

THE INTERNATIONAL
JOURNAL
of **SCIENCE**
IN SOCIETY

Volume 3, Issue 2

Science, Technology, Engineering and Mathematics
Education in the United States: Areas of Current
Successes and Future Needs

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THE INTERNATIONAL JOURNAL OF SCIENCE IN SOCIETY
<http://science-society.com/journal/>

First published in 2012 in Champaign, Illinois, USA
by Common Ground Publishing LLC
www.CommonGroundPublishing.com

ISSN: 1836-6236

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Typeset in Common Ground Markup Language using CGPublisher multichannel typesetting system
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Science, Technology, Engineering and Mathematics Education in the United States: Areas of Current Successes and Future Needs

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Abstract: The quality of the public school teacher has the greatest in-school impact on nurturing cognitive abilities, developing content knowledge, and increasing motivation of students. This paper analyzes if, and how, professional development projects enhance the quality of the public school teacher in STEM Education projects. Specifically, this paper seeks to identify particular characteristics of STEM Education professional development projects that improve teacher instruction, and further, improve student achievement. We also identify distinct needs in the research in STEM Education professional development for the projects to be useful and generalizable for the education community. Activities for quality professional development opportunities in mathematics and science need to have a strong emphasis on experiencing, planning, teaching, reflection and professionalism. The most successful teachers have deep content knowledge and then transform that knowledge into meaningful inquiry lessons for their students. We investigate what are the characteristics of successful STEM Education projects that help teachers experience, plan, teach, reflect and transform the new content knowledge and pedagogical skills from the projects into their own teaching. From these projects, can we also identify the areas of future needs in the research for STEM Education professional development?

Keywords: STEM Education, Professional Development, School-university Partnerships, Successful Characteristics

Introduction

WE ARE NOW in the STEM Generation (Zollman, 2012). STEM refers to the first letters of science, technology, engineering, and mathematics. Now STEM has an even broader meaning, including such areas as agriculture, environment, economics, education and medicine (Zollman, 2011). Hundreds of reports and programs have been commissioned in the United States regarding STEM Education—all having three parallel concerns: the future need for more scientists, technicians, engineers, and mathematicians (the supply pipeline); the necessity for more innovative workers (a knowledgeable population) trained in science, technology, engineering and mathematics; and recommendations for what schools should do to solve the shortage (Zollman, 2012).

The quality of the public school teacher has the greatest in-school impact on nurturing cognitive abilities, developing content knowledge, and increasing motivation of students (Ferguson & Ladd 1996; Haycock 1998; Rivkin, Hanushek, & Kain 2005; Rice 2003; Sanders & Rivers, 1996). Therefore this paper analyzes if, and how, professional development projects enhance the quality of the public school teacher in STEM Education projects. Specifically,

this paper seeks to identify particular characteristics of STEM Education professional development projects that improve teacher instruction, and further, improve student achievement. We also identify distinct needs in the research in STEM Education professional development for the projects to be useful and generalizable for the education community.

Activities for quality professional development opportunities in mathematics and science need to have a strong emphasis on experiencing, planning, teaching, reflection and professionalism (Mills, 2003; Marzano, 2003). Ma (1999) states that the most successful teachers have deep content knowledge and then transform that knowledge into meaningful inquiry lessons for their students. We investigate what are the characteristics of successful STEM Education projects that help teachers experience, plan, teach, reflect and transform the new content knowledge and pedagogical skills from the projects into their own teaching. From these projects, can we also identify the areas of future needs in the research for STEM Education professional development?

Background

So what do successful STEM Education projects look like? What are their characteristics? To answer these two questions we first need to be aware of the wide diversity of STEM Education projects. First, most projects have varied definitions of “successful” – and many times the term “success” changes over the life of the project. Second, most projects evaluate the total program, not the separate characteristics of the project that one can compare across projects.

From analyzing a multitude of math-science and STEM projects, seven distinct measures of success are found (Zollman, 2012):

1. student engagement,
2. student affective domain measures,
3. student STEM content knowledge,
4. teacher STEM content knowledge,
5. teacher STEM pedagogy knowledge,
6. teacher affective domain measures, and
7. teacher practices in the classroom.

Student engagement measures vary very much: from the counting the number of STEM area graduates produced in some studies, to tallying the total number of students taking higher-level mathematics and science courses in other projects. *Student and teacher affective domain measures* gauge such things as motivation, self-esteem, self-confidence, attitudes, beliefs, and self-identity. *Student and teacher STEM content knowledge measures* are measured by a variety of project-made, standardized, and state-mandated tests. *Teacher STEM pedagogy knowledge measures* refer to knowledge, skills and abilities in the teaching of such things as scientific inquiry, problem-solving mathematics strategies, problem-based learning, and reverse engineering. Finally, *teacher practice in the classroom measures* observe and evaluate the transfer of project objectives into the real world of schooling. We now can look at specific large-scale, long-term studies that exemplify these measures.

Specific Large-Scale, Long-Term Studies

Using data, as reported by Wilson (2011), from Eisenhower Professional Development Programs; Garet, Porter, Desimone, Birman, and Yoon (2001) examined the correlations between professional development aspects of the various programs and teacher outcomes of knowledge, skills and teaching practices. Garet, et al., found: (a) slight positive effect of “reform-minded” professional development activities with an increase in teacher content knowledge and pedagogy skills, and (b) this increase in teacher knowledge and skills was coupled with positive changes in instructional practices.

Wilson (2011) also cited the Roschelle, Shechtman, Tatar, Hegedus, Hopkins, Empson, Knudsend and Gallagher (2010) study on a long-term math-technology program for seventh/eighth grade teachers. Roschelle, et al., reported in two randomized experiments that students of the professional development teachers learned significantly more mathematics than students in the control group. Further, the professional development teachers reported more use of “high-demand” mathematical tasks and more teaching practices using technology than the control teachers.

In a similar large-scale science inquiry project of randomly assigned schools, Borman, Gamoran and Bowdon (2008) experimentally tested the science knowledge of students of professional development fourth-grade teachers. Wilson (2011) noted that Borman, et al., found no overall effect on student science knowledge, but there was a statistically significant positive effect on student science achievement of early career teachers – and a statistically significant negative effect on student science achievement of students with professional development teachers having more than three years of teaching experience – all versus the control schools.

Wilson (2011) also referenced a large-scale study of middle school teacher in Math-Science Partnership (MSP) institutes. In this study by Hill (2011), MSP teachers with an average of eight hours of professional development “lost” mathematical content knowledge compared to teachers with no professional development. Hill attributes this to the teachers’ minimal level of involvement in “fragmented experiences.”

The National Science Foundation commissioned an analysis of 200+ STEM education reports and research articles written since 1995 (National Commission on Teaching and America’s Future, 2011). NSF found that STEM teaching is more effective and student achievement increases when teachers develop strong professional learning communities in their schools. This report, and a one-year-earlier report, *Team Up for 21st Century Teaching*, (National Commission on Teaching and America’s Future, 2010) state that teams of teachers are able to create a “culture of success” leading to student learning gains. These two reports advocate for teams (Professional Learning Communities) of teachers to create schools that look like learning organizations with six principles: 1) shared values and goals; 2) collective responsibility; 3) authentic assessment; 4) self-directed reflection; 5) stable settings and 6) strong leadership support.

The US Department of Education (Abt Associates Inc., 2010) in its *2008 Annual Report* investigated 626 Math-Science Partnership (MSP) projects between high-need school districts and institutes of higher education. This report found an increase in content knowledge (67% in math and 73% in science) involving 57,000+ teachers and a resulting 13% increase in mathematics and a 9% in science proficiency levels involving their 2.7 million students. The report credits these increases to the intensive (an average of 97 hours) and sustained content-

rich professional development that integrates the content areas of mathematics and science with effective pedagogical knowledge. Further, the report points out that the MSP teachers received ongoing mentoring and coaching as they implemented their new knowledge and practices.

Similarly, in one intensive 33-semester-hour MSP project with middle and high school science, math and career/technical teachers, Tahernezehadi and Billman reported a significant increase in teacher content knowledge, a significant increase in classroom use of inquiry, and a slight increase in student content knowledge (Tahernezehadi & Billman, 2010; Zollman, et al., 2009; Zollman, et al., 2011). This project is unique from other MSP projects in three specific areas. First, the schools' *career and technical teachers* as well as the mathematics and science teachers were in the cadre of teachers. For many teachers, this was the first time these teachers interacted in an academic program. Second, the teachers were involved with business and industry through *internships*. The teachers worked in business and industries during the summer in internships, similar to what an undergraduate engineering student might do. Third, the teachers each did *Action Research* investigation with their students in their classrooms. The Action Research allowed the teachers to see what, if any, immediate impact the MSP project had upon learning *specifically* with their students.

General Characteristics of Successful Programs

In these projects cited, as in several papers prepared for the National Research Council *Workshop on Successful STEM Education in K-12 Schools* (National Research Council, 2011a; National Research Council, 2011b; Wilson, 2011; Schmidt, 2011), three common characteristics of successful STEM programs emerge:

- A strong focus on developing teacher knowledge of and ability to teach the subject matter;
- A solid relevancy to the teacher's classroom situation; and
- An intensive, sustained duration for the professional development.

These three characteristics fit with the consensus for "general" high quality professional development by the National Staff Development Council (2001) as well as specific guidelines of math-science professional organizations from the *National Science Education Standards* (National Research Council, 1996) and the National Council of Teachers of Mathematics *Professional Teaching Standards for Teaching Mathematics* (1991).

Future Needs

Through all the "cacophony of pathways" (Shulman, 2005) available in teacher professional development, and the "carnavalesque" options of professional development (Wilson, 2011), there are definite needs for the future in STEM Education professional development.

Point One: Research needs a common, accepted definition of success of STEM projects that includes a growth model approach to track changes in teacher's STEM content knowledge, pedagogy knowledge, practice in the classroom, and affective characteristics such as attitudes towards STEM, their students, and their ability to teach. Furthermore, the growth model needs to track students' changes in engagement, content knowledge, attitudes towards

STEM, and a propensity to a STEM pathway career. Too often the success of a STEM project is measured in terms of increased student performance on statewide assessments; however, little information is provided to determine which students improved the most and under which circumstances. Likewise, not all teachers benefit equally from professional development opportunities. What are the characteristics of the teachers who did benefit that led to increased student performance?

Point Two: Research needs a central clearinghouse of STEM research articles and reports—ala ERIC Clearinghouse of Educational Research of the 1970's – that categorizes the studies using an evidence-based pyramid approach common in medical research so practitioners can readily assess the quality and type of research study. Teachers, like physicians, could benefit from instant access to indexed critiques of research to easily identify quality research to inform instruction.

Point Three: The “bricks in a field” research needs organization and centralized purpose to build upon each other, instead of re-inventing itself every time. What research findings do we know that do not need to be done again? What gaps exist in the research? How does each new project build upon the others?

Typically projects provide outcome data showing the impact of STEM professional development on teacher knowledge and classroom practice and on student academic performance. The missing piece of information is the quality of the professional development itself. Even when research-based professional development programs are used, the fidelity of the implementation needs to be assessed.

Combining the above three points would provide evaluation data of professional development programs that could lead to answering questions such as *What are the critical components/characteristics of STEM professional development that are necessary under different circumstances, such as with beginning teachers, in high poverty areas, with low performing students, etc.?* In other words, are there interactions rather than the major effect we should be analyzing to truly understand the quality, duration, and components of STEM professional development needed to effect change in various situations? What works in a wealthy suburban school district may not be the best approach for another type of district.

Point Four: “The 800-pound gorilla in the room” needs to be addressed, namely the overarching influence that state-testing mandates have upon the classroom instruction. STEM factual content is fairly easy to test. Will STEM classroom instruction that goes beyond factual content be allowed?

STEM literacy, which is needed by all students, extends far beyond content knowledge that is not easily measured. STEM literacy is *deictic*; it is constantly changing. Our students will need STEM literacy (composed of skills, abilities, factual knowledge, procedures, concepts, and metacognitive capacities) to further their learning for economic, societal and personal needs—going beyond “learning to *know* and learning to *do*” to “learning to *live together* and learning to *be*.” (Zollman, 2012).

Closure

This paper sought to identify characteristics of STEM education professional development that help teachers transform content knowledge and pedagogical skills into their teaching. What was found was that successful STEM professional developments share the three characteristics of good professional development: (1) a strong focus on developing teacher

knowledge of and ability to teach the subject matter; (2) a solid relevancy to the teacher's classroom situation; and (3) an intensive, sustained duration for professional development. But there is a need for the professional development to be organized, with consistency in the design and measures for success, and a long-term focus on building upon others' research rather than a continual re-invention of the projects. Teachers need easy access to research results that have been categorized by level of evidence (e.g., an opinion paper versus a randomized trial) and a critique of the quality of the study. In order to fully understand the effectiveness of various STEM professional development projects, projects need to include the quality of implementation/fidelity measures as well as growth model approaches to track teacher and student changes within specific environments.

Acknowledgment

This work was supported in part by the Illinois Mathematics and Science Partnerships Program/ISBE/US Department of Education, funded by NCLB, Title II, Part B, US DOE.

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