BUILDING BRIDGES: INTEGRATING MATHEMATICS, ENGINEERING, AND SCIENCE ON THE SOUTH PLAINS

PROJECT DESCRIPTION

Introduction: There is a strong national and international interest in promoting interaction between university research-oriented mathematics, engineering, and science departments with Colleges of Education in the development of cross-disciplinary STEM education activities throughout the entire education infrastructure. Dr. Arden L. Bement, Jr., Director of the National Science Foundation, in testimony before the House of Representatives, has recently stressed the need for integrative STEM curricula. Indeed, NSF has provided funding for the development of integrated math/science/technology curricula for more than fifteen years. In a review of the efficacy of integrated STEM curricula, Wicklein and Shell determined that "after a careful examination of each of the pilot demonstration schools, three primary factors were identified that significantly affected the success or failure of the multidisciplinary curriculum: (1) teacher and administration commitment to the integration approach, (2) innovation and effort in curriculum re-design, (3) administration and teachers coordination of the integration plan. Each of these factors is of paramount importance in creating the type of integrated curriculum that will help students learn, apply, and transfer learning beyond the classroom environment."

The vision and overall theme of this GK-12 program is the development of deep thinking about the integration of mathematics, science, and engineering by STEM research graduate students. During this process, the GK-12 program will provide a vehicle for STEM graduate students to 1) teach in a K-12 environment through the Lubbock Independent School District (LISD) in a manner reflective of their increasing sophistication concerning the connection between math, science, and engineering as a tool for effective STEM education, 2) develop communication skills through dialogue with K-12 teachers regarding the ties between math and science in effective STEM education, and 3) produce through group teamwork an integrated math/engineering/science curricula to improve K-12 STEM education.

The College of Arts and Sciences, the College of Engineering, and the College of Education at Texas Tech University (TTU) in Lubbock, TX have been partners for more than a decade in a variety of ongoing Science, Technology, Engineering, and Mathematics (STEM) programs with a strong commitment to K-12 activities. Examples of K-12 projects with major STEM and College of Education involvement include, among others: The Texas-Wide T-STEM Center Initiative, CISER (Center for the Integration of Science Education and Research), Science: It’s a Girl Thing, Service Learning in Science Teaching, Emmy Noether Mathematics Day, Endowment for Mathematics Teachers, TexPREP, Summer Mathematics Academy, Teaching College Mathematics in High School, Institute for the Enhancement of Advanced Learners (IDEAL), Project SERVE (Science Education using Retired Volunteer Educators), and Shake Hands With Your Future. The proposal described here is a natural outgrowth of dialogues between the three colleges that have occurred via collaborative experiences throughout the years.

Results From Prior NSF Support Texas Tech University has not received an NSF GK-12 Award within the past five years.

Goals and Objectives The main goal of this program is to prepare doctoral-level STEM researchers and in-service secondary mathematics and science teachers to thrive in an interdisciplinary environment through the development of novel Mathematics, Engineering, and Science Bridge Quartets (MESBQs). The MESBQ participants will engage in 1) Dissemination and promotion of the research activities of the GK-12 graduate students, 2) Tailored professional development experiences for both Fellows and teachers; 3) Community building between
mathematics, engineering, and science Fellows, between mathematics and science teachers, and between Fellows and teachers; 4) Opportunities for graduate-level development in pedagogy through course work; 5) Collaborative design and implementation of integrated mathematics, engineering, and science curriculum; and 6) Manuscript productions suitable for publication in STEM-based education (e.g., the Journal of Chemical Education), National Science Teachers Association, and National Council of Teachers of Mathematics journals, 7) Development of cyber-enabled dissemination platforms for statewide outreach using our T-STEM and Three Rivers Foundation partners.

The project’s objectives are:

- To provide research-based, education-related, communication-building experiences and knowledge for graduate students in mathematics and the sciences through partnering with other STEM Graduate Fellows and with K-12 science and mathematics teachers.
- To foster the relationship between mathematics, engineering, and science through the development of mathematics-engineering-science bridge quartets (MESBQs).
- To develop new contexts, connections, and experiences for thinking about teaching in secondary (grades 9-12) environments, focusing on the integration of mathematics, engineering, science and education.
- To provide professional development and enhanced science/engineering and mathematics content knowledge for practicing teachers.
- To provide enhanced learning experiences for secondary students.
- To develop collaborative links with several West Texas school districts using the Texas Tech-based T-STEM Center and CISER as points of dissemination.
- To establish distance learning environments involving remote rural schools using T-STEM as a platform.
- To foster increased collaboration between STEM departments and the College of Education at Texas Tech University.
- To create environments which support the advancement of scientific/engineering and mathematical learning.
- To research how experiential, situated learning via MESBQs influence participants’ understandings, communication, and implementation of their own instruction and research.
- To provide a unique experience of how mathematics/engineering/science are applied outside academia and also broaden the horizon beyond what is usually presented in graduate education.

The primary purpose of the program will be to create opportunities for STEM graduate students to experience and develop their communication skills with fellow STEM researchers in other disciplines and with K-12 schools. This will be accomplished through the formation of MESB quartets (two Fellows and two teachers) and through the quartets’ development and enactment of mathematics-engineering-science, inquiry-based curriculum modules at the secondary level. Teachers and Fellows will attend professional development institutes and Fellows will take two specialized graduate courses (one in education and one in applied mathematics). All members of the quartet will meet on a regular basis to explore the relationships between mathematics, engineering, and science fostered through the development of mathematics-engineering-science, inquiry-based curriculum modules. In a unique addition, education researchers will assess program components, and track the development of participants’ scientific and mathematical reasoning and progress of participants’ integrated curricular design. Teachers will follow up with dissemination of their expertise among their colleagues. Details of each of these activities are included in later sections.
Project Plan: (i) The Mathematics-Engineering-Science Bridge Quartet: It is hypothesized that strengthening the relationship between mathematics and science/engineering will result in stronger, more cohesive education and research venues. There are three components to our action plan. The first involves placing the GK-12 fellows during the academic year in the K-12 classroom setting, the second employs the GK-12 Fellows as both teachers and students during the summer, while the third places in-service teachers in interdisciplinary research labs after the first two years of the program. These three components are outlined below.

Academic Year: The interdisciplinary relationships between the sciences and mathematics described above have prompted us to attempt to model action groups based on cognitive tetrads that we are naming "math-engineering-science bridge quartets" (MESBQs). A schematic diagram of a typical quartet that is being proposed is shown in Figure 1. In this model, each of the science teachers involved will partner with a mathematics teacher from their home institution with whom they can interact on a regular basis. One pair of GK-12 Science/Engineering and GK-12 Mathematics Fellows will then be partnered with a corresponding pair of science and mathematics teachers.

The Fellows will spend ten hours each week in the classroom sharing their research experience and excitement with the students and co-teaching with the mathematics and science teachers. Five additional hours per week will be spent in preparation and discussion with teachers. There will also be time spent as a consultant for teachers or students on a range of mathematical and scientific issues. The GK-12 Science/Engineering Fellow will help fortify the content knowledge of the science teacher, and the Math Fellow will help fortify the content knowledge of the mathematics teacher. The science and math teachers, on the other hand, will provide pedagogical training for the Science/Engineering and Mathematics Fellows. All four members of the quartet will meet on a regular basis (two times per month) to explore the interactions and relationships between mathematics and science through the continued development of mathematics-science-engineering inquiry-based curriculum modules for use by the K-12 students. While engaged in the K-12 classroom, the Fellows will also take two courses, one through the TTU College of Education entitled Designing Interdisciplinary Project-Enhanced Environments in Mathematics/Science Classrooms (EDCI 5373), and the second through the Department of Mathematics and Statistics called Industrial Mathematics (Math 5346). The EDCI 5373 course emphasizes the contents, technology, instructional strategies, and assessments necessary in designing and developing a research-based, interdisciplinary, project-enhanced environment. The role of this course is to give students the opportunity to experience, evaluate, and design interdisciplinary, project-enhanced environments within mathematics and/or science classrooms. The interdisciplinary topic within MATH 5346 concerns the application of mathematical and computational techniques to industrial problems and employs the philosophy of “here is a problem, use mathematics to solve it” rather than “here is the mathematics, use it to solve the problem”.

The principal theme of the interaction, research, and teaching base for this program must satisfy national standards\(^4\)\(^-\)\(^6\) as well as the statewide Texas Essential Knowledge and Skills (TEKS) set. A key partner in teacher recruitment and in the distribution of the MESBQ curriculum modules is the West Texas T-STEM Center which is based in the College of Engineering at Texas Tech. T-STEM is part of a State of Texas initiative designed to motivate
and prepare more K-12 students for careers in science, technology, engineering and mathematics using an engineering design approach. This center is connected to over 200 school districts around the state, and is developing distance education platforms that we will employ for one of the MESB quartets and later for distribution to their K-12 client base.

In order to visualize our program’s developmental and recursive stages, we created a concept map of the Building Bridges program shown in Figure 2. The initial stage involves the collaboration of participating STEM faculty, the GK-12 Educational Researchers (from the College of Education), the participating K-12 schools, T-STEM, and the Garrison Center (*vide infra*). Recruitment and selection of the Fellows by participating STEM faculty and the recruitment and selection of K-12 teachers using T-STEM as a nexus will occur during developmental stage two (see Figure 2). Stage two will also involve the formation of the MESB quartets where Fellows and teachers will be carefully grouped (by STEM faculty and participating school administrators) in order to provide diverse and balanced strengths and expertise within each quartet. Developmental stage three highlights the MESB Quartets’ responsibilities during the academic year and summer. As stated earlier, the Fellows will spend approximately ten hours per week within the K-12 school teaching and co-teaching. In addition to this, Fellows will be expected to meet with their K-12 teachers for additional module development for five more hours each week. The teachers will be invited to participate and present results at a series of seminars on their experiences in using the modules in classroom explorations. Such seminars will educate Fellows and TTU STEM faculty on the importance of integrating mathematics, engineering and science education. In order to reinforce the content knowledge of the in-service teachers, after the second summer, each teacher will be provided the opportunity to work with the Fellow’s research mentor’s research group on an interdisciplinary mathematics/science or engineering research project designed by the Fellow. Other MESB Quartet responsibilities will be to attend and present materials during summer institutes and during a final year summer conference. Throughout all of these stages, researchers from the College of Education will study the proposed Mathematics/Science/Engineering GK-12 program with specific focus on the MESB Quartets’ progress and development.

Each MESBQ will have an assigned faculty advisor from the STEM PI and Senior Personnel pool. The faculty advisor will oversee curriculum module development and act as a liaison between the Fellows and their faculty colleagues. This is necessary in order to preempt any conflict over the Fellows GK-12 role and their regular graduate student assignments.

Four MESBQs will operate during each year of the grant. Three of the quartets each year will be supported by NSF funds. *As a measure of institutional commitment to this program, funding for one of the Fellows each year (two during the first year) will be supported by the Graduate School and the Vice President for Research at Texas Tech University. The College of Engineering will provide $12,500 each year to support mentoring by the previous year’s graduate student cohort during the summer institutes, while the College of Arts and Sciences will provide $12,500 for materials and supplies for the institutes and module development. Three quartets each year will assume a direct, face-to-face role with an LISD K-12 institution. One
quartet during each of the five years will work with an LISD partner school primarily using
distance delivery platforms provided through partnership with the T-STEM Center. They will
make extensive use of distance learning facilities such as ITV links (available at the partnering
schools) and the Internet. The inclusion of the pilot remote learning component affords the
opportunity to test this novel approach, as the experience will be entirely different from that of
the face-to-face fellows. This also matches a key objective of the GK-12 program in that it
prepares future STEM faculty to deliver online and ITV courses and institutes. This facility is
becoming more important in the role of all educators in the 21st century and most especially
those entering careers in more remote geographical regions.

Summer: The summer programs will involve two week-long summer institutes and one
intersession for each of the first four summers of the funded grant prior to the start of the K-12
academic year. A final culminating conference will take place during the fifth summer. Summer
institutes will occur during the first and last weeks of June with a two-week intersession during
weeks two and three of June.

Both Fellows and teachers will participate in a week-long institute during the first week
of June. Mornings will be spent with STEM faculty, beginning with a discussion of learning
topics related to STEM integration and pedagogy. The second half of the morning will be spent
in experiencing integrated STEM modules that have been previously developed by the STEM
faculty. An example of such an integrated module (math/engineering) concerns signals and
periodic waves. Fellows and teachers will engage in an activity designed to bridge the ideas of
triangle trigonometric ratios to the graphs of sinusoidal curves, which will lead to participants’
understanding of frequency, period, amplitude, and wavelength concepts. Various software that
aid learners’ understanding about waves and sound waves will also be incorporated. An
interactive simulation software package that allows participants to explore superposition of
waves, standing and running waves, normal modes, and the influence of boundary conditions
will be used. Fellows and teachers will use sound probeware to examine waveforms and
periodic functions. The sound probeware allows for the examination of sound intensity, beats,
and waveforms created from voice or musical instruments. Real-time data will be collected, and
the resulting waveform will be shown as an oscilloscope display with its associated fast Fourier

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Table 1 – First-Week June Institutes

transform (FFT). Students will analyze the sinusoidal waveforms with different frequencies
(shown in FFT), amplitudes, and phases whose superposition created the waveform of the
physical sound.

In the afternoons of this first week of the summer institute, participants will work in their
MESB Quartets in a research capacity to begin the development of their own integrated STEM
curriculum modules. The Fellows will work with the teachers to develop modules that are based on the mathematics and research interests of the Fellows. Not only will this allow for integration of math/science/engineering to permeate into the K-12 curriculum, it will also provide the K-12 students with access to cutting-edge problems in the STEM discipline. One example of a possible summer research project for an MESBQ team which is of interest to a range of faculty in the STEM disciplines at Texas Tech is the development of applications of technology for persons who are aging or suffering from physical or cognitive disabilities. Several collaborative research projects between faculty in the College of Engineering and researchers affiliated with the Garrison Institute for Healthy Aging (a partnering agency housed at the Texas Tech Health Sciences Center) are focused on addressing problems associated with aging. Among these projects are: determination of EEG (brain wave) patterns in patients with dementia and normal age-matched controls, manipulation of cell membranes with electrical pulses, development of devices to detect falls, and humanoid robotics. Additional work that is planned includes the application of smart sensors and wireless data transmission to problems associated with aging. These sensor systems can be used to instrument and environment - such as cameras to detect unusual motion or behavior; or to monitor the individual – such as continuous monitoring of blood oxygenation levels in persons with pulmonary problems. Projects of this type provide a complete integration of several important math-science-engineering concepts. As an example, consider the fall detection. Students must first understand the concept of acceleration due to gravity (a physics concept) and how falling (and crashing) represents a significant change from the normal and static acceleration due to gravity. Relationships between position, velocity, acceleration, and the rate of change of acceleration can be determined via simple derivatives – by measuring the different quantities, students can get a physical interpretation of the mathematical concept of the derivative. Finally, the probes and sensors, which typically rely on basic physics concepts, must be integrated with an appropriate measurement, data logging, decision making, and actuator system. This integration fits well within the basic engineering design model (Define a Problem, Design a Plan, Finalize Design, Produce and/or Build, Deliver and/or Implement), and allows the students to become familiar with engineering product development. Our T-STEM partners have produced a system incorporating the engineering design model with the familiar five E's (Engage, Explore, Explain, Elaborate, Evaluate) that will be discussed and implemented with the MESBQs during the first-week workshops as a possible method for producing the curriculum modules.

The teachers will work with the Fellows to make the integrated STEM modules accessible to 9-12th grade students (the target grade band). This process will improve both the communication skills of the Fellows as well as the "translation" skills of the K-12 teachers. During the two-week intersession, Fellows and Teachers will be given readings and will be required to continue working (with their MESBQ) on their research problems. Communication between quartet members will occur via personal WebCams (purchased by grant funds).

Participants will meet again for the second summer institute during the last week in June where they will continue to work within their MESB quartets on integrated mathematics/engineering/science modules during the mornings and receive seminars on cutting-edge topics in math/science/ and engineering from TTU STEM faculty. The afternoons will be spent finishing and presenting their modules to each other.

The MESB Quartets will have opportunities to construct new thoughts and understandings through their research and teaching experiences and their collaborative co-development of interdisciplinary mathematics/science/engineering inquiry modules. The Quartets will find patterns, relationships, and connections across their disciplines. It is planned that the MESB learning Quartet will uncover a ‘reality connection’ between theoretical ideas and
the real world as they practice their integrated role of mathematician, scientist, and engineer. By teaching contextualized mathematics and applied science within inquiry-based curriculum modules, both mathematics and scientific/engineering content knowledge can be achieved by all. The experiences and the results from the proposed program of study will provide additional information for STEM professors and teacher educators regarding development and design of their instructional programs of study (graduate, undergraduate, and K-12) for future scientists, technologists, engineers, mathematicians, and mathematics and science teachers.

(ii) Research Base: The Mathematics-Engineering-Science Connection and Education Research: “Connected knowing,” which establishes a rich network of association, is among the most durable and accessible forms of knowledge. Connected knowing is most easily generated when “knowledge is primarily being constructed in interaction with other people, in a process that depends on understanding others’ experiences, perspectives, and reasoning, and incorporates this understanding into the individuals knowing and understanding”. Lave and Wenger and Adler might refer to this “connected knowing” as the theory of situated learning, which claims that learning and understanding is most conducive when interacting and participating with others. Situated learning transpires in authentic activities in which problem-solving strategies are used for real life advancements.

Lave and Wenger view schools that use traditional education programs as the institutions where knowledge is "decontextualized" and not transferable to real world working situations. The proposed development of interdisciplinary connections and relationships by building mathematics/engineering/science bridges can be considered a situated learning program that contextualizes and transforms understanding of a single subject culture. In this interdisciplinary endeavor, graduate students work on projects and curricula with other graduate students and in-service teachers in which they share their content knowledge and pedagogical content knowledge to create a common discourse for understanding. The doctoral students and in-service teachers, the mathematics and science teacher, and the mathematics and science/engineering doctoral student relationships should result in outcomes that are greater than the sum of its parts, where participants learn new methods of developing knowledge and curriculum that can be transformed across boundaries, opening new perspectives for all learners.

The National Council of Teachers of Mathematics’ (NCTM) Principles and Standards for School Mathematics, the American Association for the Advancement of Science’s (AAAS) Benchmarks for Science Literacy, and the National Science Education Standards (NSES) advocate integration of the mathematics and science disciplines. NCTM argues that students need to experience contextualized mathematics. “Mathematics is used in science, the social sciences, medicine, and commerce. The link between mathematics and science is not only through content but also through process. The processes and content of science can inspire an approach to solving problems that applies to the study of mathematics” (p. 66). AAAS makes a similar argument stating “it is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others” (p. 3). The NSES asserts in its Program Standard C that “the Science program should be coordinated with the mathematics program to enhance student use and understanding of mathematics in the study of science and to improve student understanding of mathematics” (p. 214). NSES further expounds that “if teachers of mathematics use scientific examples and methods, understanding in both disciplines will be enhanced” and describes how students should “develop ability to use realistic applications and modeling in trigonometry; understand connections within problem situation, its model as a function in symbolic form, and the graph of that function; use functions
that are constructed as models of real-world problems; know how to use statistics and probability” (p. 219).

Van de Walle describes how mathematics classroom environments need to shift toward ‘conjecturing, inventing, and problem solving and away from an emphasis on the mechanistic finding of answers,’ and ‘toward connecting mathematics, its ideas, and its applications and away from treating mathematics as a body of isolated concepts and procedures’ (p. 6).

Much of science is grounded in mathematics. Mathematics provides the machinery to be able to make sense of the world in an analytical and quantitative fashion. Science and engineering, on the other hand, provide a plethora of applications to which the theoretical underpinnings of math can be applied. Too often instruction in mathematical educational settings (K-12 through graduate school) underdevelops these important relationships.

It is hypothesized that strengthening the relationship among the mathematics, engineering, and science disciplines in both the educational and research venues will result in stronger, more cohesive learning and exploration in K-12 through graduate educational settings. It is proposed that integrated curricula are needed within the mathematics and science classrooms in order to allow students the opportunity to contextualize, to connect to other disciplines, and to experience mathematical and scientific concepts. This will be accomplished by a focus on an integrated mathematics/science/engineering, inquiry framework within the MESB learning Quartet program.

(iii) Concurrent Education Research Activities: The AAAS and the National Research Council advocate collaboration among students from multiple disciplines for fostering innovative ideas. This proposal describes a cognitive apprenticeship where learning is tied to authentic activity, context, and culture. The GK-12 program will examine the following questions:

- How does experiential, situated learning via the Mathematics, Engineering, and Science Bridge Quartets (MESBQs) influence participants’ understandings and implementation of their own research and/or instructional agendas?
- Does the MESBQ program create environments that support the advancement of scientific and mathematical learning of all participants (particularly historically underrepresented groups in advanced science and mathematics)?
- What components of the MESBQ program aid in the development of participants’ understanding and communication?
- How will the “distance teaching and learning” MESB quartets’ experiences compare to their “local-based” MESBQ counterparts?

Much research has been conducted on students’ ways of knowing and understanding various science and mathematics concepts at the K-12 level and even at the undergraduate level. However, few studies examine science and mathematics graduate students’ ways of knowing and understanding. A Science/Mathematics Education doctoral student will assist one of the co-PIs (Wilhelm) in studying the MESBQ program and contrast it with traditional PhD work and the better-understood K-12 and undergraduate environments. Mathematics/Science Education researchers will assess and evaluate program components, and track the development of students’ scientific and mathematical reasoning and progress of participants’ integrated curricular design through both empirical and naturalistic methods in the forms of action research and participant observation. This research will involve triangulation and collection of data in the forms of pre- and post-surveys, tests, and clinical interviews with MESB Quartet participants. Other data collection will include participants’ reflective journals, and videotaped and transcribed meetings. The surveys, tests, and interviews will be used to explore the evolution in participants’ beliefs concerning the most challenging aspects of their project tasks, and their
expectations of the outcome. MESB Quartet participants will elucidate interactions that aided understanding and assisted task completion. All interviews will be confidential and semi-structured, allowing the interviewers to follow other paths raised by the students. The Mathematics/Science Education research will specifically examine how experiential, situated learning via mentor-mentee quartet interactions influences and shapes the participants’ understandings and applications of their own research and/or instructional agendas. Results will be disseminated at conferences and in archival publications.

(iv) Timeline of Activities: The following timeline of events is designed to optimize the development and implementation of the MESBQs as well as the production and application of the curriculum modules.

• January, 2008 – June, 2008: During this time the initial cohort of students will be recruited. A website will be developed to be used both for recruiting and to highlight the activities of the Bridge Quartets.

• June, 2008 – August 2008: Institutes will be held for the cohorts of Fellows and teachers as described above to develop modules as well as pedagogy and teambuilding and communication skills.

• September, 2008 – May, 2009: The Fellows will be in the K-12 classroom setting. Teaching will occur from both the traditional curriculum and the integrated STEM modules that have been developed during the summer. During this time, the new math-science curriculum modules will be refined and new modules will be developed. The Fellows will take the two required courses. Weekly meetings with the STEM and Education advisors will take place to provide advice and feedback concerning the modules and to strengthen cohort formation.

• January, 2009 – June, 2009: During this time the second cohort of students will be recruited.

• June, 2009 – August 2009: Institutes will be held for the second cohorts of Fellows and teachers as described above to develop modules as well as pedagogy and teambuilding and communication skills.

• September, 2009 – May, 2010: The Fellows will be in the K-12 classroom setting. Teaching will occur from both the traditional curriculum and the integrated STEM modules that have been developed during the summer. During this time, the new math-science curriculum modules will be refined and new modules will be developed. The Fellows will take the two required courses. Weekly meetings with the STEM and Education advisors will take place to provide advice and feedback concerning the modules and to strengthen cohort formation.

• June, 2010 – August, 2010: The in-service teachers will be given the opportunity to do summer research in the laboratory of their graduate student counterpart in the MESBQ. The research will be interdisciplinary in nature, involving the connections made by the graduate students in the MESBQ.

The remainder of the years will follow in similar fashion.

• August 2012 (Summer 5): A national institute will be organized by all of the Fellows who have matriculated through the program and the STEM faculty to disseminate the curriculum modules as well as to discuss the research results from the study. The target groups will include both teacher (NSTA, etc.) as well as discipline-specific education groups. The goal of this institute is to make the curriculum module deliverables and research component of the program accessible to as wide an audience as possible. Teachers and Fellows will engage in manuscript writing concerning their developed modules and experiences throughout the program. They will also take part in proposal writing for grants that would further their research and instructional agendas, such as Toyota Tapestry grants. During this time the results of the education research concerning MESBQ effectiveness will be prepared for publication.
(v) Benefits and Deliverables: The benefits to the shareholders in this GK-12 program are numerous. In the case of the GK-12 Graduate Fellows, the fellows will gain an enhanced understanding of science pedagogy through coursework as well as an understanding of inquiry-based learning concepts. Their interactions with some of the best STEM teachers in the region will give them access to state of the art teaching methodologies, and will help them to be well-trained to lead research-based outreach efforts upon graduation. The math/science collaboration will provide an enhanced understanding of the relationship between the various STEM disciplines, both with regard to teaching and research.

By pairing the teachers with their STEM graduate student analogs, the teachers will be exposed to cutting-edge math, science, and engineering research. Through cohort formation, the teachers will develop an enhanced understanding of the relationship of math and science in their teaching. The GK-12 Fellows can function as both a sounding board and a quality check with regard to the science and mathematics that is taught. The K-12 students will also benefit from these learning quartets through the development of new inquiry-based math-science curriculum modules. They will also benefit not only from exposure to the graduate students, but also by the mentoring that the graduate students will be able to afford in the classroom.

We recognize that the actual number of schools and school districts impacted in this work is roughly halved due to the pairing of mathematics and science Fellows and teachers in the MESBQ model. However, it is our contention that these learning quartets will have enhanced benefits, particularly for the graduate students and the teachers, relative to a more traditional Fellow-teacher dyadic pairing. We believe that the results will translate into superior learning outcomes for the students whose teachers are involved in the MESBQ cohort formation.

The other benefit that this study will provide is an in situ research study by one of the co-PIs (Wilhelm) concerning the efficacy of this multidisciplinary math-science pairing mechanism. The research aspect of this proposal may also stimulate the Fellows with regard to learning more about education research, in order to enhance delivery of their STEM research as well as to be able to critically evaluate research performed outside of their areas of STEM expertise.

Several deliverables are expected as a result of this proposal. Each quartet will be expected to develop at least one math/science inquiry-based module per year that will be grade-specific. In addition, each cohort will be required to produce a “how-to” video of the development of the modules, in order to provide a “how-to-think-about module development” plan for dissemination to other teachers who may be interested in their own module production. Finally, all of the MESBQ’s will be involved in the development of an interactive website that highlights interdisciplinary science and math pedagogy, especially with regard to the intersection of math, science, and engineering education.

Recruitment and Selection: Graduate Fellows: A total of 40 graduate students (eight per year) will be recruited from the STEM disciplines for the development of the MESBQs. All graduate students will be required to have finished basic course work and must have at least one year of experience conducting graduate-level STEM research. Although a majority of the Fellows will be selected from the senior graduate student population at Texas Tech, we anticipate that, especially in the case of mathematics students (since they represent 50% of the number of required Fellows), incoming Ph.D. students who have finished master's level course and research work at another institution will be recruited. A national recruiting program will be established to attract historically underrepresented students to the MESBQ program. Fliers, posters, and targeted letters will be developed and sent to HBCU institutions with graduate programs, primarily Hispanic-serving universities, and peer institutions around the country. The universities in the Big 12 maintain a list of STEM graduating master's students that we will use to send out invitation letters. Advisory board member, Dr. Sheryl Santos, (Dean of the College of
Education) is president of the South Plains Closing the Gaps Coalition, a group that works to alleviate economic, cultural and political barriers to facilitate access, participation and success in educational opportunities. She will help to identify underrepresented students for solicitation.

In addition to paper recruiting methods, a website will be developed that will feature several interactive presentations, including program information, a sample math-science module, and radio buttons to allow for on-line application, PI contact, and links to related and contextual websites. Essays will be required of all applicants to assess their interest in interdisciplinary science and math-science connections. One of the benefits of this program from a student perspective is that by participating with science and mathematics teachers, the applicants will of necessity develop a broader perspective, appreciation, and depth of the variety of STEM disciplines. Careful consideration will be given in the selection process to attracting students who have a more global view of science and mathematics, while ensuring that all Fellows are US citizens, nationals or permanent residents. It is planned that at least 60% of the Fellows will consist of women, underrepresented minorities or students with disabilities.

Once an applicant pool is established, a group of graduate students for the first MESBQ cohort group will be selected based on criteria which includes undergraduate and graduate performance, socioeconomic background, underrepresented minority or female status, experience in a wide range of STEM disciplines, interest in teaching and working with K-12 teachers, etc. The applicants will initially be screened by the PI development team, and the final list will be sent to the advisory board for approval.

**Teachers:** Given the nature of the MESBQs, teachers will primarily be selected from those involved in high school STEM teaching within LISD, although the possibility of having at least one or two of the MESBQs based in junior high or middle schools will be considered in order to explore possible curriculum effects and impact on graduate student training. A list of potential teachers will be developed after consultation with the T-STEM Center and CISER (Center for the Integration of Science Education and Research), housed at Texas Tech in the Colleges of Engineering and Education respectively. CISER has access to a wide teacher base due to its Traveling Lab Program, a module-based program supporting STEM education in West Texas. Letters will be sent out explaining the project and their required commitment. The principal criterion for teacher selection will involve the demographics of the schools supported by the teachers as well as answers to required essays by the teachers describing the advantages to them of the combination of mathematics and science/engineering in the classroom. Special attention will be paid to those schools that serve primarily underrepresented and low socioeconomic populations. Each of the science teachers will be required to partner with a math teacher at their home institution (the selection of the math teacher will be based upon the science emphasis of the teacher, the availability of math teachers at the K-12 institution, and the working relationships already established between the science and mathematics teachers at the schools). It is planned that at least 60% of the teacher cohort will consist of women or underrepresented minorities or teachers with disabilities. Teachers will reapply each year, and it is conceivable that cohorts may include recurring teacher pairs. The possible advantages to repeating teacher teams in the MSEBQ model will be explored by the external evaluator.

**Organization, Management, and Institutional Commitment** The PI will have overall responsibility for project management, with the co-PIs and Senior Personnel involved in the administration, instructional development, and research involving the MESBQ’s. This arrangement of Mathematics, Science, Engineering, and Education faculty on the PI team mimics the structure of the MESB quartets, and, as such, a situated learning environment is expected to evolve within the team through discussions and monthly meetings that will inform the team concerning the quartets as well as the interrelationships between math, science, and
Judy Patterson, Academic Program Advisor for the Department of Electrical Engineering, has agreed to act as the manager for the summer institutes. She will be assisted by the PI group and the grant secretary.

An advisory board has been established to provide guidance to the PI team throughout the year. The board will meet twice a year, in January and in June, to review information from the PI team, the Fellows and teachers, and the external reviewer. Based on this information, the advisory board will make mid-course recommendations for program improvement. The advisory board consists of the following members: Dr. Gerald Botrell (Lubbock H.S. Physics Teacher), Dr. Luis Martinez (Chemistry, University of Texas El Paso), Dr. John Zak (Chair, Biological Sciences, TTU), Dr. Javad Hashimi (Associate Dean, College of Engineering), Dr. Fred Koch (Three Rivers Foundation), Dr. Sheryl Santos (Dean, College of Education), and Dr. Jane Winer (Dean, College of Arts and Sciences).

**Evaluation:** The external evaluator for the project is Diane Ebert-May, Professor of Plant Biology at Michigan State University. The research her group pursues requires linking the concepts and processes of biology to theories and processes of cognitive science with emphasis on how students construct understanding of the discipline.

The evaluation strategy will use a combination of self-report data as well as statistical analysis. Although data such as surveys and interviews alone are often used as primary evaluation tools, factors that influence graduate student development are directly observable. The evaluator will modify for use in this project an established Structural Equation Model (SEM) of faculty change (Ebert-May and Weber developed this model for FIRST, an NSF National Dissemination Network) that provides a basis for systematic analysis of faculty/graduate student professional development programs. This model uses path analysis to enable the evaluator to compare the graduate fellows professional development over time.

The overall aim of the evaluation will be to assist the PI to monitor the development, implementation, and testing of a new and effective way of creating enriched educational learning experiences and communities for STEM doctoral students and secondary math and science teachers. The goal of the program is to achieve the implementation of several key outcomes. Outcomes include the development of a MESB learning quartet, the educational enrichment of STEM doctoral students’ graduate programs of study, the creation of a new curricular approach to mathematics and science instruction, the design of integrated math/science curricular modules, and the building of integrated math/science communities within and between institutions. These identified target goals will be assessed (using formative and summative analyses) to determine the extent to which intended outcomes, including progress toward the overarching program goals, are achieved. Metrics will include gains in understanding of mathematics and science connections; and teachers’ and fellows’ success in building synergistic, productive, integrated math/science environments. Metrics will also include the number of participating Fellows and teachers where at least 60% from each group (Fellow and teacher groups) should include women or underrepresented minorities or students with disabilities.

The evaluation research methods designed for this MESBQ program will include a content analysis of activities surrounding the planning, development, and implementation of an integrated curriculum approach during the first year of funding. When the program curriculum has been developed, the evaluators will use a descriptive anthropological approach to answer both “how” and “how well” the MSB project’s goals and objectives are being accomplished and correlated with information gathered from data sources. Data sources will include surveys (conducted locally and at a distance) as well as the specific breakdown, path development, and statistical analysis of the activities of the cohorts. These will be combined with on-site observations and interviews, and correlated with artifacts (teaching materials, student work,
Wilhelm’s research data) being collected by the project. Interviews will be conducted with representatives of all groups involved in the MESBQ project. Each of the nine MESBQ objectives will be transformed into a question to which the evaluators will address formative progress; for example (objective 6): How and how well has the program developed collaborative links with several West Texas school districts? By working in response to these evaluations, the program can identify particular strengths and weaknesses, and monitor progress when these same questions are answered again. Integrating the trajectories of these annual evaluations over the period of the grant will provide a summative picture of how (and how well) the program has achieved its goals. The evaluation timeline is shown below.

- **Spring–Summer 2008**: Evaluator meets with Co-PIs to assess MESB Quartet recruitment and development and makes suggestions for implementation.
- **Fall 2008–Spring 2009**: 1) Evaluator observes MESBQ curriculum design meetings and develops path models. 2) Evaluator observes videotaped pilot classrooms, assesses new modules developed, and makes suggestions for implementation. 3) Evaluator administers pre-surveys.
- **Summer 2009**: 1) Evaluator meets via videoconferencing with Co-PIs to report on results of evaluation of course and curriculum, makes suggestions for changes in the next academic year, and assesses new module development. 2) Evaluator interviews participating students involved in summer institute and begins initial evaluation of program components.
- **Fall 2009–Spring 2010**: 1) Evaluator observes live and videotaped classrooms. 2) Evaluator assesses modified modules and makes suggestions for further implementation.
- **Summer 2010**: 1) Evaluator meets via videoconferencing with Co-PIs to report on results of evaluation of course and curriculum, including results of pre/post and other evaluation instruments and makes suggestions for the next academic year. 2) Evaluator interviews new fellows and teacher participants involved in the summer institute.
- **CONTINUATION OF PROCESS DURING NEXT TWO YEARS**
- **Fall 2012**: 1) Evaluator observes classrooms, assesses modified modules, and makes suggestions for further implementation. 2) Evaluator interviews program participants. 3) Evaluator reviews manuscript production. 4) Evaluator reports to the advisory board.

**List of Faculty Participants** The faculty members from the Colleges of Arts and Sciences, Engineering, and Education who will be involved in the Project, include: 1) Dominick Casadonte (PI; Arts and Sciences (Chemistry); Materials, Environmental Chemistry/Chem Ed), 2) Jerry Dwyer (Co-PI; Arts and Sciences (Mathematics); Complex Dynamics, Math Ed), 3) Mary Baker (Co-PI; College of Engineering (Electrical Engineering), Functional Brain Mapping), 4) Jennifer Wilhelm (Co-PI; College of Education; Science/Math Education), 5) Kim Perry (Lubbock Independent School District; Science Coordinator for LISD), 6) David Lamp (Senior Personnel; Arts and Sciences (Physics), Physics Education), 7) Ron Wilhelm (Senior Personnel; Arts and Sciences (Physics); Astrophysics), 8) Brock Williams (Senior Personnel; Arts and Sciences (Math); Discrete Conformal Mapping), 9) Richard Gale (Senior Personnel; College of Engineering (Electrical Engineering); Microelectromechanical systems design and processing, 10) John Chandler (Senior Personnel; College of Engineering; Director, T-STEM), 11) Gerald Skoog (Senior Personnel; College of Education; Director of CISER).

The Principal Investigator, Casadonte, Chair of the Department of Chemistry and Biochemistry at Texas Tech University, has had extensive experience in the area of chemistry education applied to a diverse portion of the population. He was one of the inaugural recipients of an NSF Discovery Corps Fellowship for Project SERVE (Science Enrichment using Retired Volunteer Educators) for 2004-5. Besides teaching and doing STEM research in materials chemistry and photochemistry, the PI has been involved in teaching honors general chemistry for the past four years. In 2004 he received the Spencer Wells Award for Creativity in Teaching at Texas Tech. He is well known for outreach regionally, having performed over 200 chemical demonstrations shows in the past ten years across Texas and New Mexico to more than 30,000
people, ranging in age from 3 to 60. His activities for the annual American Chemical Society-sponsored National Chemistry Week have resulted in the receipt of three CHEMLUMINARY awards from 1999-2003. He was the inaugural recipient of the Chancellor's Distinguished Teaching Award for the Texas Tech University system in 2001. In 2000, he was named the 2nd Annual Alpha Phi Foundation International Professor of the Year. This was followed in 2000 by his designation as a Fulbright Senior Scholar to France. In 2001 the PI was given the designation of Minnie Stevens Piper Professor by the State of Texas Higher Education Coordinating Board for his activities in teaching, research, and service without regard to discipline. Casadonte has been teaching courses entitled "Conceptual Chemistry for Teachers I and II" as part of a unique multidisciplinary masters in science degree for teachers since 2000.

Co-PI Dwyer was recruited to join the mathematics TTU faculty with the specific purpose of directing and leading outreach activities. He also has extensive experience in computational mathematics with applications in mechanics and rock engineering. He has previously received support for his endeavors from NSF, from the American Mathematical Society, and from several foundations. He is the director of The Joy of Thinking, a program designed to increase enthusiasm for scientific reasoning and mathematical activities among preadolescent and adolescent girls. A major feature of the program is to have successful young women facilitate the clubs and these include a science education graduate student, mathematics graduate students, a senior engineering student and several pre-service education students. The participation of graduate students in this program lends it a flavor of the proposed GK-12 program. Dr. Dwyer is director of TexPREP, an intensive summer program of mathematics, science and engineering for grades 7 to 10. TexPREP has a high school graduation rate of 99% among 4,000 statewide participants.

Co-PI Wilhelm is the education specialist of the PI team. She is unique in that her undergraduate and masters degrees are both in physics, while her Ph.D. is in mathematics/science education. Her area of research interest is in the intersection of mathematics and science in science education. She teaches both in the College of Education and in the Physics Department at TTU. For the past three years, Dr. Wilhelm has implemented and coordinated an Interdisciplinary Astronomy project with middle level students and teachers at four schools. She also has designed and implemented an after school science program called Science in Our World. Besides Dr. Wilhelm’s extensive work in secondary schools, she has also developed and taught the Designing Interdisciplinary Project-Enhanced Environments doctoral course that the Fellows will take in education.

Co-PI Perry is currently the Science Coordinator for the Lubbock Independent School District (LISD). She has worked extensively with each of the co-PIs on a variety of STEM-related activities and projects over the past five years.

Co-PI Baker is a faculty member in the Department of Electrical and Computer Engineering. She is current the co-PI on a grant by the Texas Higher Education Coordinating Board that provides for a summer Introduction to Engineering course for high school junior female students. The grant also includes a series of teacher institutes to develop curriculum materials that incorporate engineering concepts into high school mathematics courses. Dr. Baker chairs the College of Engineering task force on diversity. She has previously served as the PI on a U.S Department of Education Graduate Assistance in Areas of National Needs grant focused on graduate education of under-represented groups in Engineering. Dr. Baker serves as the faculty advisor to the Association of Women in Electrical Engineering. The College of Engineering Office of Engineering Outreach has been involved in the development of teacher institutes involving rocketry, Lego® robotics, and Environmental Engineering, as well as the development of curriculum materials for Engineering I and II at the high school level.
School District Involvement: The Lubbock Independent School District (LISD) is part of Region 17 as defined by the Texas Education Association. As reported in the accompanying letter of support, LISD includes four high schools (Lubbock, Coronado, Monterey, and Estacado), ten middle schools, and 37 elementary schools. The enrollment (according to the 2005-2006 AEIS report) is given as follows: 1) Secondary (6-12) 14,067, 2) Elementary (1-5) 10,801, 3) EE/Head Start/4 yr. olds, 1,123, and 4) Kindergarten, 2,306, bringing the total number of students served to 28,297. The Ethnicity of the Student Population is: 1) Anglo/Other, 38%, 2) Hispanic, 47%, 3) African-American, 15%. This GK-12 proposal will have an impact on some of the poorer and underserved populations in the district. Approximately 71% of the students in the Lubbock Independent School District, for example, are considered economically disadvantaged. As mentioned earlier, the PI has had extensive experience working with minority populations in an outreach capacity. In addition, schools in LISD whose performance on the Texas Assessment of Knowledge and Skills (TAKS) test is such that less than 50% of the students achieved a passing score on the math and science portions of the tests will be specifically targeted. It is significant to note that Dr. Kim Perry, Science Coordinator for LISD, has agreed to be one of the Co-PIs on this proposal.

Once the MESBQ curriculum is developed, we are pleased to have three partners for distribution and dissemination throughout the state of Texas. The Three Rivers Foundation for the Arts and Sciences (3RF) is a private educational foundation whose mission is to promote and foster arts and science education within the desert plains of Texas. Located 100 miles northeast of Lubbock in Quanah, TX, the Foundation is well placed and well funded for the development of distance education tools for rural outreach. Additionally, the T-STEM Center at Texas Tech has access to more than 200 school districts through regional collaboratives within the state of Texas. They have agreed to develop distance education platforms for distribution especially of those projects and curriculum units that relate to engineering education and the engineering design/5 E's approach to STEM education. Finally, CISER (Center for the Integration of Science Education and Research, a Howard Hughes Medical Institute-funded center at Texas Tech University) will be one of the distribution centers for the curriculum modules through their Traveling Lab program, a program that has a ten-year history of outreach to rural Texas.

Conclusion and Vistas: Mathematics, science, and engineering education have often been viewed as complementary but rarely interactive. The formation of mathematics-engineering-science bridge quartets involving STEM teachers and graduate GK-12 Fellows will develop a level of interaction that will strengthen the learning of mathematics and science. We anticipate that the MESBQs will have ramifications beyond the improvement of K-12 mathematics and science education. As the graduate students in each cohort begin to work with each other, a respect for the role of mathematics and science in their respective disciplines will develop. It is possible that this relationship may transcend the education venue such that the graduate students will be able to provide positive interactions with each other within their respective STEM dissertation projects. The education research that is built into the project will examine the efficacy of the quartets as a model for improvement in mathematics and science education that may be easily transported to other parts of the nation. If the quartet development is successful, funds will be sought to expand the program in order to make available a valuable tool to help partner universities and K-12 schools in a common mission to improve the state of mathematics and science education in their respective communities. The acknowledged support of three diverse colleges at Texas Tech University, the TTU Vice President for Research's Office and the Graduate School, the Texas T-Stem Center, CISER, and the Three Rivers Foundation, as well as over 100 years of combined continued outreach interest on the part of the senior personnel will ensure sustainability of this program beyond the grant period.