An Innovative Integrated STEM Program for PreK-6 Teachers

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Abstract

In this article, we describe an innovative, 6-course, 18-credit post-baccalaureate certificate (PBC) program for pre-kindergarten through grade six teachers (PreK-6) in Integrated Science, Technology, Engineering and Mathematics (iSTEM) Instructional Leadership. Here, the acronym, "iSTEM," refers to education that not only addresses each of the S, T, E and M subjects, but also emphasizes the connections among them. We collaboratively contributed to the development of the program, and teach courses within it. The program graduated its pilot cohort of teachers in 2015, is running its second cohort, and is recruiting for a third. The article summarizes the program's origins and integration approach and key aspects of program design. Those key aspects include: make-up of the program team; a deliberate course sequence; decrease in structure (and increase in more open-ended, student-centered learning approaches) over time in the program; and movement in the program from growth as an iSTEM teacher towards growth as iSTEM teacher leader. Each of the courses is described in greater detail, followed by a discussion of program assessment and evaluation. The article concludes with our reflections about the program's challenges and successes thus far.

Introduction

In this article, we describe an innovative, 6-course, 18-credit post-baccalaureate certificate (PBC) program for pre-kindergarten through grade six teachers (PreK-6) in Integrated Science, Technology, Engineering and Mathematics (iSTEM) Instructional Leadership (hereafter, the iSTEM program) at Towson University (TU). Here, the acronym, "iSTEM," refers to education that not only addresses each of the S, T, E and M subjects, but also emphasizes the connections among them. We collaboratively contributed to the development of the program, and teach courses within it. The program graduated its pilot cohort of participants in 2015, is running its second cohort, and is recruiting for a third. We begin by describing the program's origins, courses, and program team, and then expand on what we mean by an "integrated" approach to STEM education. This is followed by a discussion of: key aspects of program design and course descriptions, program evaluation and assessment, and our reflections on the program's successes and challenges.

Origins, Courses and Program Team

From 2011 to 2014, the Maryland State Department of Education (MSDE) used Race-to-the-Top (RTTT) funding to award institutions of higher education in Maryland with small (max: $40K) one-to-three-year grants to seed the development of programs for preservice or inservice teachers to grow expertise in iSTEM education and be prepared to implement the state's STEM Standards for K-12 students (MSDE, 2012). We received one of those grants between 2012 and 2014, enabling us to develop four iSTEM courses for in-service teachers. Within this same timeframe, MSDE approved an *Instructional Leader: STEM* endorsement (i.e., an additional credential for an already certified teacher) for PreK-6 teachers (Appendix 1). This endorsement was developed by a work group comprised of stakeholders – including teachers, school system science leaders, and higher education faculty – from across Maryland, one of whom was the first author (Instructional Leader: STEM (Grades PreK-6), 2014). To meet the needs of this endorsement, the program grew from four to six courses.

Within the six-course program, we refer to the first four courses as its "content courses." These are: 1) *Engineering,* 2) *Mathematics,* 3) *Environmental and Biological Science, and* 4) *Earth-Space and Physical Science* *<u>in iSTEM Education</u>*. (Each content course title ends with "in iSTEM Education.") These were completely new to TU and underwent the curriculum review process at the university. The fifth course, *Transformational Leadership and Professional Development*, was an existing course. The final course, *Practicum in iSTEM Education*, was a revised and renamed course from a previous science education graduate program. In 2014 and 2015, our iSTEM program went through thorough review by MSDE and the Maryland Higher Education Coalition (MHEC), ultimately gaining approval as a new PBC program able to award graduates with the aforementioned endorsement. Each course is three credits, taught one course at a time over a regular (i.e., fall or spring) semester, one evening per week. Our pilot program included a summer semester course; however, this is not a standard program feature.

Program team members were recruited by the first author to develop the pilot program based on their expertise in STEM education and interest in teaching within the program. All team members are engineering, science, or mathematics *education* faculty (not content faculty). They each have extensive experience providing preservice and inservice teacher education and conducting research in their respective areas of education. For example, among the authors who are also program team members: Lottero-Perdue specializes in engineering and physical science education; Haines specializes in environmental and biological education; Bamberger specializes in mathematics education; and Miranda specializes in Earth-space and physical science education. While some had some experiences integrating their main content area with another (e.g., mathematics and science), most had not engaged in integration across all STEM subjects prior to engagement in this program.

All but one of the pilot cohort instructors have taught or will be teaching the second cohort of the program. The exception is the instructor who helped to develop and taught the practicum course, Ms. Christine Roland. She had extensive science teaching experience, was a STEM coach for a local school system while she taught the pilot cohort, and is currently a Co-

Director and Master Teacher for our university's UTeach program. The new practicum instructor can be chosen from any STEM education area, and we have plans for this replacement. Recently, our mathematics team member, Dr. Honi Bamberger, retired. She recruited another member of her department, Dr. Ming Tomayko, to co-teach the mathematics course for the second cohort prior to her retirement. This provided support to the new team member to teach the mathematics course for subsequent cohorts.

Our participants for our initial pilot program consisted of two elementary art teachers – both of whom were interested in the integrated nature of our program – with the rest being elementary level regular classroom teachers. Our current cohort participants are all regular elementary level classroom teachers who collectively teach grades 2 to 5.

Integration

Integrated STEM education aims to engage students in learning experiences in which STEM subjects symbiotically work together to answer real questions and solve real problems. Rarely are human pursuits solely in one of these particular subject areas (National Academy of Engineering [NAE] & National Research Council [NRC], 2014). Three approaches implemented in PreK-12 education are multidisciplinary, interdisciplinary, and transdisciplinary integration (Vasquez, Sneider & Comer, 2013). In what follows, we briefly review these approaches, and then present our hub-and-spoke model of STEM integration.

In multidisciplinary and interdisciplinary integration, one subject is addressed through the lenses of different disciplines. In multidisciplinary integration, a theme (e.g., penguins) is addressed in each subject, yet there are few conceptual linkages between the subjects. For example, students may learn about penguin habitats in science, and read the fictional storybook *Tacky, the Penguin* (Lester & Munsinger, 1990) in language arts. In interdisciplinary integration, a disciplinary approach is still taken on a topic, but conceptual links are stronger (e.g., social studies instruction about the geography of Antarctica informs science learning about the habitat of Emperor penguins). Transdisciplinary approaches are guided by an essential question or problem, ideally that has been shaped by student interests. In order to answer the question or solve the problem, students must learn and apply knowledge and practices from various disciplines. For example, if students wanted to design a penguin habitat for a zoo, they would need to explore how and where penguins live in their natural habitats to do so, apply mathematics as they considered the size of the habitat, and so on. Our iSTEM program favors interdisciplinary and transdisciplinary approaches over a multidisciplinary approach, given that our intent is for integration to involve conceptual links across disciplinary boundaries.

Our iSTEM program uses what we call a hub-and-spoke model of STEM integration. Each of the content courses in the program emphasize both content knowledge and pedagogical content knowledge (PCK) for a "hub" or core content area (Gess-Newsome & Lederman, 1999). PCK represents "the distinctive bodies of knowledge for teaching" particular subjects

(Schulman, 1987, p. 8). Each content course intentionally and meaningfully connects to other STEM areas via "spokes." In this way, the hub-and-spoke model emphasizes interdisciplinary integration. The spokes for the engineering course are science, mathematics, and technology (Figure 1). Although not featured as a separate course or hub, technology appears as part of the hub in the engineering course since one conception of the T in STEM, which we will call T1, is that technologies are products of engineering, and can be simple (e.g., pencils) or sophisticated (e.g., robotic arms). Thus, T1 technology and engineering are inherently paired. Another conception of technology, which we will call T2, is that sophisticated tools (e.g., digital scales) are used to develop STEM knowledge; T2 is addressed as a spoke in all of the courses. Hub-and-spoke depictions for the other content courses in the program are shown in Figures 2 and 3.

Figure 1 (Click on image to enlarge). Hub and spoke model for the *Engineering in iSTEM* course.

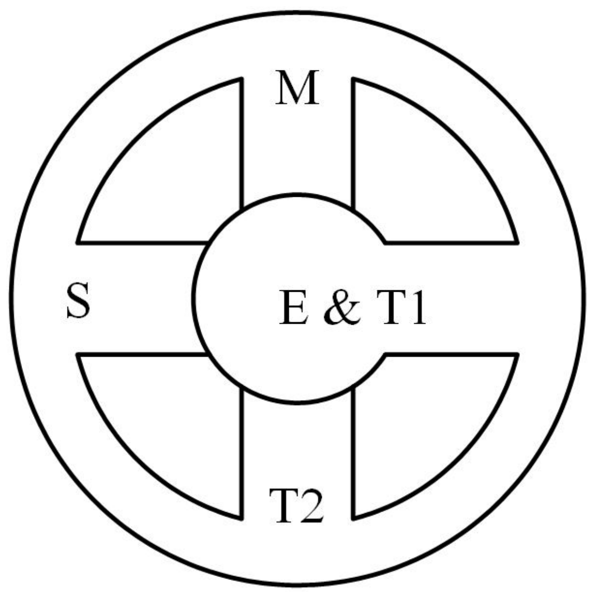


Figure 2 (Click on image to enlarge). Hub and spoke model for the *Environmental and Biological Science in iSTEM* course and the *Earth-Space and Physical Science in iSTEM* course.

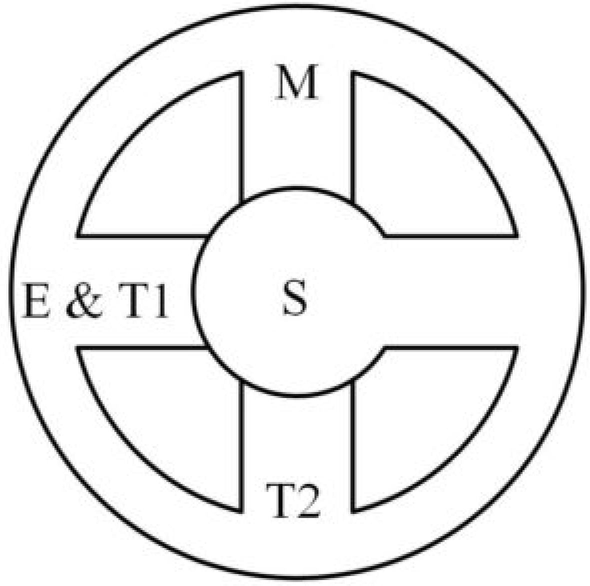
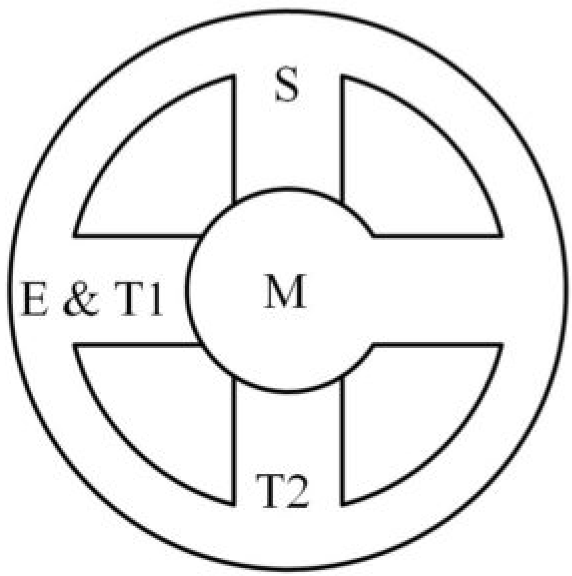


Figure 3 (Click on image to enlarge). Hub and spoke model for the *Mathematics in iSTEM* course.



Whether as a hub or spoke, STEM subject matter content and practices are addressed with rigor in the program. This is ensured by requirements across course assignments to reference STEM subject matter standards, e.g.: the *Next Generation Science Standards* (NGSS Lead States, 2013); Maryland Technology Literacy Standards for Students (MSDE, 2007); the Maryland State STEM Standards of Practice (MSDE, 2012); the Standards for the Professional Development and Preparation of Teachers of Engineering (Reimers, Farmer & Klein-Gardner, 2015); and Common Core State Standards (CCSS) in mathematics (National Governors Association Center for Best Practices [NGAC] and Council of Chief State School Officers [CCSSO], 2010).

Course syllabi were developed collaboratively by program team members, contributing to the STEM integration within each course. During syllabi development, team members took on roles as “hub leaders” *and* as “spoke experts” depending on the course. Hub leaders have explicit expertise in hub areas and were the pilot instructors of program's content courses. For example, Lottero-Perdue is an engineering educator, conducts engineering education research, and provides PreK-8 preservice and inservice teacher education in engineering. She is the hub leader for the engineering course, and was a spoke expert for the other content courses, offering suggestions and advice to other hub leaders regarding how to approach engineering within their courses.

This collaborative process was most intense during syllabus development, with syllabi developed, modified, and improved with input from hub leaders and spoke experts. Input was provided in face-to-face meetings, as well as electronically. Once courses were in session, hub leaders reached out as needed to spoke experts for additional support. For example, Lottero-Perdue reached out to Bamberger for advice on the integration of mathematics within a new unit for the engineering course that ran in fall 2016 for the second cohort of the program.

The hub-and-spoke integration model in the iSTEM program is consistent with four recommendations made by the NAE and NRC within their report, *STEM Integration in K-12 Education*, for designers of iSTEM education initiatives. Two of these recommendations are relevant here. First, the report urges designers to "attend to the learning goals and learning progressions in the individual STEM subjects" (2014, p. 9) – i.e., the course hubs. Second, the report encourages designers to make STEM connections explicit – i.e., via the spokes. The two remaining recommendations regarding professional learning experiences and program goals will be addressed in what follows; all four recommendations are summarized in Table 1.

Table 1 (Click on image to enlarge)

Four Recommendations from the NAE and NRC for Designers of iSTEM Experiences

Topic	Recommendation Description
STEM Subject Areas	Designers of iSTEM education initiatives need to attend to the learning goals and learning progressions in the individual STEM subjects so as not to inadvertently undermine student learning in those subjects. (p. 9)
Explicit STEM Connections	Designers of iSTEM education initiatives need to build in opportunities that make STEM connections explicit to students and educators (e.g., through appropriate scaffolding and sufficient opportunities to engage in activities that address connected ideas). (p. 9)
Professional Learning Experiences	Programs that prepare people to deliver iSTEM instruction need to provide experiences that help these educators identify and make explicit to their students the connections among the disciplines. These educators will also need opportunities and training to work collaboratively with their colleagues, and in some cases administrators or curriculum coordinators will need to play a role in creating these opportunities. Finally, some forms of professional development may need to be designed as partnerships among [and] between educators, STEM professionals, and researchers. (p. 9)
Goals	Designers of iSTEM education initiatives need to be explicit about the goals they aim to achieve and design the iSTEM experience purposefully to achieve these goals. They also need to better articulate their hypotheses about why and how a particular iSTEM experience will lead to particular outcomes and how those outcomes should be measured. (p. 8)

The hub-and-spoke model is relevant to the overwhelming majority of elementary educators who have dedicated blocks of time in mathematics and science, and can use those "hubs" to reach out meaningfully and purposefully to the other STEM subject areas. This model is ideal for interdisciplinary integration, and is also inclusive of transdisciplinary approaches.

Program Design & Courses

The order of the courses, as well as the degree of structure provided throughout these courses via the instructor and curriculum, was highly intentional in the program's design (see Table 2 for a summary of program courses). The first course is the engineering course since this is the STEM subject that is most likely to be unfamiliar to elementary teachers (Cunningham & Carlsen, 2014; Cunningham & Lachapelle, 2014; NAE & NRC, 2009; NAE & NRC, 2014). After this course, the integration of engineering within other courses is less onerous. As participants move through the program, the structure provided by the curriculum and instructor is gradually reduced. The first course has participants engage in and reflect on particular, instructor-selected iSTEM units. By the time participants get to the fourth content course, they are driving their own open-ended, transdisciplinary, iSTEM projects. The imposed structure of having to attend to particular STEM content is removed completely within the final two courses in the program. These courses support participants as they develop into iSTEM leaders who decide how to craft their own curricula and design and lead their own professional learning experiences. This addresses the "Professional Learning Experiences" recommendation for STEM education in Table 1 (NAE & NRC, 2014).

Table 2 (Click on image to enlarge)

iSTEM Program Courses

Order	Subject Code	Course Title
1	SCIE 650	Engineering in Integrated STEM Education
2	BIOL 651	Environmental & Biological Science in Integrated STEM Education
3	MATH 650	Mathematics in Integrated STEM Education
4	SCIE 652	Earth-Space & Physical Science in Integrated STEM Education
5	ILPD 742	Transformational Leadership and Professional Development
6	SCIE 685	Practicum in Integrated STEM Education

In this section, we describe each content course. Following this, we briefly summarize the final two leadership courses. One common theme across all of the courses is that they all utilize constructivist, active learning approaches (Johnson, Johnson & Smith, 2006). In this way, no matter the course, participants work collaboratively, communicate their ideas regularly, think critically, and problem solve.

Engineering in iSTEM Education

Three principles for K-12 engineering education identified in the report, *Engineering in K-12 Education*, were that engineering education should: 1) "emphasize engineering design," 2) "connect to other STEM areas", and 3) "promote engineering habits of mind" (NAE & NRC, 2009, pp. 151-152). The first and third principles represent key "hub" ideas for this course; the second represents its STEM spoke connections. Engineering design involves generating solutions to problems via an engineering design process (EDP). The EDP includes defining and researching a problem, brainstorming, planning, creating, testing, and improving (NGSS Lead States, 2013). Engineering habits of mind are fundamental dispositions of the engineering community, and include creativity, collaboration, systems thinking, and resilient responses to design failures (NAE & NRC, 2009). The hub of the *Engineering in iSTEM Education* course emphasizes the EDP and engineering habits of mind.

The course is organized into thirds. Participants have reading assignments each week, write a brief reflection, and discuss the readings in peer groups. During the first third of the course, they read sections of a chapter about how to incorporate engineering within science education (Lottero-Perdue, 2017). The chapter provides foundational hub content knowledge and PCK early in the semester. In each of the second and third parts of the semester, participants read a biography of an innovator who – perhaps not by title, but by action – has engineered in a real-world context. One of these was *The Boy who Harnessed the Wind (*Kamkwamba & Mealer, 2016). At the end of the semester, participants write a paper reflecting on how the individual engaged in the EDP, demonstrated engineering habits of mind, and applied other STEM areas.

There are three major engineering-focused, interdisciplinary iSTEM units in the course. In each unit, science, mathematics and technology are in service to the goal of solving an engineering problem through the use of an EDP and by applying engineering habits of mind. For all three units, participants keep an iSTEM notebook, work in teams, and present their findings in a poster presentation. During one of the class sessions, participants visit a local engineering or manufacturing company relevant to one of the three units; e.g., a packaging facility related to a package engineering unit (EiE, 2011).

The three units focus on different age bands: PreK-Grade 2, Grades 2-4, and Grades 4-6. For example, in the PreK-2 unit, participants used an early childhood EDP to design a sun shelter – a technology – for a lizard (Kitagawa, 2016). They made science connections to thermoregulation in lizards via trade books, and used flashlights to explore light and shadows via experimentation. The EDP reinforced counting and simple measurement, and attended to precision as they planned and tested their designs (NGAC & CCSSO, 2010). After learning the first two units of the course, participants selected one and wrote a paper describing: how they engaged in the EDP and engineering habits of mind in the unit; how the unit connected with other STEM areas; and how they would apply and improve the unit for use within their school.

Environmental and Biological Science in iSTEM Education

A key purpose for environmental and biological science education is to develop students' environmental literacy, the guiding principle for this course. Developing this literacy involves growing knowledge of significant ecological concepts, environmental relationships, and how humans relate to natural systems (Berkowitz, 2005; Coyle, 2005; Erdogan, 2009). It also focuses on developing responsible environmental behavior, without specifying what that behavior should be. The hub in this course satisfies the central objective of enhancing participants' environmental literacy, and preparing them to develop this literacy in their students. Course topics include: environmental issues related to the Chesapeake Bay; human population growth; environmental aspects of farming and agriculture; and urban planning. Special attention is given to global climate change and water issues. Emphasis is also placed on applying the concept of field science to students in the elementary grades, encouraging learning in “outdoor classrooms” (Haines, 2006).

The course includes a variety of inquiry-based class activities and projects, including finding the biodiversity of a sample, conducting a biological assessment of a local stream, analyzing physical and biological parameters of habitat, and conducting a soil analysis. Participants engineer solutions to problems (e.g., designing a floating wetland), use technology (e.g., GIS, Vernier probeware), and apply mathematical concepts (e.g., logarithms in pH, biodiversity in square meter plots) as they engage in these activities and projects. As with the engineering course, participants read, reflect on, and discuss reading assignments each week.

Assessments require participants to integrate natural science concepts into a variety of teaching formats, and design learning experiences that combine in class and field based instruction with all STEM subject areas. Final projects are unit plans that must include an outdoor component and issue investigation. Each participant fully plans an iSTEM environmental action project (Blake, Frederick, Haines, & Colby Lee, 2010) appropriate for completion at his/her school site with his/her students. Each project must include a clear rationale as to why the project was chosen for the particular school site. In addition, each project must have planned activities and learning experiences for the K-6 students that integrate environmental content with other STEM subjects. These learning experiences must include written lesson plans that are appropriate for students at the grade level the participant is teaching with appropriate objectives. Emphasis is placed on projects that are focused and manageable. Strong emphasis is also placed on project planning and implementation that are possible at the proposed school. Projects have included stream assessments, installing ponds on school property, planting trees to provide habitat and reduce erosion, and creating rain gardens to alleviate run-off issues on school grounds.

Mathematics in iSTEM Education

The *Common Core State Standards for Mathematics* (CCSS-M) represents not only what content and skills K-12 students need to know to prepare them for college and career, it also develops students’ mathematical habits of mind (NGAC & CCSSO, 2010). These habits of mind are developed as students investigate problems, ponder questions, justify their solutions, use precise mathematics vocabulary, and realize how mathematics is used in the real world. There are two primary objectives of this course: 1) to develop participants’ mathematical habits of mind, content and practices, and to prepare participants to help students do the same; and 2) to situate mathematics within the real world, which is inherently integrated in nature.

As part of addressing the first principle, participants routinely solve engaging problems in teams; share diverse problem-solving strategies; and read and interpret graphs, charts, and facts. To address the second, we employ a thematic approach for this course. Thus far, the course theme has been water and its importance to survival; a different theme may be used in the future. Mathematics-infused iSTEM activities related to water and survival topics include: representing the distribution of water on Earth; exploring precipitation amounts around the world and considering the causes and consequences of drought; investigating the causes and effects of floods; considering the effects of the public water crisis in Flint, Michigan; and looking at how water-borne illness is spread (The Watercourse/Project International Foundation, 1995).

During the first half of the course, participants read, write reflections about, and discuss two texts: 1) *STEM Lesson Essentials* (Vasquez et al., 2013); and 2) the STEM focus issue from the journal, *Mathematics Teaching in the Middle School* (National Council of Teachers of Mathematics, 2013). In the second half of the course, participants read *A Long Walk to Water* (Park, 2010), the true story of Salva Duk, one of the “lost boys” of the Sudan who walked 800 miles to escape rebels in his homeland and to find clean water.

There are two major assessed projects in the course. One is the generation of a mathematics-focused iSTEM lesson plan. Participants write the plan, teach the lesson to their students, and reflect – in writing and via a presentation – on the implementation and success of the lesson. The lesson, written reflection and presentation are graded using rubrics. The other major project is the iSTEM Collaborative Research Project. It is a semester-long project in which participants, working in teams of two, decide upon and research a water-and-survival related problem (e.g., oyster reduction in the Chesapeake Bay). Each participant writes an extensive paper reflecting the results of their research, and each team presents the results to the class. Among many other parameters, participants must demonstrate how mathematics is used to better understand the problem, and how connections are made to other STEM subject areas.

Earth-Space and Physical Science in iSTEM Education

This final content course of the program is the second course in which science is the hub; the first science hub course focused on environmental and biological science. As such, this final course reinforces prior learning of scientific practices (e.g., evidence-based argument, development and use of models) and crosscutting ideas (e.g., patterns, cause and effect), while emphasizing a new set of disciplinary core ideas in Earth-space and physical science (NGSS Lead States, 2013). Beyond attending to these dimensions of science learning, the major principle of this course is for participants to learn and practice more student-centered, open-ended, transdisciplinary iSTEM educational experiences. Two related objectives of the course are to: 1) explicitly utilize Project-Based Learning (PjBL) as a framework for transdisciplinary iSTEM education (Buck Institute for Education [BIE], 2011); and 2) employ and practice the Question Formulation Technique (QFT) as developed by Rothstein & Santana (2011), a technique to encourage students to generate their own questions.

The course has three major units in which assignments and course readings are interwoven: 1) Landforms & Topography on Earth and Beyond, 2) Communicating with Light and Sound and Other Signals, and 3) Tracking the Sun: Solar House Design. Each unit includes an iSTEM project, primarily done during class time. For example, in the second unit, the hub focused on science content knowledge and PCK related to light travel, light reflection, sound travel, electromagnetic waves, and satellites. Participant teams are informed that they are members of the Concerned Citizens about Asteroid Impact on Satellites (CCAIS) and are asked to write a persuasive letter to Congress arguing how our current communication satellites are in danger of asteroid impact, what effect that might have on society, and how funds should be directed towards research and development on alternative communication systems. Teams specifically connect to other STEM areas by drawing from knowledge of satellite technology systems, mathematical and scientific principles of those systems, and knowledge of asteroid impact likelihood in their argument. Teams are assessed for project quality and presentation quality. Individual team members are assessed by their team for their collaborative efforts and contributions to the team, and by the instructor through a short (one-to-two-page) reflective paper regarding the project.

There are two out-of-class projects in the class. One of these is the Encouraging Student Questioning through QFT Project. In this project, each participant identifies an opportunity in her/his science, mathematics or STEM curriculum to apply the QFT. Each participant writes a proposal explaining the context in which she/he will apply the QFT and the details of the planned QFT focus (Proposal Stage). After employing the QFT in her/his classroom as planned and collecting student artifacts, each participant writes a reflection regarding the process, impact on students, and impact on subsequent engagement in the curriculum (Reflection Stage).

The second major project in the course is the iSTEM Unit Analysis and Redesign Project. Each participant redesigns an existing Earth-Space science or physical science unit of instruction in his/her school system, redesigning it within iSTEM PjBL framework that utilizes at least one QFT experience. For the first part of the project, each participant conducts an analysis of the existing unit. For the second, each participant submits a redesigned unit proposal and a PjBL plan, including a Project Overview, Teaching and Learning Guide, and Calendar (BIE, 2011).

Leadership Courses

After growth in content knowledge and PCK in the four content courses in the program, participants focus on the development of leadership skills in their final two courses. The first of these courses, *Transformational Leadership and Professional Development*, helps grow participants' knowledge base regarding best practices and standards for professional learning at the school and system level (Leaning Forward, 2012; Reeves, 2010). This course is taught within the TU College of Education's Department of Instructional Leadership and Professional Development (ILPD). Kathleen Reilly, an ILPD faculty member, has taught this course for the iSTEM program, helping participants to identify an area of need and create a plan for an iSTEM professional learning experience (PLE) within their school or system. Part of the second leadership course, *Practicum in iSTEM Education*, involves implementing that PLE plan and reflecting upon it. Participants meet face-to-face for approximately half of practicum sessions. Participants must design a second PLE in the practicum, implement it, and reflect upon it; this second PLE must be different than the first.

Additionally in the practicum, participants must design and teach an iSTEM lesson to preK-6 students in a grade level other than those whom they normally teach, and include an assessment of impact on student learning for that lesson. For example, a second grade teacher in the program may develop, teach, and reflect upon an iSTEM lesson for fifth grade. Each participant negotiated teaching a class in another grade level. Participants arranged to swap with another teacher in the school for approximately three to four one-hour teaching sessions. Participants were required to organize this, and administrators were supportive of their need to do so.

At the end of the practicum, participants reflect upon and present to an audience of peers, teachers, administrators and instructors about their iSTEM leadership growth. Throughout the course, participants work in professional learning communities (PLCs), i.e., peer groups who provide feedback and input as participants develop and reflect on their iSTEM professional development, lesson, and leadership growth projects (Dufour, 2004). Across all of these projects, participants implement essential learning from previous coursework about integration, STEM standards and best practices, and best practices in professional learning and leadership.

Program Evaluation and Assessment

Program quality has been evaluated via: 1) external evaluation of the grant-funded portion of the four-course pilot (engineering, environmental and biological science, mathematics, and the practicum); 2) the development and subsequent external approval of its assessment plan; 3) results from assessment implementation; and 4) the new opportunities made available to and work of its graduates.

External Evaluation of the Pilot Program

The external evaluator's review of the four-course pilot program was extensive and included: 1) a short pre-program survey; 2) affective behavioral checklists given after each of the three content courses (Appendix 2); 3) visits by the external evaluator to each class, including to major project presentations within each course; 4) a 37-question final program survey (Appendix 3); and 5) exit interviews conducted after each course. It is beyond the scope of this paper to share all results from the evaluation report; we share major findings here.

The pre-program survey indicated that 9 of the 10 incoming pilot program participants had received some PLEs in STEM subject(s) prior to the program; for six, this included a week of participation in a Science Academy. Also on this survey, when asked about their comfort level giving a one-hour presentation on iSTEM education in the next month, the responses were: Very uncomfortable (1 participant); somewhat uncomfortable (2); slightly comfortable / slightly uncomfortable (3); somewhat comfortable (4); very comfortable (0) (median = 3).

Aggregating affective behavioral checklist data across all three content courses, all 10 participants felt: more confident using, teaching or designing iSTEM lessons; and that the courses increased their interest and/or capabilities of assuming future iSTEM leadership roles in their schools, the school system, and the state. Post-course interviews included feedback – given anonymously to the instructors through the external evaluator – from participants about each content course; feedback was both positive and constructive.

Eight of the nine participants who completed the first four courses of the pilot program completed a final program survey. This survey utilized an ecosystem rating scale (Suskie, 2009) to assess confidencea in STEM subject and iSTEM teaching, curriculum writing and analysis, and leadership at program completion compared to recalled confidence at the start of the program. Confidence was indicated as follows: not at all confident (Score of 1); a little confident (2); somewhat confident (3); confident (4); very confident (5). Post-program confidence was higher than recalled pre-program confidence for all 37 criteria, as determined by Wilcoxon Signed Rank Tests ($a < 0.05$). For two final program survey items – “presenting curriculum development or other work in iSTEM to peers, teachers, and administrators” (post-program median = 5) and “presenting curriculum development or other work in iSTEM to parents and other members of the public” (post-program median = 4) – all eight participants moved from “not at all confident” or “a little confident” at the start of the program to “confident” or “very confident” at the end of the program. (These recalled low-confidence levels are consistent with the aforementioned pre-program survey result.)

While post-program responses were most often “confident” or “very confident” across all measures, for three criteria, half or fewer participants expressed that they were “very confident.” These criteria suggest areas in which participants are continuing to grow, and in which the program can improve. Each of these criteria regarded aspects of iSTEM leadership. Half of the program survey participants indicated that they were “very confident” “planning and leading iSTEM PLEs for teachers or administrators;” the remainder were “confident.” Similarly, half were “very confident” critically analyzing and evaluating engineering curriculum, while one participant was “somewhat confident” and the rest were “confident.” One quarter were “very confident” with regard to “presenting curriculum development and other work in iSTEM to parents and other members of the public;” one participant was somewhat confident, and the remainder were “confident.”

Program Assessment and Approval

While innovative assessments of student learning were developed for each program course – including those in four-course pilot – a formal program assessment plan was not implemented for the pilot cohort. Rather, the assessment plan was developed as the pilot cohort of the iSTEM program took their courses. Also, the pilot cohort took the courses out of order. This was due to the initial grant-funded version of the program being four courses (engineering, mathematics, environmental and biological sciences, and the practicum), and the final version being six courses (adding the leadership and professional development course and the Earth-space and physical science course) in order to earn the endorsement. The endorsement was not in draft form until after two of the first four courses had been taken by program participants; it was not formally approved until after participants completed the fourth course.

Ultimately, seven key program assessments were developed to evaluate the program (Appendix 4). These assessments address required outcomes of the program for the *Instructional Leader: STEM Endorsement*, i.e.: STEM subject content, iSTEM content, iSTEM research, planning, impact on student learning, and leadership. Five assessments measure student performance directly via course assignments evaluated via extensive rubrics. Two are indirect measures: grades and the final program evaluation.

As mentioned previously, the six-course iSTEM program underwent rigorous external, administrative review by the state MSDE and the MHEC. Representatives from these agencies ensured that the program’s assessment plan addressed the aforementioned outcomes. MSDE representatives not only reviewed the overall plan, but also reviewed each assessment and corresponding rubric to determine whether or not the program addressed specific aspects of state STEM standards. Formal approval of the assessment plan and program was finalized in May 2015, just days before seven pilot program participants earned their iSTEM PBC.

Initial Results from Assessment

As our assessment plan suggests, a robust program assessment includes both direct and indirect measures. Much of the external evaluation of the pilot program included participants’ assessments of their learning outcomes (e.g., in the final program evaluation). While these provide some good information, participants’ answers may have been biased towards attempting to please the external evaluator or its instructors. Grades are another indirect measure of program success, but are more objective. Of the 7 PBC graduates from the six-course pilot program, all earned As or Bs in their courses. Thus far, all participants in the second cohort have earned As or Bs in their first two courses. More telling about learning outcomes is participant performance on direct assessments. What we can share here are results from two of those: 1) from the first cohort's iSTEM Unit Analysis and Redesign Project; and 2) from the second cohort's iSTEM Research Project (see Appendix 4 for a more robust description of these projects). On the iSTEM Unit Analysis, after revisions were allowed to improve overall quality, grades ranged from 80% to 100% (mean = 94%); the range was from 60% to 100% initially. The range for the iSTEM Research Project was 70% to 80% (mean = 92%).

Opportunities for and Engagement of Graduates and Participants

The external evaluator also mentioned anecdotal evidence in her report that spoke to participants' iSTEM leadership potential and engagement at the end of the program. S/he noted: at the end of practicum final presentations, leaders from two school systems in which participants taught inquired about their interest in designing new iSTEM units for the school system; one participant got a new job at a private school in a large city as a science and math teacher; another received a grant from an ornithological organization; and three were planning to deliver an iSTEM PLE to administrators in their school system.

Since this time, most of the 9 pilot program completers and 7 PBC program graduates have stayed in their classrooms, have become enrichment teachers, or work as integration specialists. Collectively, they have led numerous iSTEM PLEs for teachers and administrators, some of which have been at the state level. They have implemented iSTEM clubs and family nights at their schools, contributed to re-writing district science curriculum to better align with the NGSS, and three have earned regional recognition as "Rising Stars" or "Mentors" in STEM education by the Northeastern Maryland Technology Council. Of the ten members enrolled in the ongoing second cohort of the program, two have recently received scholarships to receive Teacher Educator training through the Engineering is Elementary program in Boston, Massachusetts.

Challenges and Successes

The biggest challenge we face has to do with teacher recruitment. Many teachers may be too overburdened with curricular changes and new testing demands to begin a new and optional program. Also, for some school systems – particularly without STEM funding through efforts such as RTTT – iSTEM is less of a priority compared with other initiatives in early childhood and elementary education. Further, some school systems have clearer career pathways (e.g., STEM specialist positions) than others to motivate teachers to join an iSTEM program or earn the endorsement. For those who *are* interested in iSTEM education, we have competition; participants can choose from about five other programs in the state that offer a path to the endorsement (funded by the same grant that seeded our program.) A secondary challenge is retention. We have a master's-level program; rigor is essential, but participants with many demands and busy schedules may drop out if the work burden is too high. Some attrition is to be expected, yet we are observing and making some changes to ensure that the program has the right balance of rigor and flexibility to meet the needs of busy, hardworking teacher-participants.

Despite these challenges, we are optimistic about our current and future cohorts, and have made changes to improve recruitment. Our program is available as a stand-alone post-baccalaureate certificate (PBC), and it serves as a set of electives for a master's degree in educational leadership. This provides future graduates with master's and an administration certificate in addition to the PBC and STEM endorsement. The first author, who is also the program director, has worked with colleagues in the ILPD Department of TU's College of Education to make this combined degree pathway clearer to our students.

We offer courses during the regular semesters (fall and spring) of the academic year, typically once per week in the evening. This is preferable for full-time faculty who teach in its courses and typically want the courses to be taught as part of their teaching load. This also works with school systems' reimbursement schedules (e.g., for those that offer two courses per year worth of reimbursement to participants in system-supported programs). Recently, we have begun to blend the iSTEM PBC, mixing online with face-to-face instruction. Our goal: content courses will be one third online and two thirds face-to-face; the fifth course will be completely online; and the final practicum course will be half online and half face-to-face. This will reduce the frequency of participants' visits to campus, focusing those face-to-face visits on hands-on, team-based experiences, and will encourage participants' use of interactive technologies (e.g., uploading project-related video logs).

Conclusion

We conclude by sharing that the process of growing this program has been messy and non-linear. A more straightforward trajectory would have included knowing the parameters of the endorsement *prior to* creating a program that aimed to address it. Instead, these criteria arrived mid-way in our innovation process. Such is the case with design: sometimes the criteria or constraints change, and designers must respond accordingly. The (small) amount of seed money that we gratefully received from the MSDE aimed to spark the creative development of an iSTEM program for practicing PreK-6 teachers, something that had not been done before. Five years after receiving this award, we continue to improve and refine our program, and yes, we continue to innovate. Innovation is generative, exciting and frustrating, and for this program, has contributed to the growth of our iSTEM program graduates who – we believe – are prepared to lead students, teachers, and administrators in meaningful iSTEM learning experiences.

Supplemental Files

Appendices-iSTEM-Program.docx

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