AC 2010-1064: A UNIQUE MULTI-DISCIPLINARY STEM K-5 TEACHER PREPARATION PROGRAM

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A unique multidisciplinary STEM K-5 teacher preparation program

Introduction

K-5 school years are crucial, setting the framework for all subjects as well as critical thinking skills. However, in a formative timeframe for elementary-school aged children the number of K-5 teachers that are educated with a Science, Technology, Engineering or Math (“STEM”) specialization is substantially underrepresented. A lack of STEM subject matter expertise and experiences, coupled with high anxiety and low self-efficacy can lead to low teacher effectiveness and lack of interest from the K-5 students. At our institution, The College of New Jersey (TCNJ), it was felt that the Department of Technological Studies, housed within the School of Engineering, was well positioned to provide a unique K-5 academic major by combining the T&E with the M&S components of STEM, resulting in a program breadth that matches well the breadth of skills needed by a highly skilled K-5 teacher.

Such a program was established at TCNJ in 1998 and is formally referred to as the Math-Science-Technology or MST program. The program has substantial requirements in all STEM areas, and takes a truly integrated-STEM approach. To the authors’ knowledge, this is the only undergraduate STEM major for K-5 teacher preparation in the USA. Currently, there are ~160 MST majors. All students in elementary, early childhood, special education, and deaf & hard of hearing education can elect the MST major as their required “disciplinary” major. As opposed to post-service activities, a pre-service STEM teacher preparation seemed most appropriate since (i) it provides a systemic solution to the K-5 “STEM-teacher void,” (ii) teachers are the largest single influence on a student’s education¹ and (iii) a pre-service environment provides 4 years of time, time enough for important and synergistic areas to be covered in depth. Two key initial goals for the program were to achieve a higher number of STEM-trained K-5 teachers and to bring valuable contextual experiences to our future teachers, and subsequently their K-5 students, through substantial and relevant T&E content. If these goals are achievable then the MST program could have a long-term beneficial impact on student outcomes in STEM and non-STEM subjects at the National level, impacting grades K-5(8), and eventually 9-20⁺.

Many articles have discussed the qualities of effective teachers.¹⁻³ A list of qualities provided by Darling-Hammond is reproduced below.⁴

- 1) strong general intelligence and verbal ability that help teachers organize and explain ideas, as well as to observe and think diagnostically;
- 2) strong content knowledge- up to a threshold level that relates to what is to be taught;
- 3) knowledge of how to teach others in that area (content pedagogy), in particular how to use hands-on learning techniques (e.g.- lab work in science and manipulatives in mathematics) and how to develop higher-order thinking skills.
- 4) an understanding of learners and their learning and development– including how to assess and scaffold learning, how to support students who have learning differences or difficulties, and how to support the learning of language and content for those who are not already proficient in the language of instruction.

- 5) adaptive expertise that allow teachers to make judgments about what is likely to work in a given context in response to students' needs.

Data presented in this paper suggests that our program produces future teachers with a rich level of skills in all five of these areas. The program provides these skills in a unique and powerful fashion through a full STEM, liberal arts and professional curriculum. The T&E content plays a special role. T&E content includes substantial emphasis on the design process (an “adaptive optimization” process), open-ended projects, hands-on skills, teaming as well as verbal and visual communication skills. T&E skills also provide direct experiences with Bloom’s higher levels of learning (analysis, synthesis & evaluation) as well as several of Gardner’s multiple intelligences (visual-spatial, bodily-kinesthetic and intrapersonal). These combined experiences also provide future teachers with valuable context-setting abilities. Context-setting alone is very powerful since it effectively answers the common student complaint, “I’ll never need to know this. Of what good is this?” The beneficial impacts of T&E components have been discussed in several articles for both STEM and non-STEM subjects.⁵⁻⁸

A concern with multidisciplinary programs like the MST program is that the breadth of the program could adversely affect the depth, resulting in a compromised level of content knowledge (a lower level of the #2 quality in Darling-Hammond’s list above). The purpose of this paper is to quantitatively investigate the MST program in the depth of content knowledge in the STEM elements, as well as several key non-STEM subjects. The growth of the program is also investigated, as are several gender effects. Additionally, this paper discusses how an informal learning environment, a result of how the MST program was implemented, may also play an important role in the effectiveness of the program.

Summary

Data presented in this paper indicate that the MST program has been successful both in terms of growth and measured outcomes. In the past 6 years the MST program has grown from only a few percent of the total TCNJ K-5 graduates to over 20%. Current class enrollment strongly suggests that the MST percentage will increase to ~30% in the next few years. This is an approximately 3-fold increase compared to the 8-13% total math and science K-5 graduates before the MST program was established. Additionally, the MST major attracts a substantially higher percentage of males. Males comprise ~25% of the graduating MST population, which is 3-to-5 times larger than the national average of ~9% and the 4-6% observed historically at TCNJ. Analyses of MST graduate outcomes indicate that competencies in all STEM areas are high while achieving performance equal to non-MST majors in very important non-STEM subjects. Specifically, MST majors scored significantly higher than non-MST majors in national math and science tests while scoring equivalently in language arts and social studies. Also, measurements of math anxiety indicate that as the MST majors progress through the math curriculum they attain a math anxiety level approximately equal to K-5 math majors. An analysis of the T&E courses suggests that substantial T&E skills are also being learned. Collectively, these measurements indicate that the breadth of the MST program did not adversely compromise the depth of STEM skills, resulting in graduates with a powerful mix of new skills, understandings and capabilities.

The mix of skills and capabilities acquired by MST graduates suggests to us that the MST program is an excellent candidate for a National model for STEM, and in some ways non-STEM, K-5 teacher preparation.

Program History

Following the adoption of New Jersey's Department of Education (DOE) Core Content Standards in 1996, the Department of Technological Studies was asked to convene chairs from the departments of elementary education, mathematics, biology, chemistry, physics and the coordinator of "New Jersey Statewide Systemic Initiative to Improve Math, Science and Technology Education in K-12" to consider designing a new multidisciplinary major to fulfill a recognized need for more K-5 teachers with strengthened STEM skills. There was concern over the trade-off between disciplinary "depth" and interdisciplinary "breadth." However, this concern was overcome by creating a major with a broad "core" and a required in-depth "specialization." Three specialization areas are possible: math, science (biology, chemistry or physics) or technology. The major was approved by TCNJ's Board of Trustees in 1998 and subsequently as a disciplinary major for education majors by the NJ DOE in 2000. The MST major is one of several program offerings in the Department of Technological Studies within the School of Engineering. Other programs include a Technology/Pre-engineering education (T/PrEE) major and a Masters in the Art of Teaching (MAT). All majors are fully accredited by the National Council for Accreditation of Teacher Education (NCATE). All disciplinary major advising, recruiting and program requirements for the MST program are coordinated by the Department of Technological Studies, while education requirements and additional education advising are coordinated by the School of Education.

There are four works that set important context to the Department of Technological Studies curriculum, and the design of the MST program: (i) Benchmarks for Science Literacy ("Project 2061"), (ii) Technological Literacy Counts, (iii) Standards for Technological Literacy (STL) and (iv) Technically speaking- why all Americans need to know more about technology.⁹⁻¹² These documents discuss the important role of teacher preparation in meeting educational goals in math, science and technology. STL states that technological literacy is critically important for the general population, not just for STEM-oriented persons. A STEM teacher preparation program is consistent with this philosophy, bringing STEM skills to an important group; teachers of impressionable K-5(8) students.¹³

Program description

All MST majors have the same core requirements but every student must also choose and complete a specialization. There are three choices for specialization areas; math, science (biology, chemistry or physics) or technology, giving a total of five specific specializations. Taking four successive classes (2009-2012), totaling 125 students, an assessment of specialization indicated that the technology and math specializations were chosen most often, each comprising ~35% of the total. Science specializations were chosen by ~16% of the students, while 12% were undecided. Past experience indicates that the majority of the undecided will likely choose a technology specialization. Prior to the MST program, the only STEM majors chosen by K-5 students were mathematics and biology.

The MST major is a 32 unit (128 credits) baccalaureate degree with requirements generally

divided into three areas; (I) Liberal Studies, (II) MST Core Studies and (III) Professional Studies.

(I) Liberal Studies [10 units]

TCNJ has extensive liberal learning requirements that include history, arts & humanities, global studies, gender, race & ethnicity, community-engagement, a freshmen seminar experience, mid- and senior-level writing experiences, as well as requirements in science and quantitative reasoning.

(II) MST Core & Specialization [12 units]

The MST academic core consists of 8 units including Multimedia Design, Structures and Mechanisms, two additional science options, one additional math, two MST electives (fulfilled by taking M, S or T), and a course titled “Integrated MST for Young Learners.” The final four units are reserved for specialization courses.

(III) Professional Courses [10 units]

MST education majors at TCNJ meet New Jersey’s Certification requirements for a K-5 “highly qualified teacher.” Courses include several literacy/literature courses, psychology, math and science methods and a series of student teaching experiences.

The STEM requirements for the MST major are summarized in Table 1. The courses summarized in Table 1 consist of the core requirements required of all MST majors, including courses required for the specialization.

Table 1 STEM requirements for all MST majors

Math	2 courses: Calculus-A, MAT105 (Content for Elementary) [and MTT202 (Math methods for Elementary)]
Science	3 courses [and MST202 (Science methods for Elementary)]
T&E	5 courses: Creative Design, Multimedia Design, Structures & Mech., Engineering Math & Integrated-STEM for Young Learners
M/S/T Electives	2 courses: Can be math, science or technology (in support of Specialization and/or certifications)
Specialization	4 advanced courses determined by the chosen specialization. Specializations are (i) Math, (ii) biology, (iii) chemistry, (iv) Physics or (v) Technology

In New Jersey, MST majors can qualify for middle-school endorsements in math and science, and often complete these endorsements. A middle school endorsement has two requirements: (i) completing 15 credits (4 courses) of appropriate course work in the discipline and (ii) passing the appropriate content knowledge PraxisTM test. A K-12 endorsement in Technology Education is also possible for an MST major by possessing at least 30 specified credits in technology and passing the PraxisTM technology education test.

The MST program was designed to be structurally consistent with the K-12 technology education program. TCNJ’s technology education program has its roots in industrial

education, dating back to the 1930's. A major revision of the industrial education program was completed in 1985 when the “technology education” (TE) major was created with an emphasis on studying the human designed world. The program was revised again in 2005 with a “pre-engineering” emphasis (Technology/Pre-engineering Education, or T/PrEE), which integrates more math and science.

Program Growth & Gender

The MST program has experienced substantial growth. The MST program grew from 2 graduates in 2002 to 25 graduates in 2009. Current class sizes predict graduating class sizes in excess of 40 in the next few years. A high growth rate is a sign of a healthy program but also produces more STEM-trained teachers, an important and under-represented population for K-5.¹³ Previous to the MST program, non-STEM majors (Psychology, English, History ... etc.) comprised approximately 90% of the total, leaving historically 8-13% for the STEM majors of mathematics and biology.

The growth of the MST program, measured as a percentage of the total K-5 graduates, is shown in Figure 1. Also included in Figure 1 are the percentages for the other two STEM majors of math and biology. For the most recent 4 years, math and biology graduates have comprised approximately 6% and 2% of the total, respectively. From 2004 to 2009 the MST program grew from 5% to 20%. Current class sizes predict that the MST major will grow to ~30% in the next few years, resulting in a total STEM percentage of ~38% after adding in the historic numbers for math and biology majors. This level of STEM-trained K-5 teachers is 4-to-5 times higher than the near-term average of ~8% for math and science. A comparison of this level of STEM-trained teachers to a National average would be interesting but the authors could find no such statistics. Some states do not require a disciplinary major, and in states that do require a disciplinary major only the type of elementary certification appears to be tracked.

Figure 1 The number of biology, math and MST K-5 program graduates by year as a percentage of the total number of K-5 graduates.

While investigating growth rate, an interesting gender effect was discovered. The fraction of MST graduates that are male is quite high. Over the last 6 years the male percentage for MST program graduates has been a consistent 20-25% (see Figure 2), which is an approximately

5-fold increase over other TCNJ K-5 major averages and almost 3-fold higher than the 2001 national average for male K-5 teachers. For comparison, the fraction of non-MST K-5 majors at our institution that are male has been ~6% (see Figure 2). Also, at TCNJ the percentage of K-5 math and science graduates has been ~4% over the last 5 years. These non-MST averages at our institution are consistent with the stark drop in the national average of male K-5 teachers (in 2001 the male percentage was ~9%, down from ~18% in 1981).¹⁴ Investigations into the reasons for the higher male fraction have not been undertaken. However, it may be that males are attracted to the T&E components, a dominant effect in engineering schools across the USA.

Another gender effect has not been investigated directly but is surely very important. Not unlike most institutions offering K-5 teacher preparation programs, the MST graduates are mostly female (~75%). However, there is a substantial difference; female MST graduates are well versed in all areas of STEM, which should result in these teachers being effective role models for female K-5(8) students.¹⁵⁻¹⁶

Figure 2 Percentage of MST and non-MST program graduates that are male. [Data for male non-MST graduates for 2009 were not available at the time of writing this paper.]

Competencies in STEM, and non-STEM, components

In this section a characterization of competencies in science, mathematics and technology/engineering are presented, as are two non-STEM subjects of language arts and social studies.

(1) Math and Science

All K-5 teacher candidates in NJ are required to take the Elementary Education Content Knowledge test (test #0014), maintained and monitored by Educational Testing Service (ETS). ETS published a national summary for 2008-09 and a portion of the summary is reproduced in column (a) in Table 2. PraxisTM scores were manually collected from students starting in April-2002.¹⁷ The collection of these individual scores enables a more detailed statistical analysis than is possible by looking at the typical statistical parameters provided by ETS.

Table 2 Elementary Education Content Knowledge Praxis™ test (ETS test #0014) results for (a) the nation, (b) TCNJ non-MST students and (c) TCNJ MST program students

Parameter	(a) National Averages	(b) TCNJ Non-MST	(c) TCNJ MST
Test score range	100-200	100-200	100-200
# of examinees	92910	346	59
Median score	164	179	181
Ave. perform. (middle 50%)	151-176	169-184	174-187

Each category of TCNJ students performed well compared to the national averages. For example, the median Praxis™ score for TCNJ students was approximately 16% above the national average. (Note: the minimum possible score is 100.) Moreover, the middle 50% distribution of scores is substantially narrower for the TCNJ populations. For example, the 50%-width of the national distribution is 25 while the TCNJ distributions are 15 for the non-MST students and 13 for the MST students.

The total populations for the data were 346 non-MST majors and 59 MST majors. The MST population scored on the average of 180.3 on the Praxis™ with a standard deviation of 9.3 compared to the non-MST population that exhibited an average score of 176.3 with a 15% larger standard deviation of 11.0. A statistical significance “t-test” was completed using Microsoft Excel and indicated that the difference between the MST and non-MST populations is significant; for a 95% confidence level, $p = 0.003$.

Over the same timeframe, the subject-specific subscores in math, science, language arts and social studies for the Praxis™ test (#0014) were also collected enabling a detailed statistical analysis. The average test scores are shown in Table 3 for four K-5 major populations (non-MST, MST, Math and Science). Figure 3 shows a summary of the average Praxis™ subscore tests for MST graduates as a percentage, a percentage relative to the non-MST students.

Table 3 Elementary Education Content Knowledge Praxis™ subscore test results and standard deviations for 4 populations; Non-MST majors, MST majors, Math majors and Science majors. [Data are entered as (Average, Standard deviation).]

Population	Math	Science	Lang. Arts	Soc. Studies
Non-MST	25.5, 3.2	21.9, 3.2	25.9, 2.4	19.1, 3.0
MST	26.9, 2.7	23.6, 3.0	26.2, 2.4	18.9, 3.2
Math	28.3, 1.0	23.0, 3.5	27.2, 1.8	19.8, 3.9
Sci. (Bio.)	27.5, 1.7	23.5, 2.4	26.5, 1.7	19.8, 3.3

Figure 3 Content Knowledge Praxis™ subtest scores of MST graduates shown relative to non-MST graduates. (As an example, for the math subtest the MST population scored 5.5% higher than the non-MST population.)

A statistical significance test (t-test in Excel) was conducted for both the math and science subscore distributions between the MST and non-MST populations. This analysis indicated that the 5.5% and 7.8% differences (in Figure 3) were statistically significant (for 95% confidence levels); [math: $p = 0.004$; science: $p = 0.001$]. A statistical significance test (t-test) was conducted for the language arts and social studies subscore distributions and indicated that there was no significant difference. These data show that, compared to non-MST majors, MST graduates scored significantly higher in math and science competencies, while maintaining high competency on non-STEM subjects.

Other useful comparisons are scores in math and science amongst only the STEM majors (MST, biology and math). All of the STEM majors scored high on the math and science tests, within a few percent of each other. Perhaps as expected, the math majors scored highest on math but did not perform as well on science. Also, in the subject of science MST majors scored equivalently to science majors.

The average Grade Point Averages (GPAs) for MST and non-MST populations over the same time frame were 3.41 and 3.47, respectively. A statistical significance test concluded that this difference was not significant. These GPA data indicate that MST and non-MST majors are generally performing identical in their college course work. The combined verbal and quantitative Scholastic Aptitude Test (SAT) scores for the MST and non-MST populations were 1253 and 1194, respectively. Of the ~60 point difference in these scores about 42 points was due to higher scores on the quantitative portion of the test. This is not surprising due to the higher interest level in math and science for the MST population. Finally, scores on the math and science middle school Praxis™ exams for Spring-2009 also verified high competence for MST majors, with scores at or above the national median.

Of substantial importance to a teacher is low anxiety for the subject matter. Hence, low math anxiety is critically important for teaching math. In this work measurements of math anxiety were taken using the “Revised Mathematics Anxiety Survey” (R-MANX).^{18,19} The R-MANX survey consists of 30 questions with answers ranked from 1 (low anxiety) to 5 (high anxiety) on a Likert scale. Therefore, higher R-MANX scores correspond to higher math

anxiety. The minimum and maximum possible scores are 30 and 150, respectively. As a part of the instrument design there are seven questions that are negatively-coded, requiring correction in the arithmetic. Measurements were taken at four measurement points; before and after two math classes (MAT105 and MTT202). MAT105 is called “Math Structures & Algorithms for Educators-I.” MAT105 is a math “content” course and deals with the development of number systems, algebraic structures, and algorithms. MAT105 is not required of K-5 math majors, but is required for other K-5 majors. MTT202 is a “methods” course (mathematics pedagogy) for early childhood. A summary of math anxiety measurements is shown in Figure 4. These data show the average math anxiety levels for three populations; MST majors, K-5 Math majors and non-STEM majors. Table 3 shows the number of students in each population at the four measurement points. The non-STEM population consists of 6 separate populations- the K-5 majors of psychology, English, history, woman & gender studies, Spanish and social studies). Anxiety levels of two other non-STEM majors (art and music) were calculated but were not included in the weighted average since their total populations were small. The anxiety level of the non-STEM population was calculated as the weighted average of these 6 non-STEM groups.

Having chosen a rigorous math curriculum, the K-5 math major population serves as a good comparison since they should have a fairly low level of anxiety. The data in Figure 4 confirms this showing that K-5 math majors with the lowest anxiety levels (~65 both before and after MTT202). For non-STEM majors the anxiety level starts at a substantially higher level of 86 and decreases by ~7% to 80, indicating that this 2-course sequence does reduce the anxiety level. [A t-test, with a 95% confidence level, between the non-STEM population before MAT105 and after MTT202 gave a p-value of 0.003) indicating that there is a statistically significant difference.] However, this level is still 23% (80 vs. 65) above the anxiety level of the K-5 math major population. The anxiety level of the MST major population (pre-MAT105) starts significantly lower than the non-STEM major population (78 vs. 86). However, the anxiety level for the MST population decreases further to ~68 after MTT202. The results of t-tests on the post-MTT202 populations indicate that the differences in the average anxiety between the MST and non-STEM populations as well as between the Math and non-STEM populations are statistically significant. For example, for 95% confidence levels the p-value between the MST and non-STEM populations after MTT202 was 1.3×10^{-7} . A t-test was also run between the post-MTT202 Math and MST populations. After MTT202, the difference in anxiety levels between the MST and K-5 math major populations were only marginally statistically significant (for 95% confidence levels; $p=0.17$). These measurements indicate that the MST majors attain a level of math anxiety that is essentially equivalent to the K-5 math majors.

Previous work has shown that low math anxiety levels are also associated with low science levels.¹⁸ A similar result is expected with the MST majors, except in addition to low levels of math and science anxiety they should also have low levels of “T&E” anxiety, allowing them to comfortably execute active, hands-on and technically-rich lesson plans for both STEM and non-STEM subjects.

Table 3 The number of math anxiety measurements for three populations (MST, Math and non-STEM majors) taken before and after two math classes (MAT105 and MAT202).

Group	Pre105	Post105	Pre202	Post202
MST	24	22	51	56
Math	0	0	15	25
Non-STEM	205	203	169	206

Figure 4 Math anxiety levels (R-MANX instrument) of MST, math and non-STEM majors at four measurement points, before and after MAT105 and MAT202.

(2) Technology & Engineering

Coursework in the T- and E-components at TCNJ can be divided into three strands: (1) Human-designed world, (2) Mechanical and (3) Electrical. T&E coursework includes topics such as technological literacy, skills in modeling & making, creative design, human factors, structures, mechanisms, analog & digital electronics, materials, industrial design, graphics design, architectural design, bio-technology, as well as the science and math required for basic design. The original MST-program proposal also included a course to reinforce the importance of integrated-STEM teaching. This course is called “Integrated-STEM for Young Learners” and is required for all MST and T/PrEE majors. MST majors acquire experience and comfort with T&E content, enabling them to more easily, and more frequently, integrate activeness, inquiry and context into learning experiences. As stated in the Standards for Technological Literacy (STL, p. 7), “... the study of technology is a way to apply and integrate knowledge from many other subjects- not just mathematics, science, and computer science classes, but also the liberal and fine arts.”¹¹

Another potentially valuable aspect of the T&E courses is that important time is spent on investigating how to effectively teach STEM, and non-STEM, concepts with T&E-based activities. The T&E professors are acutely aware that their students are future teachers, not engineers or scientists. This additional educational element is not part of other teacher preparation programs. This element is similar to, but certainly not the same as, “methods” classes which have beneficial effects.²⁰

Simply having substantial T&E content in an undergraduate K-5 program is itself unique but the question remains of how to assess competency in T&E for MST majors. The fields of math and science education have established methods to measure content knowledge (i.e.- PraxisTM tests). However, there is no such evaluation for K-5 teacher T&E content knowledge.

In this paper it is proposed that because the MST program is using the same courses as an existing NCATE accredited Technology Education program, that an analysis of the T&E courses taken by MST majors is sufficient to give good quantification of T&E competence. Competencies in T&E of MST majors are characterized in this paper by looking at three items: (i) a mapping of the T&E curricula onto the Standards for Technological Literacy (STL), (ii) an analysis of grades of MST majors, compared head-to-head with T/PrEE majors in the same courses and (iii) performance on the technology education PraxisTM exam by a few MST majors. Mapping the T&E curricula onto the STL quantifies the level of T&E exposure while an evaluation of grades indicates if T&E content is being learned. Performance on the Technology Education PraxisTM test gives an external measure of T&E content knowledge.

(i) Mapping T&E content onto STL.

Our T/PrEE program produces 10-15 graduates per year and, in order to teach, they must pass the technology education PraxisTM (ETS #0050). Analyses of the institutional reports provided by ETS over the last four years indicate that our T/PrEE graduates score 30-40 points above the median. Moreover, the width of the distribution, as measured by the total range of scores, of our technology education graduates has been one-half to one-third that of the national average. Assuming that our framework of T&E courses is a major contributor to the PraxisTM scores as well as to the overall success of our technology education graduates in technology teaching positions, and that the PraxisTM scores represent a measure of T&E competence then the level of exposure that MST majors get to the T&E course work would be a good indicator of T&E competence. The level of exposure depends on the MST student's specialization: (i) math and science, or (ii) technology. MST majors with a math or science specialization complete a minimum of five T&E courses (20 cr.). MST majors with a technology specialization complete approximately nine T&E courses (36 cr). Common additional courses include Engineering Design, Analog Circuits & Devices, Digital Electronics, Environmental and Biotechnical Systems and Architectural & Civil Engineering Design and Facilities Design & Management. Our technology education majors take approximately 16 T&E courses (64 cr.). In summary then, math and science specialization MST graduates take 32% of the T&E course load of a T/PrEE major, while technology specialization students take approximately 56%. This number of courses represents a high level of T&E content, especially considering that typical K-5 teacher preparation programs require no T&E content, no "integrated-STEM" educational content and only minimal math or science. Statistics available on the U.S. Department of Education's Institute of Education Sciences (IES) website for National Center for Education Statistics (NCES) shows that an education major graduate in 1992-93, the most recent year that data was available, completed an average number of 6.3, 10.4 and 0.3 semester credits in math, science and engineering, respectively. An MST major compares very well with these figures because they complete at least 16 credits in math, 16 credits in science and 20 credits in T&E.

The content of the T&E course load is better quantified by mapping it onto the STL. The STL consist of twenty standards organized into five categories. Benchmarks are given for each of the twenty standards for four age groups; K-2, 3-5, 6-8 and 9-12. There are 101 benchmarks for grades K-5 and another 85 benchmarks for grades 6-8. Keeping in mind that there are two MST populations with differing T&E content, Figure 5 shows the results of the mapping for grades K-2, 3-5 and 6-8.

Figure 5 A mapping of TCNJ's T&E curriculum onto Standards for Technological Literacy for the two specialization groups of (a) math or science and (b) technology.

This mapping indicates that, except for the 5th category, the math and science specializations have 80-100% coverage for grades K-5, while the Technology specialization has 90-100% coverage. The 5th category of standards includes benchmarks for 7 very specific technologies. The breadth of the MST program does not allow coverage of all of these technologies. In the 5th category, the MST program coverage is at the 60-70% level for math and science specializations, and above 80% for technology specializations.

(ii) Grades in T&E courses.

In the previous section, it was shown that MST majors are exposed to most of the T&E

content suggested by the STL. However, are MST students learning T&E content? For example, it may be that MST students are taking T&E courses but are struggling, receiving low grades indicating a lower level of learning. The analysis presented here shows that MST majors, compared head-to-head to T/PrEE students in the same T&E classes, achieve grades that are actually equal to or higher than T/PrEE students. In essence, we use the T/PrEE students as a standard to be compared to, which given the history of good performance of the T/PrEE majors, seems a valid comparison.

Individual assessment data from a 3-year period (Fall-2006 to Spring-2009) for four core and three elective T&E courses were collected. The four core courses were: Creative Design, Structures & Mechanisms, Integrated-STEM for Young Learners and Engineering Math. The three elective core courses were: Civil and Architectural Engineering, Analog Electronics and Digital Electronics. These data represent more than 200 MST student grades. For the core courses the MST students scored between 1% and 4% higher than T/PrEE students on individual assessments. For the three elective courses the MST students scored between 2% and 20% higher than T/PrEE students on individual assessments.

An analysis of grades over a three year period for a lab-intensive materials processing class produced the same result; MST grades for individual assignments were on par, or better, than T/PrEE students. This result was counterintuitive because MST majors start the program with clearly weaker skills and lower comfort with laboratory tools. However, MST students tend not to hesitate in asking for help in understanding a process. A T/PrEE student is often the one providing the help, which also benefits the T/PrEE students since he/she gathers educational experiences in providing this help.

In summary, MST students are not simply passing T&E courses but are actually performing on par or better than the TE students. This is a strong indication that MST students are learning substantial T&E content.

(iii) Technology Education PraxisTM results.

Approximately 15% of technology specialization MST students choose to obtain a Technology Education endorsement, which requires passing the TE PraxisTM. The TE PraxisTM scores for three MST majors were obtained and were between 630-640. These scores were within the national average performance range of ~620-680. These external data also suggest that MST graduates are learning substantial T&E content.

Discussion

(1) The T&E in integrated-STEM Teaching

The MST curriculum includes a substantial amount of course work in math and science, perhaps more than some K-5 teacher preparation programs. However, the inclusion of a substantial amount of T&E experiences is a unique aspect of the MST program. In this section we discuss the potential benefit that such an emphasis has on our future teachers and their K-5 students.

When substantial T&E skills, as well as science and math skills, are acquired by a teacher then the four components of STEM can be played off each other resulting in more effective

teaching and better learning. Hence, the inclusion of T&E skills results in a highly synergistic, catalyst-like action in the classroom. This breadth of STEM skills is particularly well-matched for K-5 teachers since they teach multiple subjects to one group of students. T&E courses involve a high level of hands-on skills and activities, which are utilized frequently in K-5. Additionally, having a full arsenal of STEM skills and experiences will also be very valuable in teaching non-STEM subjects. Non-STEM subjects (i.e.- language arts, social studies ... etc.) often have strong connections to STEM. The maturation level of STEM knowledge for mankind has impacted all aspects of human endeavors including art, history, philosophy and social sciences.

One way to demonstrate the impact of the T&E content is to describe how this content potentially impacts Darling-Hammond's qualities of effective teachers. Below are abbreviated descriptions (as headers) of Darling-Hammond's five qualities followed by the potential impact of the T&E content on that quality.

(i) Strong general intelligence; verbal & organization ability; observe, & think diagnostically:

If SAT scores are a measure of high general intelligence then the MST population have high general intelligence. (MST population has verbal and quantitative scores of 610 & 643, respectively.) T&E courses include a good level of communication- and organizational-intensive activities including designing, teaming, presentations, and writing. In general T&E courses contain a large number of team projects used for a variety of design and non-design oriented activities. To perform well on these team projects takes a good level of communications and organizational capabilities. Also, summaries and/or evaluations of projects are often detailed presentations or extensive written reports. Presentations give verbal communications experiences in front of audiences, simulating teaching. Presentations are expected to be professional and effective for the given audience. Writing effectiveness is important and our institution has expectations for mid- and senior-level writing experiences. For example, our T&E course "Structures & Mechanisms" is considered one of the institution's mid-level writing courses. Lastly, since our T&E courses put a large emphasis on using the design process effectively our students get a rich level of experiences with diagnostic thinking.

(ii) Strong content knowledge:

In K-5 the breadth of subjects taught is broad, including the classic 3-R's (Reading, wRiting and aRithmetic), but also science, T&E and social studies. The data presented in this paper indicate that MST majors have in-depth knowledge in all of these areas allowing him/her to not only teach each individual subject effectively but also to tie subjects together in practical and effective ways. For example, in K-5 classrooms science often gets the least attention, if any attention at all. However, many of our MST graduates find imaginative ways of bringing science, math and/or T&E content into social studies or language arts activities. This not only enables additional important content to be covered but it puts the content into a valuable practical context.

(iii) Content pedagogy, hands-on skills & higher order thinking skills:

Content in non-STEM content pedagogy, for example reading, is taught in professional courses. Also, content pedagogy courses are required for math and science (MTT202 and MST202). There is no required course in technology content pedagogy for MST majors. T&E courses give a very high level of experiences with hands-on skills, likely much more than any other K-5 teacher preparation program in the USA. Working with a variety of materials and processes are certainly a central focus of T&E courses. The (iterative) design process itself is studied formally, but the design process is also experienced through several design experiences. These T&E activities directly call for higher order thinking skills. The six levels of Bloom's taxonomy of learning are (i) Knowledge, (ii) Comprehension, (iii) Application, (iv) Analysis, (v) Synthesis and (vi) Evaluation.²¹ Having students work with open-ended design processes calls for all of these levels, but especially the four higher levels. For example, the design process directly calls for "testing and evaluation."

(iv) Learning processes (scaffolding, learning differences):

Understanding learning processes is important for any effective teachers. Effective use of "scaffolding" as well as an understanding of Gardner's 7 intelligences is important.²² Experiences with the T&E courses emphasize all of these important learning processes but are especially effective at "Visual-Spatial," "Bodily-kinesthetic," and "Interpersonal" intelligences due to the high level of hands-on activities and teaming. Visual-spatial learning is quite extensive in the required Structures & Mechanisms course. In this course the students are required to design and build a simple mechanism, typically an Automata toy. Students often have a need for a moving part (like a gear or a cam) at a specific point in space but often do not know exactly how to implement the structure to place the mechanism in that particular point in space. Activities like these expose our students to a large level of visual-spatial experiences. With the addition of engineering rigor, several of the T&E courses also call on "Logical-Mathematical" intelligence. Linguistic intelligence is called for frequently in multimedia experiences and presentations.

(v) Adaptive expertise:

One of Darling-Hammond's points is the ability to "think quickly on ones feet." Another point is for a teacher to treat his/her teaching environment as a design process, making constant judgments on how to beneficially affect the learning process. Recent work has discussed this viewpoint of looking at teaching and teacher preparation as a iterative optimization (design) process.^{20,23} An MST major likely has substantial capability in "thinking quickly on their feet" as well as adaptive teaching because they have a broad level of content knowledge, substantial exposure to the design process and are exposed to the concept of treating teaching as a design process.

In closing, several MST students have given detailed accounts of their student teaching experiences where they were able to integrate STEM experiences into the classroom. Some of the more interesting examples involved the cooperating teachers allowing the MST student teacher to organize and deliver science lessons, even though the school policy was not to give science lessons but rather to focus on Reading, wRiting and aRithmetic.

(2) Informal learning environment

This paper has focused on a description of the MST program and the resulting content knowledge and anxiety levels of MST majors. However, it may also be important to recognize the potential benefit of an informal learning environment that has established itself over time. The informal learning environment can be divided into two categories: (i) professional activities and (ii) diverse coexisting programs/populations.

(i) Professional activities:

An important source of STEM knowledge/experience for MST majors comes from a large amount of professional activities occurring outside of courses. The Department has a very active professional calendar which includes: (a) hosting an annual all-day professional conference with formal talks and workshops (typical attendance is ~80 professionals, many of which are former graduates), (b) hosting bi-monthly professional workshops, (c) annual trips to the eastern regional Technology Educators Collegiate Association (TECA) conference/competition, (d) hosting an annual robotics competition and workshop, (e) hosting the annual Technology Student Association (TSA) state-wide competitions, (f) hosting ~80 local high school students for an annual “Junior/Senior Design Challenge” as well as numerous activities organized by our Department’s Technology Education Students (TES) organization. Collectively, these events give MST majors a level of professional STEM experiences that is a substantial addition compared to typical K-5 programs.

(ii) Diverse coexisting programs/populations

At TCNJ there are two important populations that interact in significant ways with the MST population; (i) the Engineering School students and staff and the (ii) T/PrEE majors. Being housed in the School of Engineering certainly gives a strong technology focus to the environment. By example, the School of engineering has recently been considering substantial additions to our facility. This is a current and real architectural design problem, one that became a modeling assignment for MST and T/PrEE majors. The resulting models were not only good educational projects but also helped the faculty consider certain options.

By far, the T/PrEE major population interacts the most with MST majors. The MST and T/PrEE programs have had several positive impacts on each other. One important and desirable result is that T/PrEE & MST students receive a better understanding of the teaching skills required for a broader age range. MST majors are passionate about teaching K-5, while the T/PrEE majors are highly interested in learning skills for grades 7-12. This difference in intended age-range of students leads to fruitful interactions in a variety of formal and informal settings, giving both populations more skills and experiences. These experiences prepare each group to be better teachers, and for broader roles in their school districts. A second effect concerns academics. MST majors in general tend to be more skilled in classic academic tasks like writing, research and organization. This has a beneficial effect since, through interaction with MST majors, T/PrEE majors can improve their skills in these areas. There is also give-and-take here because the T/PrEE majors have more skill and comfort with hands-on materials processing, so MST majors benefit by interacting with T/PrEE majors on these tasks. A third effect deals with pedagogy. T/PrEE students, especially early in their program, are more interested in the technological aspects of

their training. In contrast, as entering freshmen MST students are interested in how to teach. MST students also have professional training earlier in their programs so, in subsequent interactions, MST students can positively influence T/PrEE students with pedagogical concepts. A fourth effect deals with gender. T/PrEE majors are primarily male while MST majors are primarily female. This has led to substantial social interaction. For example, the technology education student group organizes both a “Welcoming Picnic” in the Fall, with particular attention to incoming freshman, as well as a Spring “Semi-formal Dinner Dance.” Additionally, MST participation in a (secondary-level) Technology Education-dominated regional TECA conference is increasing sharply, due to both professional and social forces. MST and T/PrEE majors interact at a significant level throughout the course of an average school week. In the last few years the level of social interaction has increased significantly, perhaps due to the MST population growing to a critical mass. This informal “out-of-the-classroom” learning environment likely increases the content and practical knowledge of both student populations. The gender diversity between the T/PrEE and MST populations also likely results in a higher awareness and expectation of vibrant female role models in STEM-education.

Summary

In this paper, it has been demonstrated that the multidisciplinary MST program has been successful both in terms of growth and content knowledge. The MST program should be particularly well-suited in today’s educational environment that loses substantial students in STEM trained areas, scores low on quantitative literacy²⁴ and would likely score low on technological literacy. Even with the breadth of the multidisciplinary program, MST graduates scored significantly higher in National PraxisTM tests for both math and science, compared to non-MST graduates, while also scoring equivalently high on non-STEM subjects. Graduates also demonstrate high skills in T&E content, content that has substantial overlap with both the teaching skills required for K-5(8) and with the standards for technological literacy. With extensive training and experience in all areas of STEM and integrated-STEM concepts, MST graduates are well prepared to thoroughly engage students in STEM and MST majors, while also scoring equivalently high on non-STEM subjects. non-STEM subjects.

By means of summary we believe there are five key attributes of the MST major:

(i) Breadth through STEM: Through its multidisciplinary nature, the MST program offers a broad, and high quality, skills set that closely matches the broad skills needed in a K-5 classroom. Important skills include the individual STEM fields, integrated-STEM, language arts and social studies. The T&E portion of the MST program is of special importance because it brings a catalyst-like action via a large breadth in content knowledge (in all areas of STEM) and context-setting capabilities for all subjects. Real-world applications of the STEM fields (i.e. technology) are powerful motivators in the classroom. Also, the T&E content has a large overlap with often under-utilized aspects of both Bloom’s taxonomy and Gardner’s multiple intelligences, resulting in a deeper learning.

(ii) Attractive to students: The growth of the program indicates that the MST major is

an attractive major, resulting in the production of substantially more STEM-capable teachers.

(iii) Integrated-STEM: The acronym “STEM” is too often interpreted as its individual components; the S, T, E or M. For example, a chemist would correctly state that she focuses on the S of STEM and therefore does “STEM.” However, at all educational levels, but perhaps more importantly in the younger years, the inter-relationships between the four elements of STEM is of vital importance. For example, how does a teacher motivate, and therefore excite, a student about chemistry? An effective method would involve defining active ways of experiencing chemistry, demonstrating how chemistry is interesting and has a substantial impact on the student’s life. MST graduates have substantial experiences with the inter-relationship of the four STEM disciplines. For example, using T&E skills in designing & making to bring important activeness and context to lessons for both STEM and non-STEM subjects. Also, a key task for teachers, designing lesson plans, is itself an excellent exercise in design.

(iv) Teacher modeling: Contrary to major content courses in more conventional teacher preparation programs, the T&E courses teach content knowing that the audience is made up of future teachers. Hence, the context often has an important educational attribute. This “teaching context” does not exist to the same extent in many teacher preparation programs (i.e.- science professors teach science, not how to teach science).

(v) Gender benefits: The primarily female MST population provides a strong female presence in all areas of STEM in K-5(8). This results in several benefits but will certainly give positive STEM role models for female K-5(8) students. Additionally, compared to other majors, the MST major graduates a substantially higher fraction of males (~25% vs. ~6% at TCNJ) resulting in a higher male representation in the K-5(8) school environment, counteracting a trend of decreasing male teachers.

As mentioned earlier, the representation of STEM-trained teachers is low in K-5. Therefore, programs that can substantially increase the number of STEM-trained K-5 teachers should have a beneficial impact on K-5(8) student outcomes, resulting in higher skills and interest in STEM subjects. The MST program has increased the fraction of graduating STEM-trained K-5 teachers by ~3-fold in the last 5 years. If an MST program is, by its nature, more attractive to students then initiating such programs across the USA would increase the number of STEM-trained K-5 teachers on the national level, resulting in a higher number of K-5 (and eventually 8-20⁺) students interested in STEM fields. Also, having more STEM-capable teachers (and we mean the M, S and T&E) should result in a higher level of technological and quantitative literacy in K-5 (and eventually 8-20⁺) students which is of paramount importance in our ever-increasing technology-driven, democratic society.

Future research surrounding the MST program and its graduates could perhaps be divided into the following three categories: (i) “internal” studies of teaching qualities/capabilities of MST students/graduates, (ii) “external” studies of the effects of MST graduates on their environment (fellow teachers, administrators, policy and certainly K-5(8) students themselves) and (iii) institutional/governmental limitations for implementing MST-like

programs.

Internal “programmatic” studies of the MST program are important in and of themselves but are also a relatively time- and cost-efficient methods of quantifying likely benefits to K-5(8) students. Studies of MST students and their capabilities/qualities can be completed in timeframes measured in months, as opposed to longitudinal studies of K-5 students that may take years. One interesting internal point in time to study would be during MST student teaching experiences. Anecdotal data obtained from direct conversations with MST students after these experiences indicate that interesting STEM activities are being undertaken. The ultimate, and direct, measure MST graduates’ capabilities would be to measure the effects of MST-trained teachers on K-5(8) students, perhaps through test scores and/or interest-levels in STEM fields. Lastly, both institutional and governmental structures and policies can be limiting. For example, even if an institution feels they have enough data to implement an MST or MST-like program there still may be substantial institutional and/or governmental limitations standing in their way. By example, in New Jersey a disciplinary major is required of K-5 education majors, which administratively allows a quick definition of a new, and in this case, multidisciplinary major. In States that do not have a disciplinary major requirement how could curricular requirements in all areas of STEM be best accomplished? Such questions also lead quickly to the question of how much and what type of T&E capability would be optimum, and how institutions without technology education departments could offer T&E content. Investigations and research into innovative methods around these barriers should prove fruitful, and have obvious implications on T&E standards in K-12.

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