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Graduating STEM Competent and Confident Teachers: The Creation of a STEM Certificate for Elementary Education Majors

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By Tony P. Murphy and Gina J. Mancini-Samuelson

A collaborative of STEM (science, technology, engineering, and mathematics) and education faculty developed a STEM certificate aimed at elementary education majors. A four-phase process model was used to create and evaluate courses. The certificate is comprised of three interdisciplinary, team-taught, lab-based courses: Environmental Biology, Chemistry of Life, and Engineering in Your World. The biology and chemistry courses are inquiry based, whereas the engineering course is project based. Each of the courses is cotaught by a faculty member in STEM and a faculty member in education. The goal of the certificate is to improve elementary education majors' STEM competence and confidence. Initial assessment results showed significant gains in confidence and competence on the basis of knowledge test items. Curriculum continues to be refined on the basis of assessments and changing state and national education standards.

STEM is elementary, literally! Much attention has been focused on STEM (science, technology, engineering, and mathematics) education for high school and, more recently, for middle school students. However, to have the greatest impact on students and STEM learning, we believe that the emphasis needs to begin at the elementary level. Teachers play a critical role in exposing and encouraging students in STEM fields (National Science Board, 2007). To this end, St. Catherine University redesigned its elementary education program around STEM (Beering, 2009). A collaborative between STEM and education faculty created a STEM certificate consisting of three interdisciplinary courses that are required for all elementary education majors. Courses focus on biology, chemistry, physics, and engineering, with mathematics woven throughout all three courses. The goal for the certificate is to increase the competence and confidence of elementary education majors' knowledge of STEM disciplines and to model innovative, content-driven pedagogies with relevant hands-on inquiry or project-based experiences in rigorous STEM courses. This approach will enable the elementary teachers to engage their K–5 learners in the study of STEM disciplines.

A unique component to the certificate curriculum is the incorporation of engineering. Although science education has been in elementary schools in various forms for decades, the introduction of engineering in the K–12 setting has been relatively recent and in elementary schools only in the last decade. Four states—Indiana, Massachusetts, Minnesota, and Oregon—have introduced engineering into their K–12 science standards, so it is crucial that teachers are prepared to educate and inspire the K–5 learner.

In addition to specific STEM professional development for inservice teachers, preservice elementary education programs also need to respond. Research has pointed to a number of issues with the preparation of elementary educators. These include limited science knowledge, limited pedagogical experiences, and limited confidence, resulting in many elementary teachers avoiding science teaching (Goodrum, Hackling, & Rennie, 2001; Lee & Houseal, 2003).

From 2004 to 2009, a model for a STEM certificate was developed by a collaborative of education and STEM faculty at St. Catherine University. Although the certificate is open to all non-STEM majors, the focus in its development has been the elementary education major. The certificate is composed of three interdisciplinary STEM courses that use creative and innovative teaching strategies. The courses are designed, taught, and assessed as part of the pilot study. The overarching belief in the development of these courses is that STEM concepts need to be made engaging and relevant to elementary education majors so students will be motivated and have the skill set to teach these and other concepts in the elementary school.

How to develop a STEM certificate: A process model

To change the STEM preparation for elementary education majors requires a "revisioning" of STEM content courses and how they are taught at the undergraduate level. A number of reports charged STEM departments in higher education to take responsibility for developing college-level courses with appropriate content and pedagogy in the development of effective teachers (National Research Council [NRC], 1999, 2000).

The reports also clearly indicate that STEM and education faculties need to collaborate effectively and learn from each other in the development of high-quality STEM content college-level courses for education majors. This was the motivation and impetus for the development of the STEM certificate at St. Catherine University, aimed primarily at elementary education majors and open to all St. Catherine University students.

The Committee on Undergraduate Science Education within the NRC listed six visions for transforming undergraduate education in STEM (NRC, 1999). Another report from the NRC in 2000 specifically focusing on the preparation of STEM teachers, including those becoming elementary teachers, put forth a number of recommendations. These recommendations for numerous stakeholders charged that STEM departments in institutions of higher education should "assume greater responsibility for offering college-level courses that provide teachers with strong exposure to appropriate content and that model the kinds of pedagogical approaches appropriate for teaching that content" (NRC, 2000, p. 111).

Since 2004, an education faculty member has led the curricular revision for elementary education majors at St. Catherine University, funded by a generous grant from the 3M Foundation, with the help of the STEM Education Development Committee. This committee consists of 16 faculty and staff at the university, representing six departments/areas (i.e., education, biology, chemistry, physics/engineering, mathematics, and psychology). A psychology faculty member served as the evaluator for the STEM courses.

It is important to underscore the unique and highly effective collaboration that exists between these departments housed in different schools and disciplinary areas. This is due in part to the four-phase process model used that spanned 5 years and continues today (see Figure 1).

Phase 1: STEM and education collaborative

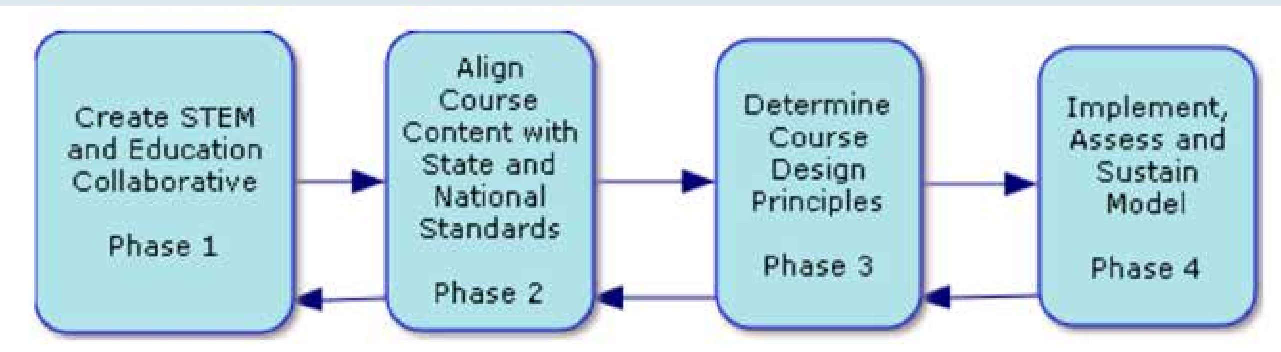
During the first year of funding, the group—consisting of STEM and education faculty—met twice a month and discussed the status of STEM elementary education in the state and the nation. Discussions led the group to list the knowledge, skills, and processes that courses needed. A needs assessment conducted with external elementary educators/administrators and business employees determined what they considered important STEM knowledge, skills, and processes. This phase was crucial in deciding on and defining a common vocabulary for the group.

Phase 2: Alignment with standards

State and national standards for elementary students, as well as teacher preparation standards, were reviewed for required concepts and skills. These included the *National Science Education Standards* (NRC, 1996), *Science for All Americans* (American Association for the Advancement of Science, 1989), *Atlas of Science Literacy* (American Association for the Advancement of

FIGURE 1

A process model to develop a STEM certificate.



Science, 2000), *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000), *National Educational Technology Standards* (International Society for Technology in Education, 2004), *Minnesota Science Academic Science and Mathematics K–6 Standards* (Minnesota Department of Education, 2004), and *Standards for Science Teacher Preparation* (National Science Teachers Association, 2003). When the project began, engineering standards for elementary students or elementary teacher preparation did not exist.

Phase 3: Course design principles

In a highly collaborative and creative atmosphere, faculty discussed the nature of the courses that would be team designed and team taught by education and STEM faculty. They would be modular and content would be contextual, with lab-based experiences. Technology and mathematics would be integrated across the courses. Learning experiences would also include field trips and expert guest speakers. It was important that active learning strategies be used in the courses and that the faculties model the use of these strategies for the students. Courses increase student awareness of specific curricular materials (such as FOSS kits); however, the courses are intentionally designed to develop students' skills and effectively use the variety of materials found in elementary classrooms. It should be noted that these courses are rigorous STEM content courses; they are not educational methods courses. Elementary education majors are required to successfully complete methods' courses in science and mathematics in addition to these STEM courses.

Phase 4: Implementation, assessment and sustainability

Environmental Biology was the first course developed in the collaborative process with STEM and education faculty. The courses were developed by teaching teams who initially created a syllabus for group review, followed by faculty engagement with selected course activities. Feedback from the group resulted in changes to the syllabus and/or activities.

This course, taught in 2005, was part of the STEM certificate pilot study. The teaching team assessed student learning and the course; on the basis of feedback and assessment, courses were modified. A similar implementation and assessment strategy was followed for the Chemistry of Life and Engineering in Your World courses.

Included in this phase was dialogue with university administration to ensure the sustainability of the STEM certificate. It is important that there is a continuous feedback loop between all phases of the model. As examples, when state standards are updated (Phase 2), the course content will reflect new standards (Phase 3), and assessment data from Phase 4 may modify teaching strategies within the courses (Phase 3).

Course descriptions for STEM certificate

The STEM certificate is comprised of three interdisciplinary, team-taught, lab-based courses. It is important that the certificate courses are open to all undergraduate majors at the institution. Each course centered on one core discipline (i.e., biology, chemistry, or engineering/physics) with three additional, integrated themes (see Table 1). The biology and chemistry courses are inquiry based, whereas the engineering course is project based. Each of the courses is cotaught by a faculty member in STEM and a fac-

TABLE 1

STEM certificate courses, their core themes, integrated themes, and teaching teams.

	STEM certificate courses		
	Chemistry of Life	Environmental Biology	Engineering in Your World
Core theme	Chemistry	Biology	Engineering/physics
Integrated themes	Physics Mathematics Technology	Earth science Mathematics Technology	Physics Mathematics Technology
Teaching teams/ instructors	Chemistry and education faculty	Biology and education faculty	Mechanical and aerospace engineer and education faculty

Note: STEM = science, technology, engineering, and mathematics.

ulty member in education. Courses are created around thematic modules with contextual content and lab-based experiences.

The Chemistry of Life course explores the chemistry of the human body and its environment. Environmental Biology focuses on the nature of scientific inquiry and basic biological, chemical, ecological, and Earth science principles in the context of environmental issues. Engineering in Your World addresses the foundations of engineering design and core engineering principles shared by many engineering disciplines, such as structures, materials, machines and mechanisms, hydraulics, pneumatics, and electronics. Supplemental information on these courses may be obtained from the authors.

The unique aspect of these courses is that current STEM pedagogy is interwoven throughout, so STEM teaching methods are taught in context. Although these are not science methods courses, they give elementary education majors early exposure to effective pedagogy, which builds on science and mathematics methods courses. This type of integration was only possible because of the STEM and education collaborative.

An important aspect of STEM literacy, especially for an elementary teacher, is the ability to communicate STEM concepts. To facilitate this, opportunities for development of communications skills are planned carefully. In Environmental Biology, the focus is on writing and graphic representations; in Chemistry of Life, the focus is on developing oral communication skills by giving formal presentations and engaging in informal discussions on STEM topics; in Engineering in Your World, the focus is on visual modes of representations, including scaled models, posters, and schematics.

Initial Assessment

Surveys on content knowledge and confidence were created and used for each of the three courses. Course participants completed these online pre- and postsurveys for each course. Where possible, pre- and postsurveys were matched. Participants identified their majors (as these courses are open to all students), and only elementary education majors are used in this analysis.

Analyses were conducted on aggregate evaluation data from STEM courses (2006–2009) and were based

TABLE 2

Pre- and postratings of confidence across eight sections of STEM courses offered 2006–2009.

	Pre (n = 106)		**Post (n = 106)**		
Presently, I am confident I can . . .	*M*	*SD*	*M*	*SD*	Change (*M* postscores minus prescores)
discuss scientific concepts with my friends or family.	2.65	0.91	3.75	0.69	1.35
think critically about scientific findings I read about in the media.	2.86	0.95	3.81	0.71	1.14
determine what is, and is not, valid scientific evidence.	2.92	0.92	3.78	0.72	1.05
make an argument using scientific evidence.	2.57	0.97	3.67	0.74	1.28
determine the difference between science and "pseudoscience."	2.38	0.99	3.47	0.79	1.22
interpret tables and graphs.	3.41	0.93	4.07	0.72	0.79
understand how scientific research is carried out.	3.09	1.05	3.87	0.68	0.88
organize a systematic search for relevant data to answer a question.	2.83	1.06	3.74	0.76	0.99

Note: M is the mean and *SD* is the standard deviation of people's responses. Response scale: 1 = *not confident*, 2 = *a little confident*, 3 = *somewhat confident*, 4 = *highly confident*, 5 = *extremely confident*. STEM = science, technology, engineering, and mathematics.

on a sample of 106 students from eight sections of STEM courses (Environmental Biology, Chemistry of Life, and Engineering in Your World). Results indicate positive and statistically significant changes in students' confidence in approaching science after they have taken one of these STEM courses.

Confidence

The largest average increase in scores was in students' confidence about discussing scientific topics with family and friends, making an argument using scientific evidence, determining the difference between science and "pseudoscience," and thinking critically about scientific findings read about in the media. Overall, the highest average confidence rating on postmeasures was for interpreting tables and graphs, understanding how scientific research is carried out, and thinking critically about scientific findings read about in the media. All average postcourse scores were greater than 3 on a 5-point scale, indicating that they were at least somewhat confident on average (see Table 2). There was an average increase of 56% in confidence scores from pre (mean = 2.5) to post (mean = 3.9) on a 5-point scale.

Competency

The students assessed their competency with knowledge items for each course. Results showed a significant difference between precourse and postcourse knowledge scores in all three courses.

Once the STEM courses are completed, elementary education majors continue in their program into a professional development school model experience with partner schools, where they teach science prior to their student teaching experience. They teach using many of the concepts and skills they have learned in the courses. (This part of the elementary education program is also being assessed and documented.)

Limitations

Environmental Biology and Engineering in Your World courses have a larger number of students assessed because courses were offered on a regular basis prior to 2009. Further data are needed for the Chemistry of Life course. The engineering test appears to be more difficult than the biology and chemistry tests. Future assessment will have a consistent number of knowledge items with a comparable level of difficulty.

The ultimate intent of this project is to improve K–5 student learning around STEM. Although the initial results from the three STEM certificate courses on confidence and competence of the elementary education majors are encouraging, the future phase will be to collect data on the impact of their teaching on the K–5 learner.

Summary

Initial assessment data are encouraging. The three courses that compose the STEM certificate showed a statistically significant increase in students' confidence for all items and a statistically significant increase in

TABLE 3

Pre- and postcourse knowledge assessments for STEM certificate courses offered 2006–2009.

Course		Precourse correct answers	Postcourse correct answers	Change (postscores minus prescores)
Environmental Biology (n = 83)	$M + SD$ (N = 15 items)	7.82 + 2.18	11.65 + 1.97	3.83
	M %	52%	78%	26%
Chemistry of Life* (n = 10)	$M + SD$ (N = 5 items)	3.10 + 0.88	4.10 + 0.88	1.0
	M %	62%	82%	20%
Engineering in Your World (n = 60)	M + SD (N = 6 items)	1.85 + 1.09	2.45 + 1.14	0.63
	M %	30%	41%	11%

Note: STEM = science, technology, engineering, and mathematics.
*Course taught in 2007.

competence on the basis of knowledge test items. On the basis of assessment data and changing state and national education standards, the curriculum continues to be refined. Since 2009, the three courses have been required for elementary education majors as part of their program. Pre- and postassessment of the courses continues to be refined.

A successful collaborative was developed at St. Catherine University between the education and STEM departments resulting in the development of the three courses leading to the STEM certificate. The components of a productive collaborative based on the four-phases process model include the following:

- a facilitator with responsibility to coordinate the group, task management, accountability to the group and to the facilitator;
- group forms around a common goal and objectives;
- developing vocabulary and respect for the different disciplines;
- funding to cover faculty time and additional resources;
- administrative support and encouragement; and
- communication between the group, their departments, and the administration.

Even though the external funding has ceased for the project, the collaborative continues to meet, discuss, assess, and refine the curriculum. The courses and the collaborative continue to be supported by the institution's administration. ☒

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