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Synergy For Science Learning: An Interdisciplinary Partnership to Improve the Quality of Science, Technology, Engineering and Mathematics Education

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Abstract: Synergy is the interaction of two or more elements to produce a combined impact greater than the sum of their separate effects. In this paper, synergy for science learning came from the amalgamation of separate, independent science education contributors. Synergy for science learning thus was created by three resulting elements: content and applications, designed by the College of Engineering and College of Liberal Arts and Sciences; research-based pedagogy, developed by the Colleges of Education and College of Liberal Arts and Sciences; and dynamic classroom implementation, guided by action research and delivered by the partnership school districts.

Keywords: STEM Education, Interdisciplinary Degree, School-University Partnership

SYNERGY IS THE interaction of two or more elements to produce a combined impact greater than the sum of their separate effects. In this paper, *synergy for science learning* came from the amalgamation of separate, independent science education contributors. Synergy for science learning thus was created by three resulting elements: *content and applications*, designed by the College of Engineering and College of Liberal Arts and Sciences; *research-based pedagogy*, developed by the Colleges of Education and College of Liberal Arts and Sciences; and *dynamic classroom implementation*, guided by action research and delivered by the partnership school districts.

Theoretical Framework

Research shows the quality of public school teachers has the greatest impact on nurturing cognitive abilities, developing knowledge, and increasing motivation of students [1]. Indeed, improving teaching quality is an effective instrument for improving students' academic achievement [2]. To be successful in improving teacher quality, projects must create a concerted, synergetic approach that engages public schools and universities as equal partners.

Typically, universities devise programs with limited input from K-12 educators, deliver the programs, and then terminate the project when funding ends. Without meaningful, continuing collaboration the projects, that may or may not have been faulty in the first place, sputter out and die [3]. Many science, technology, engineering and mathematics (STEM) initiatives – advocating worthy objectives of increasing teachers' content knowledge, strengthening the quality of instruction, and promoting student achievement – have been

content-heavy professional development programs designed using top-down models lacking consultation with public school teachers [4]. Even in projects with identified school partnerships, these projects often failed to meet teachers' and students' needs, at best, or actively have exacerbated cultural barriers between public school teachers and university faculty, at worst [5, 6].

Seeking to avoid the pitfalls of the past projects, our synergy team reversed the paradigm by starting with active recruitment of all players before any program design was initiated. Specifically, a synergistic planning team of administrators from two large, high-needs public school districts, middle and high school teachers from these districts, and university faculty from the Colleges of Liberal Arts and Sciences, Engineering, and Education came together to identify and map out cultural differences between the two educational systems and among the three colleges. This discovery process was mediated using an *Activity Theory* paradigm that triangulates the needs and priorities of a three-element system [7, 8]. In this case, the three elements were *content and applications* as represented by the College of Liberal Arts and Sciences and the College of Engineering, *pedagogy* as represented by the Colleges of Education and Liberal Arts and Sciences, and *implementation* as represented by the two partnership school districts. Once these elements were in place, the planning team devised strategies for connecting the three elements – so the program's interdisciplinary vision could become reality.

Our synergy team views the long-term beneficiary of the program is the school-aged learner, the immediate audience is the teacher. However, the teacher is an active participant, not merely a conduit. The teacher would need support. Thus, central to the program's vision was a three-pronged concept of improving the quality of the classroom teacher: improving teachers' *content and application knowledge*; improving teachers' *pedagogical skills*; and improving teachers' *implementation* of the content into a standards-based curricula in their own classrooms.

Project Design

To align the program with pertinent academic standards and to develop an overarching framework, team members engaged in a process guided by *Understanding by Design* (UBD) [9]. Commonly used in some American public schools, UBD recommends that curriculum developers engage in “backward design,” similar to “reverse engineering” in the commercial world. During Stage 1, curriculum developers first determine desired learning outcomes. During Stage 2, they identify acceptable evidence that learners have attained these outcomes and which assessments will elicit this evidence. Finally, in Stage 3, curriculum developers plan learning experiences. When this sequence is followed, learning destinations guide the curriculum's route, and all parts of the curriculum are connected in a cohesive manner.

In the fall of 2008, the first cohort of twenty-six high school and middle school teachers from industrial technology, mathematics and science began the Masters Degree (33 semester hours) in Science in Engineering Education including: Introduction to Emerging Technologies, Instructional Design and Development, Nanotechnology and Applications I, Introduction to Energy Engineering, Applied Fuel Cell Engineering II, Nanotechnology and Application II, Applied Engineering Probability and Statistics, Applied Modern Manufacturing and Quality Control, Homeland Security, Summer Internships, Master Project, Pedagogical/Content Cohesion across Courses.

Our synergy team designed this project to blend the three elements: standards-based science, technology, engineering and mathematics content and applications, research-based pedagogy, and dynamic classroom implementation into the public schools. The following discusses these three elements.

Standards-Based Curriculum Content and Applications

Content and applications to improve the teaching quality is designed around “problem-based learning” (PBL). Problem-based learning is a widely used instructional strategy where students work in collaborative groups to solve challenging, open-end applications and later reflect upon their learning [10]. Our synergy team utilized the expertise of the university faculty in each of the sciences, with mathematics and engineering personnel, to design a developmental content that was rich with applications – applications that would develop rigorous conceptual understandings of the science and mathematics content. Further, the content is rich with applications participating teachers adapt to their own classrooms to teach with their public school students.

With its focus on inquiry learning in science education [11], problem-based learning strongly resembles the scientific method. Problem-based learning centers around muddled, complex, and difficult problems – just like problems in the real world [12]. Yet the problems must be relevant to learners, so learners are motivated to solve them. Learners should have some background knowledge, although their knowledge is likely to have gaps. What learners do not know already, they will learn on an as-needed basis with support from their instructors.

A review of the research on the effectiveness of PBL shows that when students learn material in the context in which it will be used, both the retention of material and transfer of learning to new situations are enhanced. Learners engage in PBL become skilled at working collaboratively and communicating clearly [12]. Learners follow a flexible, recursive process [13]. First, learners are presented with a problem. Working in cooperative groups, they identify existing knowledge, organize their ideas, and attempt to define the problem more precisely. As they research aspects of the problem, learners acquire new information and working together, synthesize solutions. Complexity increases and new questions arise.

This iterative process can provide the organizational framework for a single class session, a series of sessions, or an entire course, if research resources are readily available. As learners progress, insights from previous PBL experiences accumulate and are progressively synthesized. Ideally, the whole curriculum becomes a large-scale, in-depth PBL experience. Learners, by engaging in PBL, are more likely to feel confident and comfortable with the complexity and no-easy-answers climate of PBL. Thus the teachers will be more inclined to implement PBL in their own classrooms.

Research-Based Pedagogy

Especially secondary teachers – who tend to have strong background in content, but weaker preparation in pedagogy – have been the recipients of dry, disengaging STEM instruction. The traditional approach to STEM education consists of lectures, homework, and tests. It is commonplace to be presented with facts, complete a page of homework problems, review answers in class, and then repeat the process the next class. Students view traditional STEM education to be boring, time consuming, and difficult.

A key principle guiding our project is that our instructors “practice what they preach,” or model in their own classes the methods they advocate our teachers use with their students. Such modeling is imperative – how teachers are taught exerts a strong influence on how they will teach [14]. Teachers’ experiences “as learner” play a powerful role in shaping their teaching. Having participated in such instruction – as learners in a safe, nurturing environment – our teachers are more likely to try innovative research-based pedagogy with their own students. For implementation, the teachers measure their own effectiveness by doing action research in their classrooms, employing the content and utilizing the pedagogy.

Dynamic Classroom Implementation

Dynamic implementation of the content and pedagogy into the teachers’ classroom is the third, and the most important element of our project. Many projects have excellent scientific content, modeled by superb instructors, but these elements must be realized in the classroom to have an impact on student achievement.

The success of our project is due to our successful teacher concurrence with the project’s mission and methodology. The teachers are respected, active participants in all stages of the project. Teachers simultaneously view themselves as learners, as teachers, as researchers, and as leaders.

Several factors are critical for successful implementation. First, all participants in the project (teachers, professors, administrators) are full partners, and all have specific responsibilities and rewards. Teachers have ownership of the project. Second, during the first three stages of the project, we, the researchers, have “on-time adjustments” to the project, based upon real-time feedback from our teachers. Third, teachers do an internship in a scientific, engineering or business company to have hands-on experience in real-world applications of the content, giving them a rare opportunity to conduct scientific research [15]. Fourth, the content assignments have two objectives: for teachers to reflect on their learning, and for the teachers to plan lessons for their classrooms. Teachers try such lessons with their students, gather evidence as to the lessons’ effectiveness, and revise subsequent instruction accordingly. Fifth, each teacher individually does an “action research” implementation project, based upon these lesson implementations. Action research empowers teachers to view themselves as change-agents, where they have substantive, direct evidence of the effectiveness of instructional interventions. Based on this evidence, teachers obtain results that affect their future practice [16, 17]. Action research has been found to have substantial, positive effects on teaching practices [18].

Lastly, teachers report their findings to program cohorts, fellow teachers at their schools, and school administrators. By documenting and reflecting upon the cycle of inquiry, teachers gain the potential to improve their own professional practice in significant ways. Further, by communicating the results of action research, teachers enhance the chances that systemic change will take place. Teachers serve as mentors to fellow teachers who wish to incorporate standards-based content and innovative pedagogy into their own instruction. Our teachers confer with colleagues about their implementation of such lessons and when schedules permit, observe their teaching. The teachers are now the leaders of the project.

Preliminary data found teachers increased in their integration of career education and general education (application and theory). At the beginning of the year, teachers were more apt to see the value in either career education or general education and placed the two ap-

proaches in silos (1.3 on 4-point scale of “isolated” to “integrated” view). By the end of the year, the mean rating increased to 3.6. The inter-rater reliability of the 2008-09 data was 0.78.

By the end of the first year, nearly three-fourths of the teacher participants’ observed classroom instruction was rated as “accomplished” or “exemplary”. All teachers were observed by at least one observer during the year to provide baseline data on instructional practices.

Summary

Our long-term goal is to contribute to the improvement of students’ STEM education. We address this overarching goal by means of our immediate goal to improve secondary STEM education by: engaging teachers in authentic standards-based content and applications; modeling pedagogy conducive to teaching and learning STEM material; and enabling the dynamic implementation of the content and methodology – empowering our teachers to be agents of change in the classroom and in the school.

Our results outperform the sum of our individual effects. By meshing the partners of the public school teachers and administrators with the expertise of the university content and pedagogy faculty, we created a synergy for science learning.

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