they can collectively provide all of the professional development needed to assure that well-qualified teachers – especially at the elementary level – are available to all children.[24] If it is our desire to ensure that all children have effective education in the STEM disciplines, it will be necessary to identify mechanisms that can effectively distribute professional development to all of the state's 20,000 or so elementary teachers, as well as to those middle school teachers who require an improvement in content knowledge.

Before this can be done, additional information is needed. It would be highly desirable to study the sources of available professional development in the STEM disciplines and to determine whether such services are sufficient to provide all of the professional development needed by Kentucky's elementary teachers.

Next Steps

Given the importance and complexity of the issues, it is recommended that the EPSB convene a task force that is charged with the development of a comprehensive strategy on the preparation and support of math and science teachers. The task force should:

1. Consist of math and science educators, effective math and science teachers, KDE math and science consultants, representatives from the CPE, school and district administrators, and others as deemed helpful to the mission of the task force;

2. Work in concert with the Math Achievement Committee;

3. Present to the EPSB, KDE, and CPE concrete recommendations on ways to improve the preparation and support of math and science teachers; and

4. Bring a final report to the EPSB within six months of the date of its first meeting.

[24] Consider also that AMSP is currently in its final year, and it is not given that the services it provides will continue beyond 2008.

References

ACT (2007). Benefits of a High School Core Curriculum

Ball, D.L. (1990a). The Mathematical Understandings That Prospective Teachers Bring to Teacher Education. *The Elementary School Journal*, Vol. 90, No. 4. (Mar., 1990), pp. 449-466.

Ball, B.L. (1990b). Prospective Elementary and Secondary Teachers' Understanding of Division. *Journal for Research in Mathematics Education*, Vol. 21, No. 2. (Mar., 1990), pp. 132-144.

Conference Board of the Mathematical Sciences. (2001). *The Mathematical Education of Teachers*.

Cornell, C. (1999). "I hate math! I couldn't learn it, and I can't teach it!" *Childhood Education, Summer 1999*, 225-230.

Franke, M.L. (2002). *How Much Can We Accomplish? Elementary Mathematics Methods Revisited*. National Council on Teachers of Mathematics.

Friedberg, S. (2005). Comments on the need for mathematician involvement in pre-service teacher training. In Milgram, R.J. (2005) *The Mathematics Pre-service Teachers Need to Know*. Stanford University.

Goldhaber, D. D., & Brewer, D. J. (1997). Evaluating the effect of teacher degree level on educational performance. In W. J. Fowler (Ed.), *Developments in School Finance*, 1996. Washington, DC: US Department of Education.

Goldhaber, D. D., & Brewer, D. J. (1998). When Should We Reward Degrees for Teachers? *Phi Delta Kappan*, 80(2), 134–138.

Goulding, M. and Rowland, T. (2002). Does it Matter? Primary Teacher Trainees' Subject Knowledge in Mathematics. *British Educational Research Journal*, Vol. 28, No. 5.

Graeber, A. O., Tirosh, D.,and Glover, R. (1989). Preservice Teachers' Misconceptions in Solving Verbal Problems in Multiplication and Division. *Journal for Research in Mathematics Education*, Vol. 20, No. 1. (Jan., 1989), pp. 95-102.

Hibpshman, T. L. (2004). Teacher College Transcript Data as a Measure of Content Preparation. Unpublished document, Kentucky Education Professional Standards Board.

Hibpshman, T.L. (2006, October). *Educational Policy and the Demand for Teachers: Useful Inferences about Mathematics and Science Teachers Using Available Data*. Paper presented at the Kentucky Teacher Quality Summit, Louisville, KY.

Hibpshman, T. L. (2007). *Analysis of Transcript Data for Mathematics and Science Teachers.* Unpublished document. Frankfort, Kentucky: Education Professional Standards Board.

Hiemstra, H. (2005). *Underprepared Students in Kentucky: A First Look at the 2001 Mandatory Placement Policy*. Frankfort, Kentucky: Council on Postsecondary Education.

Hill, H. C., Bowan, B., & Ball, D. L. (2005). Effects of Teachers' Mathematical Knowledge for Teaching on Student Achievement. *American Educational Research Journal*, 42(2), 371-406.

Kentucky Department of Education (2006a). *Kentucky Performance Report Content Index Area Trends.* Frankfort, KY: Author.

Kentucky Department of Education (2006b). *New requirements for high school graduation.* Retrieved July 30, 2007, from http://education.ky.gov/NR/rdonlyres/ B0C6621B-1E08-4560A4EBBFAF383C11A8/ 0LatestNewHSMathRequirementsDraftQAMay15.pdf.

Kentucky Legislative Research Commission (2007). 704 KAR 3:305. *Minimum requirements for high school graduation.*

Kuenzi, J. J., Matthews, C. M., & Mangan, B. F. (2006). *Science, Technology, Engineering, and Mathematics (STEM) Education Issues and Legislative Options.* Library of Congress, Computation Research Service.

Lewis, S. P., Alacaci, C., O'Brien, G. E. and , *Jiang*, Z. (2002.). Preservice Elementary Teachers' Use of Mathematics in a Project-Based Science Approach. *School Science and Mathematics*, Volume 102(4).

Task Force on Science, Math Teaching Meets. (January 1, 2007). *The Lexington Herald.*

Milgram, R.J. (2006). The Mathematics Teachers Need to Know. Presentation at the Center on Instruction Mathematics Summit November 13, 2006

Monk, D. H. (1994). Subject Area Preparation of Secondary Mathematics and Science Teachers and Student Achievement. *Economics of education review*, 13(2): 125-145.

National Center for Education Statistics (2004). *Highlights From the Trends in International Mathematics and Science Study: TIMSS 2003.*

National Center for Education Statistics (2005). *The Nation's Reportcard: 2005.*

National Committee on Science Education Standards and Assessment, National Research Council (1996) *National Science Education Standards*. Retrieved July 20, 2007 from http://www.nap.edu/readingroom/books/nses/.

National Science Teachers Association (2003) Standards for Science Teacher Preparation. Retrieved from http://www.nsta.org/pdfs/NSTAstandards2003.pdf on July 20, 2007

Newman, S. (2007) Personal communication

Rowan, B., Chiang, F., & Miller, R. J. (1997). Using Research on Employees' Performance to Study the Effects of Teachers on Students' Achievement. *Sociology of Education*, 70(October), 256–284.

Rule, A C. and Hallagan, J. E. (2006, April). *Algebra Rules Object Boxes as an Authentic Assessment Task of Preservice Elementary Teacher Learning in a Mathematics Methods Course*. A Research Study Presented at the Annual Conference of the New York State Association of Teacher Educators (NYSATE) in Saratoga Springs, NY.

Sandidge, R. (2007) Personal communication.

Shulman, L. E. (1986). Those who Understand: Knowledge growth in teaching. *Educational Researcher*, February 1986, 5-14.

Symonds, W.C. (2004, March 16). Special Report: America's Tech Might: Slipping? *Business Week*.

Taylor, P. M. (2002). Implementing the Standards: Keys to Establishing Positive Professional Inertia in Preservice Mathematics Teachers. *School Science and Mathematics*, 102(3).

Toma, E. (2005, June). *Teacher Training and Student Outcomes*. Presentation at the EPSB Title II research conference, Lexington, KY.

Weitman, C. J., & Colbert, R. P. (2003, January). *Are elementary teacher preparation programs the real problem of unqualified teachers?* Paper presented at the annual meeting of the American Association of Colleges of Teacher Education, New Orleans, LA.

Wu, H. (2005). Some points to consider in teaching pre-service elementary teachers. In Milgram, R.J. (2005) *The Mathematics Pre-service Teachers Need to Know*. Stanford University.