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DEVELOPMENT OF STEM CERTIFICATE PROGRAM FOR K-6 PRESERVICE TEACHERS

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Abstract

Minnesota is facing a shortage of teachers trained in STEM philosophy and possessing the knowledge and strategies needed to support a STEM curriculum. There is currently no licensure for STEM teachers in Minnesota. Minnesota State University, Mankato developed a certificate program to add on to the k-6 elementary initial licensure program. Prior to the development of the STEM certificate program the Elementary and Early Childhood Department assessed the current and projected need for elementary level STEM educators. Faculty members from Mathematics, Science, and Engineering assisted in developing the Elementary STEM Certificate program. One parameter that guided the development of the Elementary STEM Certificate was a limit on credit hours and time for completion. The approved certificate program includes twenty credits. Ten of these credits are embedded in the regular Elementary Education Initial Licensure program. Additionally, the program was designed to fit seamlessly into a graduate program for STEM education. Ten of the undergraduate credits are at the 400/500 level and can be imported into the Graduate STEM Degree.

Development of STEM Certificate Program for K-6 Preservice Teachers

Theoretical Framework

To help facilitate a shared understanding on STEM education, The Committee of Integrated STEM Education developed a descriptive framework to provide researchers and educators a common way to communicate integrated K-12 STEM initiatives (National Academy of Engineering [NAE] & National Research Council [NRC], 2014). This framework is comprised of four high-level features: (1) *goals* for the integrated STEM environment, (2) *outcomes* for integrated STEM environment, (3) *nature and scope* of STEM integration and (4) *implementation* and instructional design of integrated STEM environment.

Goals and Outcomes

> The world is moving at a tremendous rate; no one knows where. We must prepare our children not for the world of the past, not for our world, but for their world. The world of the future. (Dewey, 1940)

Even though they were written in the early 1900s, these words by, John Dewey, sound like they were written for today. We live in a fast paced, technologically driven society far from what Dewey experiences. Yet, Dewey's words characterize the major goal of a STEM learning environment-one that prepares students for the future world. The NAE & NRC (2014) outline five goals are what a STEM learning environment should hope to accomplish those goals are: STEM literacy, 21st century competencies, STEM workforce readiness, interest and engagement and ability to make connections among STEM disciplines. These goals are necessary for educational change and the vital skills that should be developed in students, they could easily be interpreted as too broad for many elementary educators. Colum (2017) believed that a set of "intermediate goals" are most appropriate for elementary classroom environments. Colum's intermediate goals include: critical thinking and problem-solving skills, collaboration and creating interest in STEM disciplines. Critical thinking and problem-solving skills along with collaboration are 21st century competencies that can be cultivated within the design of each integrated STEM lesson.

Creating interest in STEM disciplines is a critical goal that needs attention due to the ramifications it can have on students' future engagement in STEM disciplines, coursework, higher education and STEM workforce. Having a productive disposition is essential for developing proficiencies in STEM disciplines. "Productive disposition research" is specific to math education. Yet, it can be argued that it is essential for success in other STEM disciplines as competence in mathematics is integral to success in Science, Technology and Engineering. Having a productive disposition has been identified in the research as being part of an interwoven strand that encompasses mathematical proficiency (NRC, 2001). Productive disposition is defined as "the tendency to see sense in mathematics, to perceive math as both useful and worthwhile, and to believe that steady effort in learning mathematics pays off" (NRC, 2001, p.). Consequently, by creating interest through integrated STEM lessons, could afford the opportunity for students to perceive STEM as useful, valuable and worth putting effort into learning the STEM disciplines.

The work done by Bloom, Bertram & Krathwohl (1964) may assist in developing students interest and engagement in STEM disciplines. Bloom et al. (1964) identified three domains that encompass learning: the cognitive domain, affective domain, and psychomotor domain. The affective domain concerns itself with attitudes, emotions, values, motivation, and dispositions. Bloom et al. (1964) states that nearly all cognitive-behaviors are intertwined with an affective component. Therefore there is significant value in realizing the potential to increase student engagement in STEM disciplines by tapping into the affective domain.

The taxonomy for the affective domain has five levels of participation in the learning process (Bloom et al., 1964): (1) receiving (passive attention), (2) responding (active participation), (3) valuing (appreciation and commitment), (4) conceptualizing (organizes different values and accommodate them within personal schema), and (5) internalizing (value or belief influences behavior-characterizes a way of life). The learning process in the affective domain is the same as in the well-known taxonomy for the cognitive domain. Learning moves from lower-ordered to higher-level. It is at higher-levels where students can apply and transfer their learning. The guiding principle behind the affective domain is internalization, the extent to which an attitude or value has been incorporated into a student's total value structure. For example, when students move toward internalizing a STEM discipline such as engineering, they will most likely choose a career path when they can engage in the engineering process. The affective domain taxonomy reminds educators and researchers that attitudes, values, and emotions strongly affect learning and these should be accounted for when designing such learning environments.

Suitable desirable outcomes that should be used to identify an effective STEM learning environment for upper elementary grades would include: learning and achievement, applying STEM content knowledge and making connections across STEM disciplines, and interest in STEM disciplines. Learning and achievement along with application and connections would be measured by creating indicators of understanding for integrated STEM lessons. Instruments, such as surveys, could be developed to measure attitudes and students self-perceptions related to interest and engagement in STEM. Mahoney (2010) developed an instrument based on the affective domain research of Bloom et al. (1964) to measure high-school students attitudes and their implications toward STEM. The instrument specifically measured interest, ability and value. Tools, such as this one, can be particularly useful in measuring the influence of integrated STEM learning environments.

In a STEM learning environment, the traditional separation of the four individual disciplines of science, technology, engineering and mathematics is removed. STEM learning encompasses an interdisciplinary where two or more of the STEM disciplines are combined in an intentional and meaningful way. This integration of two or more STEM disciplines is what distinguishes a STEM learning environment from other types of integration and makes it uniquely STEM. There are natural connections between the four disciplines, however science, technology, engineering and mathematics have traditionally been approached in education as “silos” (Bybee, 2013). Meaningful contexts offer opportunities for students to extend their knowledge and understanding of concepts learned in the STEM disciplines.

In the real world problems are messy and do not present themselves with easily identifiable solutions. STEM integration offers opportunities for students to extend their knowledge and understanding that more closely models the real world. The conceptions of real-world learning can be traced back to the work of John Dewey. Dewey (1900) made similar arguments for teaching subjects in an integrated way.

> We live in a world where all sides are bound together. All studies grow out of relations in the one great common world. When the child lives in varied but concrete and active relationship to this common world, his studies are naturally unified. (p.94)

Furthermore, Dewey (1938) recognized the need for separate disciplines, but illustrated how the connections themselves create a concept of the whole for the student when he stated that we learn, but only at the end, that instead of discovering and then connecting together a number of separate realities, we have been engaged in the progressive definition of one fact.

Similarly, this aligns with a primary tenet of constructivism that true understanding of content comes from learning in situational contexts where students explore for themselves. According to learning theorist, Jean Piaget (1970), knowledge is constructed through adaptation and is furthered by two processes-assimilation and accommodation. Assimilation is when new learning is incorporated into existing schema. Accommodation is the reorganization of knowledge to build on prior knowledge and occurs when an existing schema cannot account for the new idea. Therefore the prior knowledge must be changed to accommodate the new idea. Integrating STEM disciplines in meaningful ways could cause students to experience accommodation by providing them with new ways to experience the STEM subjects and reframe their understanding of prior learning in specific contexts or “silos”.

The NAE & NRC (2014) identified three important elements, of integrated STEM initiatives from the literature, that determine the nature and scope of integration: (1) typed of STEM connections, (2) disciplinary emphasis, and (3) duration, size and complexity of STEM initiative.

Type of STEM Connections

The first element that determines the nature of integration is the type of STEM connection. As previously stated, an essential component of a STEM learning environment is that two or more STEM disciplines have to be integrated in a meaningful way. Educators may bring concepts from more than one STEM subject together in a number of ways, such as, science and mathematics, engineering, technology and mathematics, mathematics and technology, or even all four disciplines, science, technology, engineering, and mathematics.

Disciplinary emphasis.

The second element that determines the nature of integration is disciplinary emphasis. Frequently one of the subjects, science, technology, engineering or math has a more explicit focus (NAE & NRC, 2014). Concepts and skills from other disciplines are often to add support or deepen learning and understanding in the focus subject.

Duration, size, and complexity.

The scope of integration is determined by the duration, size and complexity of the STEM lessons. This can vary greatly and often is depended upon the structure of the classroom and school environment. Integrated STEM lessons can occur over an hour-long lesson, encompass several hours, an entire school day, or even after the normal school day. Complexity can vary as well, ranging from not much change within the normal classroom environment to orchestrating a new approach that may consist of co-teaching.

Christine Schnittka's (2009) popular integrated STEM unit, *Save the Penguins*, can provide an example of the nature and scope of STEM integration. In this integrated STEM unit, students presented with a global problems, global warming, and asked to apply science concepts of heat transfer to design an energy-efficient dwelling. Throughout the unit students construct knowledge of heat and energy concepts through active manipulation and testing of materials and ideas. The type of STEM integration in this unit is a three-discipline integration with science and engineering playing a dominant role and mathematics playing a supportive role. The students explore the science concepts of heat transfer, temperature, insulation, conduction, radiation, and convection throughout several of the lessons. Once the students begin the final two lessons the students are asked to apply their knowledge of the heat and energy concepts and engage in the engineering design process to construct an igloo to save their ice penguin from heat. The scope of the integration consists of five 70-80 minute lessons that can occur within the regular classroom and taught by the classroom teacher.

STEM is not a single subject to that will replace several others. Students still need to learn concepts and skills in the other fours disciplines however by integrating them together in meaningful and intentional ways, such as *Save the Penguins* did by meaningfully using engineering design to apply the science concepts of heat and energy, educators have opportunity to provide motivating lesson that more closely mirror the problems students will face in the real world. As a matter of fact, professional scientists and engineers almost always work in ways that integrate the STEM disciplines (NAE & NRC, 2014). Therefore, the first step in creating an effective integrated STEM learning environment is meaningful and intentional integration of the disciplines.

The Problem

In the United States, each state is responsible for its own educational curricula and standards. In Minnesota, there are detailed elementary grade standards in Science and Mathematics but there are none in STEM. The absence of standards means that initial licensure programs charged with preparing teachers in Minnesota cannot offer STEM licensure. At the same time, the number elementary schools identified as STEM schools has grown. While the authors could not find a single database of STEM designated schools in Minnesota, a simple web search reveals that dozens of elementary schools identify as STEM schools. A partial listing includes Apple Valley Eagan Public Schools, Bemidji Public Schools, Brainard, Buffalo-Hanover-Montrose Public Schools, Public Schools, Discovery Charter School, Faribault Public Schools, Hopkins Public Schools, LeSueur Henderson Public Schools, Lino Lakes Public Schools, Maple Grove Public Schools, Minneapolis Public Schools, Northfield Public Schools Richfield Public Schools, Robbinsdale Public Schools, Rochester Public Schools, and Winona Area Public Schools. This listing is by no means complete perhaps because of the lack of STEM licensure in the state.

With the growing number of STEM themed elementary schools in the state, teachers with a background in STEM are valued. In many districts, media/tech specialists are the front people for STEM initiatives. The media/tech labs and maker spaces are often the physical spaces used for direct STEM instruction. Yet, regular classroom teachers with STEM training can greatly enhance these “pull-out” programs. Minnesota State University, Mankato is helping to meet this need by offering an initial- licensure STEM certificate for its’ undergraduate teacher candidates.

Minnesota State Mankato’s Elementary Teacher Licensure Program

The STEM Certificate program at Minnesota State Mankato was developed to meet the needs of school districts looking to hire STEM trained elementary teachers. It was also designed to help alleviate over enrollment related issues in the K-6 licensure program.

The K-12 initial licensure program at Minnesota State Mankato includes two years of General Education and support courses followed by two years of “Professional Education”. The last two years are comprised of cohort groups completing “blocked” courses, grouped to offer graduated scaffolding that moves the candidate form the role of student to that of teacher. Included in these “Blocked courses is an extensive field experience component each semester.

The Elementary Education program at Minnesota State Mankato has the second highest GPA requirement for admission to professional education (second only to nursing). Students must complete their General Education requirements with at least a 3.0 GPA. While this ensures that only academically able students enter the program, there are often too many applicants for placement in the program. When there are too many students to admit into the program, there must be coursework that students can take in order to maintain their full time status. The STEM

Certificate can offer meaningful courses that will enhance the candidate's preparation. There are also Middle Level Endorsement programs in Communication Arts, Mathematics, and Science that also help with this need.

Certificate Design and Development

The Minnesota State College and University System has a multi-level process for curriculum development and approval. New programs and certificates begin at the Department Level. Course and program proposals are first developed within the department. In the case of the STEM Certificate, it was the Educational Studies: Elementary and Early Childhood Department (EEC). Once a curriculum change or program is approved, it is passed on to the College of Education Curriculum Committee. This body ensure that all impacted departments are given an opportunity for input on the proposed Curriculum/program. Curriculum/Program changes are the sent on to the University Committee on Academic Planning (UCAP) for approval. This body ensures that the proposed change in curriculum or new program will not negatively affect existing programs within the university. Finally, after working through all of these committees, curriculum proposals are sent to the office of the Academic Vice President for approval. Then, approved proposals are sent to the Minnesota State offices for final approval. At any step, a proposal can be kicked back to the initiating department for revision or additional documentation.

Because of this time consuming and labor-intensive process, the STEM Certificate program was designed with the help of faculty in the sciences, mathematics, technology and engineering. It was felt that their input would help shape a program that would best meet the needs of our students and most easily make it through the curriculum process at Minnesota State Mankato. In meetings over several years, Dr. Marsha Traynor gathered data and input from experts in all of the STEM disciplines. What was finally developed included twenty credit hours of course work designed to prepare the elementary classroom teacher in STEM concepts at the elementary level.

STEM Certificate Logistics

These courses developed for and included in the Elementary STEM Certificate program at Minnesota State University, Mankato were selected to model integration of STEM content areas. They include: (a) BIOL 480 Biological Laboratory experiences for Elementary Teachers, (b) EEC 436 Engineering for Elementary Teachers, (c) EEC 446 Educational Technology-STEM, (d) EEC 456 Special Topics: STEM for Elementary Teachers, (e) EEC 467 Integrating Science, Technology, Engineering, and Math for Elementary Teachers, (f) EEC 470 Field Experience in Reading and STEM, (g) MATH 203 Elements of Math III, (h) PHYS 480 Lab Experiences in Physical Science. See Appendix for exact catalog descriptions.

Of the courses in the STEM Certificate program, BIOL 480, MATH 203, PHYS 480 and EEC 470 are required courses for any Elementary Education teacher Candidate. This means that the STEM Certificate is actually ten credits beyond what every Elementary Education Candidate takes. Each of the courses that make up the additional ten credits is offered either as an evening or summer course. This means that students who are admitted into professional education can complete the STEM Certificate while taking their “blocked” courses.

Ten of the twenty credits in the STEM Licensure program, been designated as 400/500 hybrid courses. This is so in-service teachers desiring to obtain the STEM Certificate will be able to take the courses they need at the graduate level if this is beneficial for Continuing Education Unit or “lane change” purposes. (Because in-service teachers will likely have coursework to substitute for the programs Biology, Physics, and Mathematics courses, these courses are not offered as undergraduate/graduate hybrid courses.)

Course Descriptions

Because the Biology, Physics and Mathematics courses are all a part of the Elementary Education licensure, they will not be discusses. The catalog descriptions for each course is included in Appendix A. Each of the additional courses are now described in more detail.

EEC 436 Engineering for Elementary Teachers (3credit) This course is designed to help teacher candidates develop skills related to teaching engineering concepts to elementary students. The course is designed around the Engineering Design Process. Students are given daily engineering design challenges. Websites such as STEM Problem Solving Activities, Children's Engineering Educators, Elementary STEM Design Challenges, and Teach Engineering are sources of daily challenges. The course introduces Reverse Engineering (of spring driven toys). Students create 3-D renderings for printing using Tinkercad (https://www.tinkercad.com/). Students also create both orthographic and isometric projections of simple objects. (A good explanation of these projections can be found at http://www.me.umn.edu/courses/me2011/handouts/drawing/blanco-tutorial.html#isodrawing.) Robotics concepts introduced using Ozobots and Vex Robotics. Students work through units developed by Engineering is Elementary (EIE). They work with the materials to develop lesson plans that are presented to their classmates.

EEC 446 Educational Technology-STEM (3 credit) In this course students focus on developing their skills with STEM related technologies. They are introduced to coding applications; Code (https://code.org/learn), Hour of Code (www.tynker.com/hour-of-code), and Code Hunt (https://www.codehunt.com/) are examples of resources for teaching and learning to code. Students also use on-line resources for mathematics and science applications.

EEC 456 Special Topics: STEM for Elementary Teachers (1 credit) This is a one-credit course that changes form semester to semester depending on its instructor and what is current. In the fall of 2017, the course is scheduled for three Saturdays and will involve developing indoor quadcopter obstacle courses and 3-d printing covers for drones. Other semesters it has focused on coding educational games and using classroom robotics.

EEC 467 Integrating Science, Technology, Engineering, and Math for Elementary (3 credit) In this course, students focus on the logistics and strategies needed for integrating Science, Technology, Engineering, and Mathematics in the regular elementary classroom. Students learn to use the Engineering Design Process in all areas of the curriculum, asking students to develop, test and revise their reading, and writing, art and all areas of daily work. Students develop integrated curriculum units to demonstrate their mastery of the integration process.

EEC 470 Field Experience in Reading and STEM (1 credit) This course is the replacement for EEC 423 Field Experiences in Reading. STEM Certificate candidates take this four-week field experience in a STEM school and have a STEM theme in their teaching activities.

Conclusions

The Elementary and Early Childhood Department at Minnesota State University, Mankato has developed as STEM Certificate program in an attempt to provide well qualified teachers for elementary STEM classrooms. The program was developed to fit seamlessly into the regular Elementary Education Initial Licensure program. It was also designed to be easily completed by practicing teachers who desire a STEM background. The program was developed with input from Scientists, Engineers and Mathematicians. Students who have completed this STEM Certificate program are currently teaching in elementary STEM schools.

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Appendix

STEM Certificate Program Catalog Descriptions

Support Courses

BIOL 480 (3) Biological Laboratory Experiences for Elementary Teachers Provides experience with a wide variety of biological laboratory exercises to prepare prospective elementary teachers. Emphasis is on building knowledge, skills, and confidence. The course will cover major biological concepts and environmental education through classroom-ready examples selected to illustrate each concept. Fall, Spring BIOL 481 (1) Lab

MATH 203 (3) Elements of Math III Transformational and Euclidean geometry, coordinate geometry and applications of discrete mathematics. Prerequisite: MATH 202 with "C" (2.0) or better or consent Spring

PHYS 480 (3) Lab Experiences in Physical Science For prospective teachers in elementary schools. Topics include weather, weather forecasting and record keeping, simple machines, electricity, chemistry, sound, light, and others. May not count as a physics elective. Not available for P/N grading. Fall, Spring

Program Courses

EEC 436 (3) Engineering for Elementary Teachers This course provides hands-on experiences through which students learn the basics of engineering. Topics include the engineering design process, reverse engineering, and engineering fields/professions. The course focuses on the engineering strand of the K-6 Minnesota State Science Standards. (Summer)

EEC 446 (3) Educational Technology-STEM Elementary education teacher candidates will study the technology skills needed in order to become effective STEM teachers. Variable

EEC 456 (1) Special Topics: STEM for Elementary Teachers This course provides students with familiarity about emerging topics of importance in elementary STEM education. Variable

EEC 467 (3) Integrating Science, Technology, Engineering, and Math for Elementary Teachers In this pedagogy course, elementary teachers will learn to integrate the four disciplines of STEM: science, technology, engineering, and math. Prerequisite: EEC 436 Variable

EEC 470 (1) Field Experience in Reading and STEM Field experience focusing on the struggling reader and instruction in an integrated approach to teaching science, technology, engineering, and math (STEM). Fall, Spring Co-requisite: EEC 421, EEC 424, EEC 491 (Note this field experience is only for students in the STEM Certificate program. It substitutes for EEC 423 Field Experiences in Reading.)