# PROCEEDINGS

## 2009 EDUCATIONAL LEADERSHIP STEM SYMPOSIUIM

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*Journal design and layout by James L. Gentilucci, Ph.D.*

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The faculty and students of the Educational Leadership and Administration Program (ELAP) in the School of Education are proud to present these proceedings from the second annual *Science, Technology, Engineering, and Mathematics (STEM) Leadership Colloquium* held at Cal Poly on July 1, 2009.

The theme of the colloquium was *Creating Systemic and Sustainable Capacity for World-Class STEM Education: The Leadership Challenge,* and the papers contained in this edition of *Proceedings* represent efforts by ELAP students to identify exemplary practices in K-12 STEM education and develop models of capacity necessary to support world-class STEM education in K-12 schools.

This compilation of student research findings represents the continuation of a critical dialog between aspiring educational leaders and STEM practitioners. We hope the ideas presented in this second edition of *Proceedings* will guide necessary and substantive debate about this vitally important topic for our schools and nation.

Cal Poly President Warren Baker listens attentively to panelist commentary during the STEM Symposium.

# FACULTY

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James L. Gentilucci is an Associate Professor of Education and the Coordinator of the Educational Leadership and Administration Program at Cal Poly San Luis Obispo.

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# STEM Leadership for a Flat World

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**Keywords:** K-12 Leadership, Instructional Capacity, STEM Reform, Student Learning

## Introduction

In 2005, Thomas L. Friedman wrote a book titled *The World is Flat: A Brief History of the Twenty-First Century.* In this voluminous edition (660 pages), Friedman painstakingly outlines several technological forces that have "flattened the world." He begins the book with a chapter named *While I Was Sleeping*, and from there begins an account of how, while he and most of the world were preoccupied with other things, revolutionary transformations in technology occurred and were put into place. He points to innovations such as workflow software and the ability to up-and-down load digital media (e.g., pictures, video, and music) to Internet social networking sites such as YouTube, Facebook, etc. Friedman continues with a discussion of additional techno-centric advances such as off-shoring work and complex projects, installing fiber-optic cables and networks, designing inexpensive computers and plug-n-play devices, as well as a host of other technological breakthroughs that have simply made the world smaller, more connected and yes, "flatter." In other words these advances have made global communication, the use of technology and intellectual capital "cheap and abundant."

Introduced to these ideas, my colleague and I asked ourselves, what does a flat world have to do with us? Although neither of us have Ph.D.'s in astrophysics, mathematics, or engineering, it wasn't rocket science and the answer became glaring and obvious. We prepare school leaders, specifically, principals and superintendents, who manage school systems and make decisions that affect the lives of children, families, staff, and teachers who work in schools. Our degree and credential candidates, upon successful completion of the university program in Educational Leadership and Administration, will occupy leadership positions at the building level and eventually the district level. They will be responsible for articulating a vision, shaping school culture, and overseeing the academic success of our children. Provided the complexity of this new and flattened world coupled with the demands and challenges it presents our educational leaders, we believe that if our leaders and teachers are not preparing our children for a flat world, an internationally competitive landscape, then schools labor in vain and send our children unprepared, uninformed, and asleep into a world of global economic competition and reorganization.

## Creating a Capacity to Learn

*Fortune Favors the Prepared Mind*
- Louis Pasteur

The current emphasis on school reform, designed to ready students for a globalized economy and work force, has placed an enormous amount of political pressure on schools to demonstrate effective leadership (Petersen & Young, 2004). A critical indicator of that leadership effectiveness is the transformation of the core technologies of curriculum and instruction. Districts are now held accountable for providing powerful, authentic, and rigorous learning for all students (Carter & Cunningham, 1997; No Child Left Behind Act, 2001). Schools depend on leadership throughout the organization to shape productive futures (Senge, et. al., 2000). To succeed, leaders must demonstrate the capacity to create and communicate a compelling vision that motivates others and ensures their commitment to ongoing organizational success. This type of capacity building requires leaders to concern themselves with fostering a culture of collaboration and shared decision-making, emphasizing the professional development and empowerment of organizational members while also understanding how to lead and manage change (Leithwood, 1992).

Reforming education and strategically improving student learning requires leaders who are able to grasp the deeper meaning and values of complex problems, translate them into a dramatic sense of purpose and vision, and convincingly communicate them to others to obtain their on-going commitment (Sergiovanni, et. al., 2004, p. 76).

*Integrated Leadership*

Present day accountability reforms have narrowly focused on curriculum (i.e., standards). Such myopia has led to a deterioration of professional commitment, motivation, and work culture among teachers (Leithwood & Aitken, 1995). We believe *integrated leadership* can reverse this trend. Marks and Printy (2003) assert that integrated leadership (the integration of shared instructional and transformational leadership practices) reflects the transformative influence of eliciting higher levels of commitment and collaboration to develop organizational capacity for improvement, while also providing focus and direction for curriculum and instruction. In other words, integrated leaders establish an ethos of renewal throughout the organization, while practices associated with this type of leadership emphasize the mission and climate of the school organization (Hallinger, 2007; Kelly, 2009). Integration of these two leadership models encourages individual and collective capacity directed at more democratic and learner-centered leadership.

The establishment of high performance expectations, the development and recognition of shared norms and beliefs (organizational culture), and establishment of organizational policies and capacity designed to facilitate broad participation in decision making have important consequences for leadership and organizational learning.

*Building Organizational and Instructional Capacity*

In very simple terms, an organization's capacity is its potential to perform—its ability to successfully apply skills and resources to accomplish its goals and satisfy stakeholders' expectations. Such capacity includes:

- Staffing;
- Infrastructure, technology, and financial resources;
- Strategic leadership;
- Program and process management;
- Networks and linkages with other organizations and groups.

Fullan (2004) defines capacity building as the development of policies, strategies, and actions that increase the collective power or efficiency of whole groups, organizations, or systems to engage in continuous improvement for ongoing student learning. The aim of capacity building is to improve the performance of the organization as reflected in its use of resources and its management practices. It also refers to the knowledge and processes employed by the organization.

Of course the end product for capacity building related to school improvement is increased student learning. What students learn and eventually take away from their experience in schools depends on their opportunities to learn. Therefore what gets taught is a strong predictor of student academic achievement (Spillane & Louis, 2002). Instructional capacity, with respect to instructional improvement, is "the capacity to produce worthwhile and substantial learning . . . a function of the interaction among elements of the instructional unit, not the sole province of any single element" (Cohen & Ball, 1998, p. 5).

Spillane & Louis (2002) identify the following interrelated organizational components necessary for the presence and maintenance of instructional capacity: the classroom as a site for teacher learning, the development of teachers' professional community, and organizational learning. These organizational elements of instructional capacity are highly interactive and have important implications for school districts' efforts to improve the learning of students (Spillane & Louis, 2002). Figure 1 depicts how these elements work together to improve student learning.

Instruction is a function of what teachers know and do to interact with particular students around specific educational material. These three classroom elements—*teacher, students* and *materials*—form the instructional unit, central to instructional capacity (Cohen & Ball, 1998). Spillane & Louis (2002) further explain the interaction of each of these elements as "teachers' intellectual resources influence how they understand and respond to materials and students. Students' experiences, understandings, dispositions, and commitments influence what they make of teacher direction and materials. Materials, as well as the intellectual tasks mediate teacher and student interactions" (p. 84).

A teacher's knowledge, experience, and skills affect the interactions of students and materials. Teachers mediate instruction and their interpretations of educational materials affect curriculum success, and their understanding of students affects students' opportunities to learn. Because teachers mediate all relationships within the instructional unit, they have the unique potential to influence classroom capacity significantly. Therefore, school and district leaders must work closely with teachers to improve instruction and student achievement if they wish to build instructional capacity within their respective organizations (Petersen, Sayre, & Kelly, 2007).

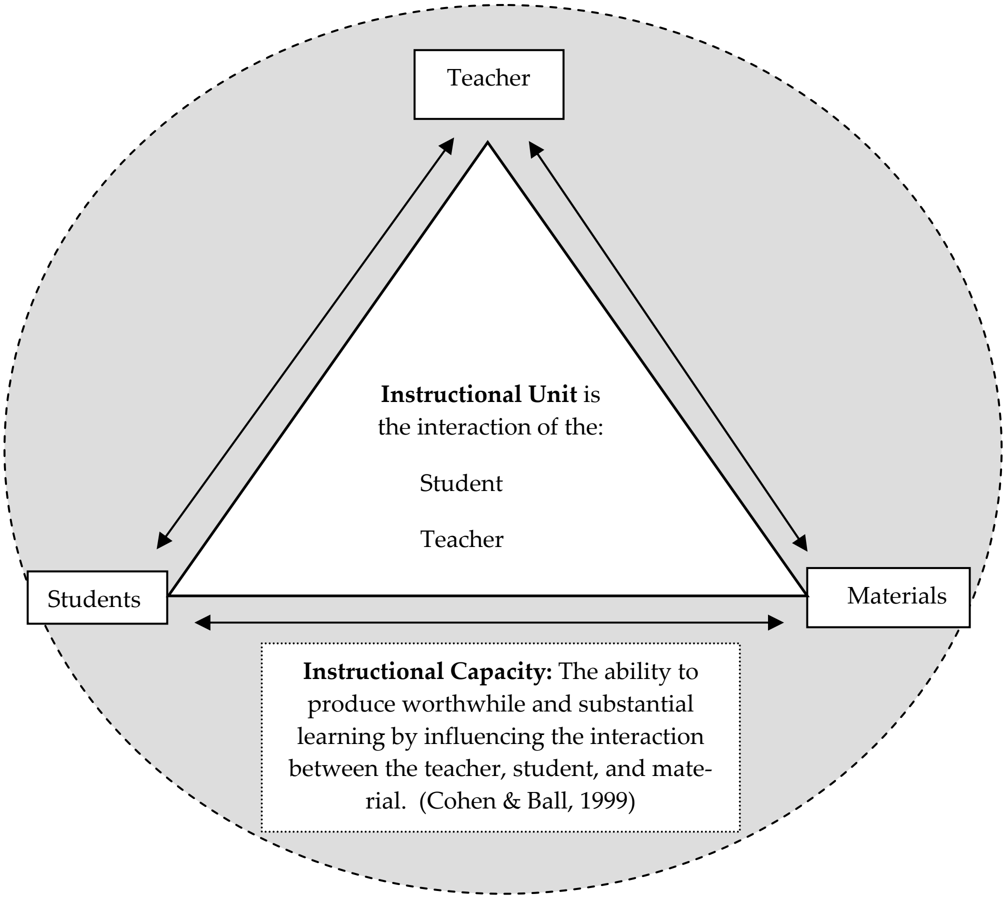


Figure 1: Diagram of the Interactive Components of Instructional Capacity

*Creating Capacity for Excellence in STEM Education*

We now turn our attention to the role district and site-level leaders play in STEM education. Before proceeding with this discussion, it is important to emphasize that research and best practices point to the fact that *superintendent and principal leadership have significant influence in the development and maintenance of instructional capacity within the organization (*Barnett, 1987; Bullard & Taylor, 1993; Levine & Lezotte, 1990; Morgan & Petersen, 2002; Petersen, 1999, 2002). Although extant literature continually points to the influence of site and district leaders, most STEM literature either ignores or only tangentially addresses their roles, devoting instead, the lion's share of attention to preparing highly qualified STEM teachers. While we agree that improvements in the quality and quantity of these STEM teachers are important, we find the lack of consideration given to the role of school administrators especially troubling because 30 years of research have established significant statistical correlations between the instructional leadership provided by these individuals and student achievement (see Andrews, Soder, & Jacoby, 1986; Gentilucci & Muto, 2007; Heck, Larsen, & Marcoulides, 1990; Krug, 1986; Leitner, 1990; Kells, 1993; Leithwood & Jantzi, 2000; Leithwood, Louis, Anderson, & Wahlstrom, 2004; O'Donnell & White, 2005). Most recently, Waters, Marzano, and McNulty (2004) performed a meta-analysis on findings from 70 school leadership studies and found 21 specific leadership behaviors that positively correlated with improved student achievement. Among these were situational awareness, intellectual stimulation, democratic leadership, collaboration, formative supervision, and the ability to lead change.

It is important to acknowledge that *school administrators are organizational gatekeepers—what matters to them gets done*. They are "street-level bureaucrats" who, through their power to enact policy flexibly in ways they deem appropriate within their districts and schools, decide which curricular programs are given additional organizational and leadership resources (i.e., capacity) and those that are provided only mandated support (Lipsky, 1980). Consequently, if school leaders are not committed to the proposition that STEM education is necessary for the success of students in a "flat" world, efforts by policymakers, teachers, parents, community members, and universities to build and sustain K-12 STEM programs have little chance of succeeding over the long term (The California Space Education and Workforce Institute [CSEWI], 2008; Youngs & King, 2002).

So, we ask, if instructional leadership matters this significantly, what specifically can superintendents and principals do to create instructional capacity for excellent STEM education within their districts and schools? Answers to this question vary widely. They range from utilizing traditional capacity-building practices (e.g., allocating money, time, and other resources) to embracing innovative approaches (e.g., creating in-school institutes and laboratories with university and industry partners). For the purposes of this discussion, however, we examine leadership behaviors that create *systemic* and *sustainable* capacity for STEM education in K-12 organizations.

We align our definition of *systemic capacity* with that of Goertz, Floden, and O' Day (1996) and note that it is a rich web of intellectual and material resources provided by school leaders to support bottom-up instructional improvement efforts. The development of systemic capacity is driven by strong leadership, clear and compelling vision, coherent policies and procedures, and cultural norms that focus on improving student learning. It permeates organizations and promotes buy-in from constituents at every level (e.g., students, teachers, parents, school boards, community members, etc.). Finally, it is nurtured by an infusion of ideas and resources from external partnerships.

While the role of school leaders in creating systemic capacity is multidimensional, it is possible to offer some tangible suggestions that will help them begin the process:

- Communicate through word and deed that science, mathematics, engineering, and technology education are curricular priorities for everyone in the organization;
- Place STEM education at the heart of the vision for student learning and success;
- Model the value of STEM education for students by participating in laboratory experiences or by teaching a STEM course;
- Supervise instruction *frequently* and coach STEM teachers to higher levels of instructional competence and performance;
- Visit classrooms, monitor student work, and meet with students *routinely* to discuss academic progress and problems;
- Praise—publicly and privately—individual academic achievement in STEM;
- Provide material resources (e.g., equipment, building space, money);
- Adapt daily schedules to accommodate hands-on laboratory time for students;
- Provide time for daily or weekly teacher collaboration and planning;
- Implement a program of STEM professional development that is delivered *in situ*;
- Create a network of parental, business, and community resources to support STEM education;
- Create a grants-development team to secure resources for STEM programs.

Instructional capacity for STEM education must also be *sustainable* (Barab & Luehmann, 2002). We agree with others that *sustainable capacity* endures over time, its innovative features and resource supports do not disappear when people and politics change, and, most important, it becomes part of the cultural fabric of the organization (Billig, Sherry, & Havelock, 2005; National Academy of Sciences, 2007). Multiple organizational factors have been identified in those districts and schools where capacity to support world-class STEM education has persisted over time. Some key factors include: strong leadership and program "champions", evidence of benefits for students, external political support, partnerships with external agencies and organizations, directed and ongoing teacher professional development, monitoring and evaluation, coherent school culture, and access to content expertise (Powers & Powers, 2007).

These factors highlight the critical role of leadership in creating sustainable instructional capacity because they all fall within the purview of school administrators. Given this reality, we offer several proposals to assist leaders with this task:

- Work to develop a shared vision of excellence in STEM education;
- Motivate others to achieve the vision;
- Build leadership teams comprised of administrators, teachers, and external partners that will support the vision;
- Implement a program of *targeted and ongoing* teacher professional development to build STEM content and pedagogical expertise within the organization;
- Advocate for political support (including resources) with school boards, parent groups, and community members;
- Develop strategic partnerships with STEM-focused businesses and industries to bring knowledge, expertise, opportunities, and resources to the organization;
- Engage in formative supervision of instruction to improve pedagogical competence among teachers;
- Monitor, measure, and report program outcomes to ensure students receive maximum benefit from the capacity;
- Communicate, communicate, and communicate the successes of the program at every opportunity!

*Summary*

So what do we know? The extant literature in the areas of integrated leadership, instructional and organizational capacity, and STEM leadership point to several critical and interconnected organizational themes. First, it is evident that articulation of a vision for world-class STEM education is key. Research has demonstrated that successful instructionally focused leaders collaborate with others to create a compelling and well-understood vision of student success (Petersen & Barnett, 2005).

Next, the use and application of material, human, and social resources directed at student instruction and learning are critical components of capacity building. The work in this area has repeatedly shown the instructional unit functions most effectively when students, teachers, and materials are appropriately synthesized around the goal of learning. Materials can mediate student engagement with the content to be learned—they can also enable or constrain student and teachers' ability to learn. The more capable the teacher, the richer the instructional materials, and the willingness of the student all interact to facilitate the learning environment (Spillane & Louis, 2002).

Third is the distribution of leadership roles in order to facilitate broad participation in decision making. The need to have collaborative relationships in schools, in order to serve the needs of an ever-changing student population, requires the establishment of a student-centered organizational culture. This type of culture requires leaders to concern themselves with active and genuine collaboration and shared decision-making, emphasizing the professional development and empowerment of organizational members' while also understanding change, and how to encourage change in others.

Finally, the critical role of school and district leaders play in facilitating and maintaining systemic and sustainable capacity for STEM education is abundantly clear. This type of leadership is complex and multidimensional and requires leaders to be savvy political actors who are able access content expertise, political support, and partnerships with external agencies and organizations. This form of leverage cannot be facilitated from the classroom – it must take place at the top of the organizational structure. It also requires leaders who are committed to directed and ongoing teacher and administrator professional development, monitoring and evaluation, and the creation and support of a coherent school culture focused on STEM education.

**Conclusion**

Friedman (2005) reminds us that one of the most compelling lessons of the last decade is that America finds itself competing in a swiftly evolving, technology-fueled environment—in a world that is "flattening" with amazing rapidity. While some sectors of American society have adapted to this new reality, others, such as K-12 education, lag behind. Friedman notes,

> A quiet crisis is happening slowly but surely as multiple and complex forces at work create the perfect storm; demographic, political, social, cultural, and economic that could lead to America falling behind in innovation, science, and technology….a lack of highly-skilled scientists and engineers, disinterest in math and science by our younger population, lack of ambition as television and video games take over, an outdated basic education system, and lack of funding for research [are the] dirty little secrets that no one is talking about.

We believe major reform in STEM education is needed if America is to maintain its position as a leader in the global economy. It will not be possible to sustain a first-class economy with a second-class workforce, especially one that lacks expertise in key science and technology fields. To that end, we invite politicians, policymakers, and other leaders to adopt a "grass tops" and "grass roots" approach to K-12 STEM education reform—one that focuses not only on the production of more and better qualified STEM teachers but also on the creation of a new generation of STEM-focused leaders.

To accomplish this, we argue that STEM education leadership should become a key component of all K-12 administrator preparation programs in the United States. Furthermore, special graduate programs and credentials should be created to educate and license school leaders who have been trained alongside teachers in hands-on STEM laboratory settings. We believe that this approach will help leaders understand the challenge of K-12 STEM education from the insiders' perspective.

These are, to be sure, ambitious goals, and we realize not everyone will share the vision we have offered in this discussion. However, we are cognizant that if we permit the status quo in American K-12 STEM education to persist while the rest of the world retools its educational systems to become flatter and more technologically savvy, we will indeed place our students and our nation in great peril.

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## Increasing STEM Capacity Though "Learn-by-doing" Pedagogy

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### Introduction

Education can be described as the interaction between teachers, students, and materials. It is the engagement of all three components that creates learning, yet efforts to improve learning typically focus on individual factors such as increasing requirements for teachers, introducing new curricula, or reducing class size. The question facing the United States in 2009, however, centers on how *leaders* can increase the capacity of teachers to facilitate improved student learning, especially in the arena of science, technology, engineering, and mathematics (STEM) education. The nation's requirements for workers competent in math and science are increasing, as measured by projected rates of job growth and job openings. For example, the top 10 fastest-growing occupations in California through 2014 require a math or science background (Rosin & Barondess, 2008).

Professors, administrators, researchers, and teachers met on July 1, 2009 at the 2nd Annual STEM Education Leadership Symposium at California Polytechnic State University San Luis Obispo. The focus of the symposium was challenging leaders to create systemic and sustainable capacity for STEM education. A constant theme that arose throughout the symposium discussions was the need to enhance instructional capacity through an inquiry-based, or "learn-by-doing," approach. One panelist said, "Teaching by inquiry is the national standard, not a method." Another panelist agreed, saying, "Teaching well and creatively is not contrary to teaching the standards. It's time to give that up. Doing a lot of stuff is not particularly inspiring; pounding in facts is not especially effective. Look at inquiry-based models, when they are done well, they are powerful ways to teach." A third panelist responded that implementing inquiry-based teaching would "transform" student learning.

Moderator Dr. James Gentilucci described what he called the leadership challenge for our nation: the critical need for K-12 leaders to create systemic and sustainable capacity for world-class STEM education in their districts and schools. Dr. Gentilucci stated that mandated instruction time, professional development, national standards, and public relations were only part of the solution for reforming K-12 STEM education. "No one is talking about the leadership aspect! We need the critical involvement of site and district level leaders," he said. "These are key stakeholders who promote or hinder capacity for [STEM] excellence."

## Literature Review

Included in the "learn-by-doing" focus is the underlying integration of physical, social, and human capital that co-exists in the pedagogy of education. For most schools in the United States, true hands-on, "learn-by-doing" STEM education has been limited since the No Child Left Behind Act (NCLB) of 2001 was enacted. Because of its failure to implement true reform in K-12 STEM education and improve the "pipeline" of gradates with STEM degrees, the United States is becoming more and more dependent on "international students and workers to fund its knowledge economy" (National Academy of Sciences, 2007, p. 112).

The National Academy of Sciences (NAS) has recommended that leaders improve student and teacher participation in STEM education and provide federal financial incentives for teachers to complete degrees in these core areas. Further recommendations for professionals include the need to fund professional development for teachers in STEM education through initiatives such as the Science-Teacher-and-Researcher (STAR) program at Cal Poly. "We need to recruit, educate, and retain excellent K-12 teachers who fundamentally understand (STEM) curriculum" (NAS, 2007, p. 114).

In conjunction with the NAS, the National Center for Improving Student Learning and Achievement in Mathematics and Science (NCISLA) conducted a study on how school organization and context influence the "learn-by-doing" change process (NCISLA, 2002). Fostering and sustaining this process requires the allocation of physical, human, and social capital. Physical, or material, capital includes items that can be bought, disseminated, or shared, such as computers and release time for teachers. Human capital involves knowledge or skills that can be shared with others, such as teacher mentoring and training. Finally, social capital encapsulates the qualities of relationships in an organization that result from human and physical resource exchange. Examples include support for collaboration in professional learning communities and the utilization of partnerships with the business community. Leaders must lend support for systemic and sustainable change of STEM education through instructional reform by encouraging professional development and staff collaboration, as well as focusing on ways to improve student thinking (NCISLA, 2002).

Carl Wieman (2007) stated the traditional pedagogical approach to teaching is no longer productive: "The traditional lecture is simply not successful in helping most students achieve mastery of fundamental concepts. Pedagogical approaches involving more interactive engagement of students show consistently higher gains on…tests" (p. 11). Teachers must be open to reform, which, according to Mintzberg's professional bureaucracy model, is not easy for most professionals (Bolman & Deal, 2003). The traditional approach to teaching science, and all other core curricular areas, must change. Teachers must collaborate with each other to design new learning experiences that are more active and participatory for students. When students engage in this instructional capacity, opportunities for active participation ("learn-by-doing") are endless (Collicott, 1991).

Student achievement is an important aspect of the "learn-by-doing" process in STEM education. Students must be actively engaged in the inquiry and understanding process. Spillane et al. (2001) found that STEM education is devalued in urban elementary schools because teachers often believe children from low-income families are incapable of handling instruction beyond basic skills, so the primary focus of learning is in language and mathematics skills acquisition. To implement successful STEM education, leaders must believe that students of all ages and socioeconomic status can benefit from the "learn-by-doing" instructional process. Leaders must mobilize school personnel and clients (stakeholders) to undertake the task of changing instructional techniques, as well as identifying and activating the resources needed to support this process (Spillane, Diamond, Walker, Halverson & Jita, 2001).

For years, data analyses have demonstrated that U.S. students' math and science achievement are far below acceptable when compared with those of students around the globe. According to Rosin and Barondess (2008), in the United States, Asian and Middle Eastern subgroups have been the most proficient in math and engineering, and they have been the top graduates in higher education. Approximately 38% of high school graduates must take remedial math courses as college freshmen (Rosin & Barondess, 2008). Science may only be briefly taught in 5th, 8th, and 10th grades because science is on the standardized tests at those grade levels but not at others. In addition, many high school students are not motivated to acquire a STEM education or career. Many students stated emphatically they did not want a career in which they were required to use higher order thinking skills, such as those used in STEM careers (Rosin & Barondess, 2008).

Strong leadership from school site administrators and superintendents must support STEM education reform, professional development of teachers, and improved instructional practices, including the "learn-by-doing" approach. Superintendents must be actively involved with student learning and the teachers who are educating the students. They must take part in the "learn-by-doing" process by stepping out from behind the desk to visit the classrooms, to promote and provide continued professional development towards STEM education, and to develop trust with the leaders and the professionals they serve (Petersen, Sayre & Kelly, 2007).

**Synopsis of Symposium Discussion**

Several local educational leaders served as guest panelists at the STEM Symposium on July 1, 2009. They described their personal experiences in education and leadership and presented numerous recommendations for "increasing capacity" for STEM education excellence. They also answered specific questions from Cal Poly Educational Leadership and Administration Program (ELAP) graduate students about STEM education.

Sarah Cameron, middle school science teacher from Santa Maria-Bonita Unified School District, expressed frustration with accountability measures that result in elementary teachers being told, "science doesn't matter because we have to focus on language arts and math to improve our test scores." Fortunately, several strategies and programs are in place to increase her instructional capacity and accommodate science standards. These include AVID (Advancement via Individual Determination), an in-school academic support program, and a partnership with Cal Poly science faculty that provides many hours of professional development and access to the university's "Learn-by-Doing" lab.

Dr. Susan Elrod, director of Cal Poly's Center for Excellence in Science and Mathematics Education (CESaME), recommended school leaders take advantage of current state and national interest in funding STEM initiatives. She also spoke about the work of CESaME, founded in 2004 with the goal of increasing the number of math and science teachers at all educational levels. Dr. Elrod described another resource to increase teacher capacity: the Science Teacher and Researcher (STAR) program, now in its third year. STAR's goal is to place aspiring and early career teachers in research institutions and federal labs such as JPL or NASA during the summer to "produce a new kind of math and science teacher-researcher, with a dual professional pathway," she said. STAR leaders also conduct weekly workshops connecting science teaching with practical experience as well as the reverse: helping science students connect with teacher training programs. The hope is those teachers, future educational leaders, will someday help others connect math and science with their real-world applications.

Dr. Ed Valentine, superintendent of San Luis Coastal Unified School District, echoed the concept of real-world applications. He believes that, overall, the teaching workforce is not prepared to teach STEM subjects, but that efforts toward that goal are encouraging. He asks himself as a leader: "How can I use all the tools of education to promote inquiry?"

Dr. Valentine believes that "sustainable reforms are more likely if they come from within rather than having been imposed from without." Referring to No Child Left Behind Act (NCLB) accountability measures, he believes that rather than viewing literacy goals "as a mountain so crucial you can't get around it," a more effective strategy is to "go through the territory of language arts in order to get to STEM." Dr. Valentine advises schools to utilize social studies as content for language arts and science as content for math. The point, he says, is "to recognize that STEM is compatible with effective language arts, math, reading, and writing. These must be applied, because students learn by doing. That is the kind of reform that makes STEM a viable commodity in the NCLB rigid world we live in." Moderator Dr. Gentilucci agreed, stating, "It's not STEM or literacy. It's STEM *and* literacy."

Arroyo Grande High School Principal Ryan Pinkerton described several strategies he employs to increase capacity for STEM education excellence. He received a grant to send a teacher for training in inquiry-based instruction not only to help students in the school's engineering lab, but also to train other teachers. He called it a "critical piece of passing it on."

Dr. Shirley Magnusson, Cal Poly elementary education expert, supports such professional development but adds that in our country "we don't have a model that supports the development of teachers. Countries that outperform us do more for continuing education of their teachers."

Dr. George Petersen, panel discussant and Cal Poly professor, distilled the themes discussed at the symposium into "the importance of learning" and the responsibility of leaders to enhance learning through increasing instructional and organizational capacity. He then described four ways of looking as the issue, through the political, structural, human resources and symbolic frames.

The political frame includes the responsibilities of administrators, university faculty, and teachers to understand accountability and other external issues that drive literacy and STEM education. Leaders must consider national and state policies, funding—both actual and expected—as well as stakeholder expectations and requirements.

Leaders can increase capacity through adjusting organizational structure, the second frame, Dr. Petersen said. This includes decisions on curriculum, scheduling, professional development activities, and adapting theoretical models to actual school situations.

The human resource frame focuses attention on the importance of children, teachers and administrators and the need to create instructional capacity. "It is evident there is a need to enhance teacher ability to understand and teach science," Dr. Petersen said, referring to the success of the AVID, CESaME and STAR programs to train teachers to apply their learning. He cited Mr. Pinkerton's efforts to hire a physics teacher and provide release time for professional development and Dr. Elrod's desire to create math and science literacy so teachers can successfully engage students.

Dr. Petersen also discussed the use of symbols to understand the issue. He asked, "Is STEM a priority perhaps only symbolically? We hear a lot of people talking about how important it is, but what is said is not always what is meant." He referred to some teachers in schools designated as being in Program Improvement being told to ignore science in favor of math and language arts.

Finally, Dr. Petersen summarized the priority for instructional leaders; that is, we must fashion policies, collaborations, environments, friendships—"whatever it takes"—to create capacity for teachers to enable their own learning and be successful in the classroom.

ELAP students asked panelists several questions related to STEM education leadership. One addressed the issue of funding in difficult economic times, and how expenditures for STEM education programs could be justified under current funding constraints. Panelists responded it would not be difficult to justify programs that built scientific inquiry skills, captured students' imaginations, or assisted them in discovering interests and abilities. The issue is, however, are enough students prepared to learn? Dr. Elrod reminded the audience, "We don't have environments where children understand…the system is disconnected."

ELAP students asked panelists how to create and maintain buy-in from stakeholders for STEM education. Dr. Elrod replied that STEM teachers simply support the natural scientific curiosity of a child who is constantly asking "why?" about real world phenomena. Leaders must articulate to legislators and other state leaders these truths as well as advocate for connections throughout the grades, Dr. Elrod added, supporting Dr. Petersen's description of the political frame.

ELAP students then asked how teachers could use inquiry-based instruction without neglecting the facts needed to pass standardized tests. Panelists agreed this is a difficult problem, but cautioned not to use it as an excuse. *The real problem is to prepare teachers properly*.

Another ELAP question concerned the well-documented drop in student math scores from fourth grade to middle school. Graduate students wondered if it would help or compound the problem to force 8th graders to take algebra. Panelists commented on the developmental needs of middle school children, including autonomy and peer relationship issues that can make it difficult to interest them in academics. Another problem may be that many students are not prepared for higher-level thinking. Yet, Mr. Pinkerton said, students need to take algebra. Ms. Cameron concurred, saying that even though middle school is a tough environment, if students are in a safe classroom, they will succeed.

A final question dealt with how leaders can activate and mobilize the resources needed to create and sustain a culture of STEM education excellence. Mr. Pinkerton responded that site and district leaders must foster the kind of climate that motivates and encourages teachers and staff. Ultimately, however, this is a question of education in general, and it is a question of what is in the heart, said Dr. Valentine. "When these priorities are in the hearts of the people, they stay, linger, and drive deep thought, deep conversations. If we start from the notion that children are precious and deserve our best…the best practices and techniques take care of themselves."

**Recommendations**

Increasing the teaching and quality of STEM education in K-12 schools will require a concerted effort by all stakeholders in education, improved collaboration with the business and university communities, mobilization of physical, human and social capital, and, most importantly, inspired and visionary leadership (see model presented in Appendix A). Educational leaders must face the challenge of changing an educational culture that is focused on standards of reading and math, and funded accordingly. With the increasingly advanced forms of technology changing the nature of industry, it important that all students, not just those who plan to pursue a STEM profession, are exposed to a solid foundation in STEM to help them be competitive in today's workforce.

The leadership role of educational administrators, from the district superintendent to the building principal, will be to make enhanced teaching of STEM a top priority in K-12 schools and beyond. Creating and fostering a unifying vision for this purpose will be the first and most important step towards achieving this goal. A well-established vision transcends the dependence on an individual dynamic leader and ensures that the capacity of the school to teach STEM is perpetuated. This will ensure the change is systemic and sustainable.

The vision must fully describe, "Where we want to go" as a nation, state, district or individual school. The leaders must clearly define the school's goals and strategic plan. If the vision is to strive for and maintain STEM literacy, then it is important to articulate in the plan exactly what is meant by STEM literacy. All stakeholders must understand that STEM literacy is an interdisciplinary area of study that bridges the four subject areas of science, technology, engineering, and mathematics. STEM literacy is a shift in the educational process that moves away from students learning discrete pieces of material and creates an emphasis on design and problem-solving situations that weave together the disciplines through relevant real world topics.

The teaching of STEM can be effectively enhanced by the adoption of a pedagogy that will ensure more effective learning, generate and sustain student interest, and demonstrate for students the relevancy of the subject matter. This so-called "learn-by doing" approach has been utilized successfully in many universities and is the hallmark of Cal Poly. In addition, current educational debate in Europe proposes a similar re-thinking of the way STEM is taught. It is essential for teachers to "change their pedagogical methods… a shift from the traditional, mainly deductive science-teaching pedagogy to inquiry-based methods ('learning-by-doing method') to combat young people's waning interest in science" to develop a "scientific way of thinking."

Since STEM classes are currently so underrepresented in the academic scheduling of students, it makes sense to maximize the limited amount that exist. As Wieman (2007) states, "Our society faces both a demand for improved science education and exciting opportunities for meeting those demands. Taking a more scholarly approach to education—that is, utilizing research on how the brain learns, carrying out careful research on what students are learning, and adjusting our instructional practices accordingly—has great promise" (p. 15). He claims that student comprehension and retention of subject matter are vastly improved with "learn-by-doing" style pedagogy.

The ideal model of STEM education is a system that begins prior to elementary school and continues through the university level. Developing this awareness early in children's academic careers is necessary to capture and maintain student interest in STEM fields throughout primary and secondary school. An imperative aspect of STEM education is to provide support outside the classrooms via expanded learning opportunities that develop and sustain student interest. This could be done through after school and summer learning programs. Alexander, Entwisle, and Olson (2007) proved the existence of "summer slide," a condition occurring when children fall behind academically during the summer months because of lack of stimulation. While affluent children make academic gains during the summer due to the plethora of enriching opportunities their parents can provide for them, their poorer counterparts lose ground. The intent of such programs would be to complement what students learn during the school year by providing them with enrichment projects and access to community resources that spark interest in STEM-related activities. Students would then have a greater understanding of the real world significance and relevance of these subjects.

The NAS (2007) also calls for summer research programs to implement inquiry-based learning. Such programs would involve public-private partnerships for sustainable funding and should make a special effort to ensure low-income and minority student participation.

Increasing "learn-by-doing" teaching methods in STEM will require school leaders to mobilize human capital to ensure that the best teachers are in the right assignments. Human capital can be developed through appropriate professional development. As the National Governor's Association (NGA) stated, "Simply increasing the number of STEM teachers through financial incentives and other recruitment strategies will not solve the problem. States must also support high quality preparation and professional development for teachers that lead to improvements in large numbers of classrooms" (2007, p. 1). A shortage of STEM teachers in the United States has been directly linked to the low quality of STEM education in this country. The United States faces a critical shortage of highly qualified math and science teachers—projected to reach 283,000 by 2015 (National Governors Association). This shortage is particularly noticeable in low-income, urban school districts in the United States. These geographical areas also have difficulty retaining highly qualified teachers.

Since a "learn-by-doing" style of teaching will likely require additional physical capital, school leaders must secure additional funding. This will require available social capital to secure support for this cause and foster "a sense of obligation" to this mission (Spillane et al, 2000, p. 920).

As these authors illustrated, identifying and activating resources for accomplishing the goals of STEM is possible for competent resourceful school leaders, even in schools facing financial constraints. Establishing partnerships with universities, as well as private entities such as technology companies, will be an essential component of this endeavor.

The "learn-by-doing" model would further benefit from supportive leadership from the state and federal levels of government. Redesigning the state's STEM education system may require an increased centralization of authority to the state while allowing appropriate local curriculum control by school districts. Acting on state and federally generated initiatives would give district leaders more authority to introduce necessary STEM policies. The NGA (2007) states: "Governors should lead efforts in their states to:

1. Align state K–12 STEM standards and assessments with postsecondary and workforce expectations for what high school graduates know and can do.
2. Focus on aligning standards and assessments with international benchmarks through state level participation in international assessments" (p. 1).

## Conclusion

Research has shown that practical, hands-on experiences contribute to student learning, especially in the areas of science, technology, engineering, and mathematics. This allows them to develop higher-level, critical thinking and problem-solving skills, which are necessary to be successful in the changing workforce. By continuing to rely on standard, lecture-style instructional models, schools in the United States are hindering their students' abilities to learn STEM subjects in a systemic and sustainable manner. According to Dr. James Gentilucci (2009), "The U.S. cannot sustain a first-class, technology-based economy with a second-class workforce."

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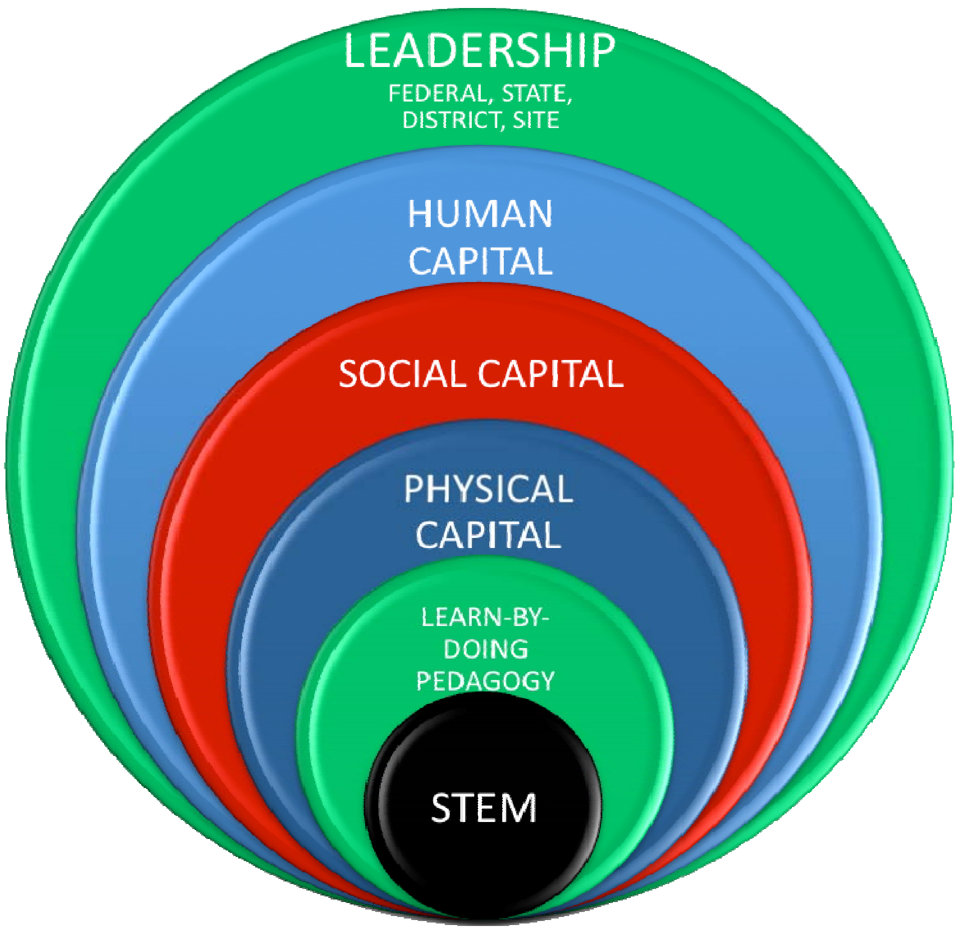
**Appendix A**

Model for Increasing STEM Capacity Though "Learn-by-doing" Pedagogy



# Raising the Ceiling: Expanding Capacity for STEM

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**Keywords:** Instructional Pedagogy, K-12 Leadership, Instructional Capacity, Instructional Practices

## Introduction

The task of improving education in the areas of science, technology, engineering, and mathematics (STEM) is critical for American political and educational leaders. Simply put, it is a matter of national security. We cannot stay at the forefront of technology and innovation if we must rely on other countries to provide properly educated, qualified individuals in STEM areas.

Capacity for improving STEM education must be expanded in two ways: vertically and laterally. Sustainable expansion is lateral. For innovative programs to continue over time, despite staffing changes, they must be both educationally effective and professionally rewarding. With both those pieces in place, programs have the greatest chance of being sustainable in the long-term. Systemic expansion is vertical. It is impossible to affect system-wide change while limited only to the classroom perspective. This study will focus on how to expand both lateral and vertical components of STEM education.

Building systemic capacity takes integration of all parts of the educational system (see Appendix A). The classroom teacher can expand her capacity but has a very limited power domain. At some point, she reaches a ceiling of sorts where the help of site and/or district leaders is needed. Administrators have the power to effectively raise the ceiling higher than teachers can, allowing for vertical, systemic expansion. Administrators have great power in this regard because they are the stewards of the system itself. Yet administrators can only go so far. They too reach a ceiling where they are not able to affect change without the help of other parts of the system.

Site and district administrators work within a set of constraints that focuses on available human resources and state policy. Universities and colleges offer training and professional development services that not only prepare new teachers but also affect the sustainability of veterans, further expanding the system's human component. State policy makers have the ability to raise the ceiling even higher by changing the very policies that constrain site and district leadership.

Lateral, sustainable change can happen independently at each of the aforementioned levels. But true, systemic capacity building must happen by integrating the efforts of all four levels. In this way, raising the ceiling becomes possible.

## Discussion

Excellence in STEM education will be achieved only through the multi-level integration of the vertical components of the educational system. To some degree, each level can expand capacity independently, but meaningful, systemic change will be maximized when each level complements the efforts of the others.

The "lynchpin" for excellence in the classroom is "*what* teachers know and *how* they are able to teach it" (Petersen, 2009). The *what* and the *how* are influenced by factors not limited to the classroom teacher. Site and district administrators, universities and colleges, and policies created at the state level are all critical components. Forces at each level contribute to the integrity of the lynchpin itself. If it is weak, the system falls apart, but if it is strong, the capacity for strengthening the *what* and the *how* expands exponentially.

To make STEM education systemic and sustainable, instructional capacity must first be achieved at the classroom level. Teachers are the "grass roots" in the systematic reform of STEM education (Gentilucci, 2009c). They may be the first, or only, contact a student has with STEM. Teachers are responsible for the education of students and facilitate students' interest in STEM. At the classroom level, lateral capacity for STEM education can be increased through cross-curricular teaching, professional development, and collaboration.

Since the inception of the No Child Left Behind Act of 2001 (NCLB), state testing accountability and scheduling mandates have driven the subjects that are taught and the allocation of daily instructional minutes in schools. As a result, at the elementary level, it is hypothesized that there has been a 50 percent reduction in science instruction time from 2000 to 2007 (Fulp, 2000, as cited by Gentilucci, 2009b). In some districts, an emphasis is placed solely on the instruction of language arts and mathematics. Teachers like Ms. Sarah Cameron (2009), a junior high school science teacher, have been told by site leadership that "science does not matter" because it is not assessed on state mandated tests.

While the middle school curriculum affords Ms. Cameron the ability to teach science, her elementary counterparts have been faced with the decision to prioritize which subjects they teach. When pressed for time, 16 percent of elementary teachers have eradicated science instruction (Fulp, 2000, as cited by Gentilucci, 2009b). To remedy this issue, Dr. Ed Valentine, San Luis Coastal Unified School District Superintendent, proposed that elementary teachers should not choose between STEM and literacy when designing instructional time; they must integrate the two. Science must be used as a content area for language arts and mathematics instruction. This cross-curricular approach will ensure that science is taught in every classroom (Fulp, 2000, as cited by Gentilucci, 2009b).

Many teachers view language arts and mathematics as academic areas that need to be mastered for student learning to advance to higher levels (Spillane, Diamond, Walker, Halverson, & Jita, 2001). Without these foundational skills, some teachers believe students will have no way to decipher and make meaning of advanced topics. Yet Dr. Valentine argued language arts and mathematics have no content. They are merely subjects used to access other curricular areas. He continued by explaining if mathematics is not used as a tool for other subjects like science, engineering, and technology, students will only acquire the ability to compute, not apply.

Integrating subjects is not always easy for teachers. The process takes time, experience, and resources, and professional development and collaboration with other teachers supports this process. Ms. Cameron spoke of the importance professional development has played in her science teaching career. Through the Advancement via Individual Determination (AVID) program and the California Mathematics and Science Partnership, she has improved her teaching skills and learned strategies that help her differentiate instruction in her classroom. Because Ms. Cameron is willing and able to attend professional development training, she promotes STEM education sustainability by being a lifelong learner of good teaching practices. Attending professional development workshops informs teachers about current best practices and allows them to learn new ways to meaningfully engage their students.

A study conducted by Adam Gamoran and colleagues found teachers place a high importance on collaboration with experts as necessary to their growth (National Center for Improving Student Learning and Achievement in Mathematics and Science [NCISLA], 2002). The study also cites that teacher communities cultivate continued learning and professional development. Ms. Cameron verified these findings through work with experts at Cal Poly and collaboration at her school site. She observed that students' lack of basic science knowledge was because the subject was not emphasized at the elementary level. Through collaboration with her colleagues, Ms. Cameron devised instructional methods to close gaps in her students' prior knowledge, making it possible to teach state standards in the required time.

Collaboration among teachers can be difficult at small or overly large school sites. To facilitate more collaboration, Ms. Cameron has drawn on resources from Cal Poly. She has Cal Poly students working in her classroom through the Teacher Apprentice Project, providing her with another means of collaboration.

Making cross-curricular teaching, professional development, and collaboration a priority will improve lateral instructional capacity at the classroom level. To engage in these activities, teachers must be flexible, innovative, and driven to ensure their students are getting the best STEM education possible.

In the quest to build systematic and sustainable capacity for K-12 STEM education, school and districts leaders play paramount roles. While extensive research has been devoted to improving STEM education, reform efforts are likely to be short-term and superficial without the support of these key leaders. According to Dr. Jim Gentilucci (2009a), site and district leaders are "the key stakeholders who either promote or hinder the creation of school- and district-wide capacity for excellence in STEM education". Cohen and Ball (1999) assert that capacity building is critical to good teaching and learning and should focus on the interaction between the student, teacher, and material. This can be achieved by site and district leaders promoting a culture that supports STEM education, facilitating professional development, building positive partnerships, and by making STEM education a priority when developing the school and district master schedules.

Promoting and nurturing a culture that supports STEM education is crucial to building both vertical and lateral capacity, ensuring sustainability at both site and district levels. Leaders have the responsibility to encourage inquiry-based teaching that extends to all subjects, not just mathematics and science. To do this, Dr. Valentine suggested retooling the workforce in education by urging teachers to consider how they can use all the tools in education to promote inquiry.

Teachers will know they are working in a culture that supports STEM when leaders make symbolic gestures to show the school and the community that science and mathematics do matter. For these symbols to have any lasting meaning, leaders must work to change teachers' attitudes about obstacles. Dr. Valentine encouraged teachers to challenge themselves and their students to not hide behind obstacles such as the standards. This attitude was echoed by Mr. Ryan Pinkerton, Principal of Arroyo Grande High School, when he conveyed the thought that getting kids excited about education and hooked on being curious learners is more important than test scores. This shift in attitudes is substantial and necessary considering elementary teachers currently spend significantly less time on science because it is not fully integrated into NCLB's measurement of Adequate Yearly Progress (Rosin & Barondess, 2008).

Creating opportunities for teachers to participate in meaningful professional development is another way site and district leaders can build STEM capacity and sustainability. In a multiyear study of the elements that contribute to fostering and sustaining instructional change, Gamoran and colleagues found professional development to be the engine of change (NCISLA, 2002). To be effective, the professional development should be high quality, content driven, and supplemented with hands on training and curricular materials teachers can take to use in their classrooms (National Academy of Sciences, 2007). This is especially important in the elementary grades because as it was unanimously expressed at Cal Poly's 2009 STEM Symposium, most elementary teachers do not enter the teaching profession with a strong science and mathematics background and are often uncomfortable teaching those subjects.

In addition to helping teachers become more engaged with STEM curriculum, professional development should also expand teachers' abilities for sparking students' curiosities about inquiry based education. Ms. Cameron demonstrated the importance of professional development by sharing her experiences with AVID. Through AVID workshops, Ms. Cameron learned how to teach her students to use an interactive notebook, enabling her to effectively differentiate instruction and the students to ask questions at higher cognitive levels than before.

While professional development can successfully create STEM capacity, leaders must be careful not to think of professional development as what Dr. Shirley Magnusson (2009), a Cal Poly professor, referred to as "quick fixes". In fact, Dr. Magnusson cited research revealing there is a three year time frame to sustain professional development. As a result, it is not only crucial for leaders to create opportunities to participate in professional development but also to incorporate time within the schools' and district's master schedules for teachers to collaborate with their colleagues. This collaboration is vital for teachers to reflect on their training and develop curriculum that incorporates the new pedagogy they acquire. As recommended by Mr. Pinkerton, through the development of a Professional Learning Community (PLC), teachers will be able to collaborate and build shared vision by building shared knowledge and examining best practices for helping students learn at high levels (DuFour & Eaker, 1998).

Block scheduling at the junior high and high school levels is a second way site and district leaders can facilitate STEM capacity through scheduling. Longer periods are especially favored by science teachers because it allows their students to complete labs that cannot be completed in a traditional period.

The last step district and site leaders can take in building systemic and sustainable STEM capacity is developing positive partnerships with institutions of higher education, businesses, and community organizations. Mr. Pinkerton expressed the advantages his school has experienced from partnerships with the California State University (CSU) system and specifically with Cal Poly. Student teachers have proven to be valuable resources in mathematics and science, and Mr. Pinkerton's English teachers have been trained to teach the specific skills their students' need to be successful in college. While this English training is not directly related to STEM education, Mr. Pinkerton foresees that such a model, and the relationship his school has established with the CSU system, can be utilized to strengthen his school's science and mathematics courses as well. In addition to Mr. Pinkerton, Ms. Cameron also conveyed the invaluable relationship her district has established with Cal Poly. Because of this relationship, Ms. Cameron has learned to teach the California State Standards through inquiry based labs, and she has been able to expand the type of labs her students can participate in as a direct result of materials donated by Cal Poly.

School and district leaders have the professional responsibility to do more than just support the everyday efforts of their teachers. They must promote a culture within their organizations that supports STEM education by facilitating professional development, forming positive partnerships, and adjusting schedules to meet the special needs of STEM classes. When this capacity building is accomplished, sustainability will naturally follow. As Dr. Valentine (2009) expressed, "when things are in the hearts of the people asked to do them, those things will stay".

Creating capacity for excellence and sustainability in STEM education is reliant on the development of our teachers during their credential programs and throughout their working careers. Universities are vital in providing content knowledge and capacity in several areas, including comprehensive credentialing programs, professional development, and hands on learning environments to get students and teachers excited about STEM. Collaboration between universities and school districts will help support the mission of expanded capacity and sustainability.

Comprehensive credentialing programs that include instructional training in the area of STEM are vital to increasing teacher capacity. "STEM departments would collaborate with colleges of education to develop teacher education and certification programs with in-depth content education and subject specific education in pedagogy" (National Academy of Sciences, 2007). The current merger between the College of Education and the College of Science and Mathematics at Cal Poly is a prime example of this form of credentialing program. This link between the two colleges will play an important role in exposing students in both fields to STEM education and its applications in the K-12 classroom. Dr. Phil Bailey from the College of Science and Mathematics stated the goal of the School of Education is to train students to be excellent teachers in the field of science and mathematics. Leadership's vision is the first step in creating a comprehensive credentialing program that creates capacity for STEM education, but the true challenge is in its implementation.

Cal Poly has implemented several exemplary programs to build the capacity for STEM within the K-20 classroom environment. One example is the Center for Excellence in Science and Education Mathematics, which incorporates a vision of improving K-20 STEM education by developing the teacher pipeline. In addition, the Science Teacher and Researcher program is helping to create a new career path that focuses on a dual professional role that incorporates both pedagogical and research components. This will assist in developing more K-20 professionals who are teaching in their fields of study while continuing to improve their content knowledge through professional research studies.

It is vital to the field of STEM for teachers to have a working knowledge of how to incorporate unfamiliar curriculum and enhance student learning. Cal Poly's philosophy of 'learn by doing' promotes an educational culture of applying classroom learning to hands on experiences. The Learn by Doing Lab is one way Cal Poly is working to bridge this gap. This lab offers college students the chance to experience teaching, often for the first time, and understand how to implement inquiry based learning. This lab also gives teachers exposure to new techniques they can implement in their classrooms.

Professional development through collaborative partnership with universities is one way for leaders to find inexpensive and valuable training for their teachers. Research on the relationship between teacher quality and student learning demonstrates the importance of professional development (National Academy of Sciences, 2007). Several programs have been developed at Cal Poly to foster such professional development of current teachers. Programs such as California Math and Science Partnership, Central Coast Science Project, and Modeling Science Project Workshop focus on building lateral capacity. All three of these programs concentrate on teaching educators how to engage children in STEM education and connect them to curriculum.

Leadership is slowly shifting its philosophy from teaching teachers how to teach, to teaching teachers how to learn and how others learn. Universities are one of the key components to producing more and better teachers in the field of STEM education, and Cal Poly offers leadership in this area. Systemic capacity is created though comprehensive credentialing programs and ongoing professional development via hands-on experience. The mission of creating both vertical and lateral capacity for excellence and sustainability in STEM education is reliant on our universities for support and direction. Through continued support of programs focused on STEM education, universities can bridge the gap and help meet the world's evolving demand for skilled, human capital.

The ability of classrooms, sites and school districts, and universities to expand capacity for STEM education is dependent upon leadership at the state level. Without leadership from the state, sustainability is next to impossible. Governor Schwarzenegger instituted the California Teach program in 2005, which is designed to help the University of California and CSU systems quadruple the number of teachers they prepare annually ("Governor Helps Launch Program," 2005). In partnership with 18 private corporations, the Governor placed the state spotlight on STEM. While enticing more scientists and mathematicians into the ranks of the K-12 system is necessary to meet demand, it does not address the issue of sustainability or capacity. To expand STEM and make it a long-term priority, the state must provide significant changes in current policy.

A disconnect exists between the trend toward expanding STEM and the requirements of NCLB. "What's tested is what's taught" (Valentine, 2009). The first step toward building capacity is to place more emphasis on science testing as a part of the California High School Exit Examination and California Standards Tests. Until this happens, teachers and principals will be forced to choose between meeting state-mandated testing targets and STEM education. While science curriculum at the high school level is somewhat protected by A-G college entrance requirements, it is in danger of disappearing at the elementary level. Until the abyss between the tests and the espoused priority placed on STEM education is remedied, no sustainable change can occur. Through this vertical integration of priority setting, the potential for increased capacity would be substantially increased.

Collaboration and professional development are also critical components of professional education. More than just an opportunity for teachers to connect, collaboration and professional development work in concert to expand professional repertoires, disseminate current educational research, and create integrated programmatic improvement. In short, they expand capacity. Yet as budgets shrink and more emphasis is placed on NCLB requirements, inservice days and collaboration time have fallen by the wayside. Funding for organized, sustainable professional development is ad hoc at best. The state must introduce policy that not only allows for professional development but also funds it. Allocation of money is the state's most accurate representation of its priorities.

While the universities are meeting the challenge of expanding STEM education, they are hampered by the current credentialing model. At the secondary level, the required credentials are single-subject. It can be argued that subject specialization is more and more necessary as subject matter becomes more complicated. Yet integration of curriculum, especially between science and mathematics but amongst all subjects, is critical for subject matter retention and higher level thinking skills. Furthermore, science teachers at the secondary level are hired into the science department without subject specificity. A teacher coming in with a background in chemistry would likely find herself teaching physics or biology as well because few schools can offer a full schedule of just one subject. If the state is truly committed to expanding capacity for STEM education, it must examine not only how many teachers are produced, but also how they are prepared and credentialed as well.

## Conclusion

This paper presented a concept for building capacity for excellence in STEM education by proposing a model based on lateral and vertical integration of leadership components. Leaders in the classroom, at sites and districts, in the college and university system, and at the state level all have the ability to affect change laterally. When vertically integrated, the efforts of these crucial stakeholders become magnified and systemic - the whole is greater than the sum of its parts. Both vertical and lateral capacity must be expanded to most effectively increase capacity for STEM education. With vertically coordinated and integrated direction of leadership throughout the system, the ceiling will be raised, and true excellence in STEM education will occur.

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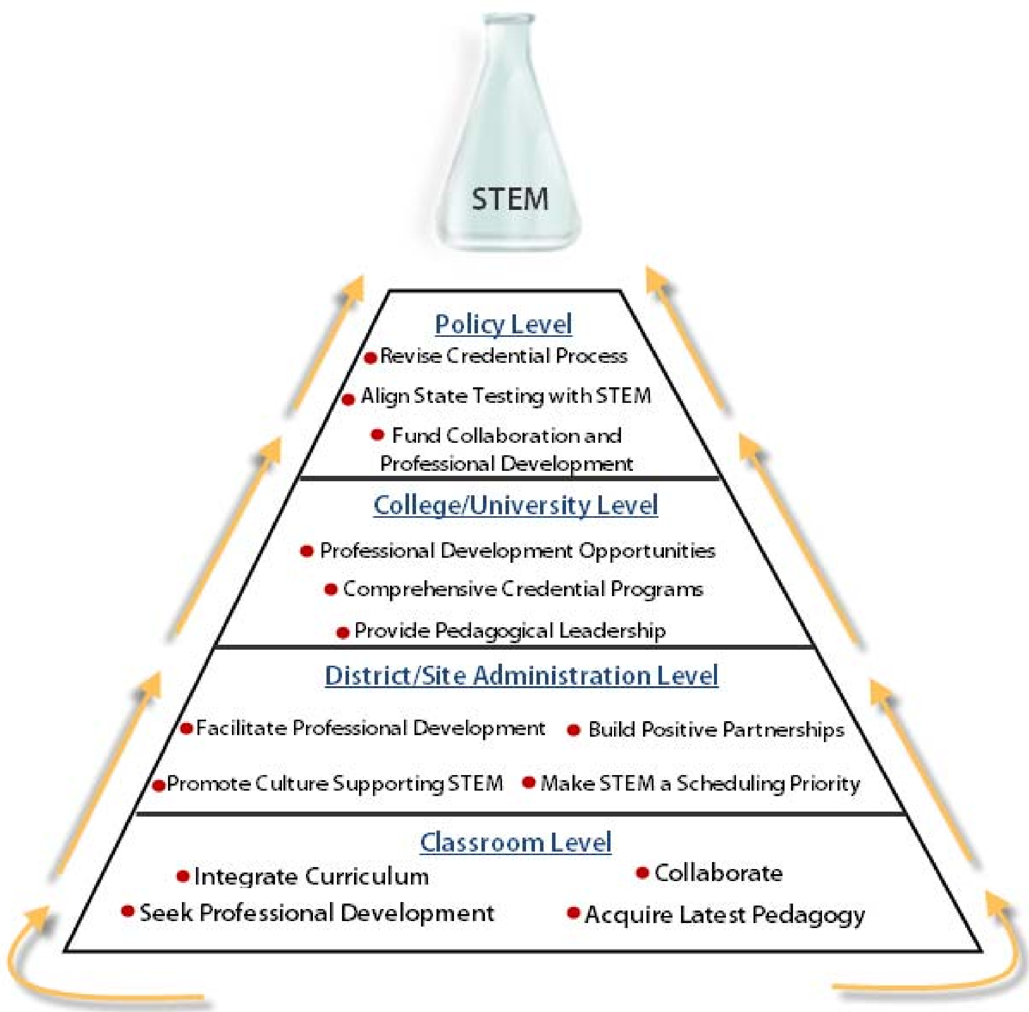
**Appendix A**

**STEM Model**



## Leaders Creating the Capacity for Excellence in STEM Education

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**Keywords**: Instructional Capacity, Teachers, Leaders, Instructional Practices

### Introduction

America's global competitiveness in the areas of math, technology and science education is forefront in the minds of educators and policy makers. When put side by side with other nations, U.S. student achievement is seen by many as inconsistent with the nation's role as a world leader in scientific innovation. Reports indicate that America is falling behind in the areas of science, technology, engineering, and mathematics (STEM). In fact, the National Assessment of Educational Progress (NAEP) has evaluated and monitored the progress of students' core subject knowledge since 1969. Their most recent appraisal came in 2005 and revealed that only approximately one-third of 4$^{th}$ and 8$^{th}$ grade students in the United States were scoring at the proficient level in challenging subject matter. For 12th grade students, the most recently published NAEP results in 2000 showed just 17% of students were proficient in the same subjects. (Kuenzi, J. J., Matthew, C. M., & Mangan, B. F., 2007).

The need for improved proficiency in math and science education began in the early 1990's. Accordingly, the National Science and Technology Council (NSTC) was established by Executive Order No. 12881 on November 23, 1993, under President Clinton. The cabinet-level council was the principal means within the executive branch to coordinate science and technology policy across the diverse entities that make up the federal research and development enterprise. (NSTC, 2009). In 2002, congress appropriated $25 million toward STEM talent expansion programs, and again in 2004. In 2005, congress increased this amount to $25.3 million. The Science, technology, engineering and mathematics Talent Expansion Program sought to increase the number of students receiving associate or baccalaureate degrees in established or emerging fields within STEM. Additionally in 2004, congress appropriated $3 billion toward STEM education programs. Nearly three-quarters of these funds supported 99 programs in two agencies – the National Institutes of Health (NIH) and the National Science Foundation (NSF).

On April 25$^{th}$, 2007, the 110$^{th}$ congress passed the "America Competes Act", also known as the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act (Brown, 2007). This Act provided billions of dollars toward new STEM projects. It increased the National Science Foundation (NSF) funding from $5.6 billion in 2006 to $11.2 billion in

2011 and increased the Department is Energy's Office of Science funding from $3.6 billion in 2006 to $5.2 billion in 2011. It authorized the National Institute of Standards and Technology (NIST) from approximately $703 million in 2008 to approximately $937 million in 2011. In addition, the America Competes Act allocated grant money to be used toward STEM education and the promotion of science and math training for current and future teachers (The Library of Congress, 2007).

In December of 2007, a report issued by the National Academy of Science (NAS), Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (also known as the *"Augustine"* report), brought further attention to the problem in America regarding poor student achievement in science and math, offering several recommendations to achieve success. Many of the recommendations in this report matched those of the Bush Administration's American Competitiveness Initiative. The five identified recommendations sought to: 1) increase the supply of new STEM teachers; 2) improve the skills of current STEM teachers; 3) enlarge the pre-collegiate pipeline; 4) increase postsecondary degree attainment; and, 5) enhance support for graduate and early-career research (Kuenzi, J. J., Matthew, C. M., & Mangan, B. F., 2007). With all of these STEM-based policy initiatives and funding becoming available, one would think our students' test scores would be improving – so, why aren't they?

**Literature Review**

Research has demonstrated, for some time, that the United States is in need of producing students, teachers, and other professionals who are both competent and skilled in the areas of science, technology, engineering and mathematics or STEM (American Institutes for Research, 1999; Kuenzi, Rosin & Barondess, 2006; Matthews, & Mangan, 2006; National Academy of Science, 2007). Numerous reports and studies have articulated that the United States may have lost sight of the importance of scientific literacy for its citizens (American Institutes for Research, 1999; Kuenzi, Rosin & Barondess, 2008; Matthews, & Mangan, 2006; National Academy of Science, 2007). America's tepid attitude toward the development of a systemic and sustainable method of bolstering STEM literacy is evidenced in our nation's schools. As a result of the lack of interest and investment in STEM programs in today's schools U.S. has become increasingly reliant on international students to fuel our human capital economy (Petersen, 2009). It is a fact that in the 1970s the United States produced over fifty percent of the world's science and engineering doctorates and today it produce less than fifteen percent (2009). The need for science, technology, engineering and mathematically skilled professionals is so great that the Congressional Research Services have published a report with recommendations to Congress (Kuenzi, Rosin & Barondess, 2006).

In a 2006 report from the Congressional Research Services (CRS) the authors state, "there is growing concern that the United States is not preparing sufficient number of students, teachers, and practitioners in the areas of science, technology, engineering, and mathematics" (p.13).

Exacerbating this situation are some recent studies indicating that a large majority of secondary schools employ teachers who are lacking adequate subject matter competency and students are failing to reach proficiency in STEM related areas (Barab & Luehmann, 2003; Kuenzi, Rosin & Barondess, 2006; Corcoran & Goertz, 1995). In a major study of today's schools it was found that eighty percent of K-5 teachers report spending less than sixty minutes each week on science, and sixteen percent of teachers are spending no time on science at all (Gentilucci, 2009). In response to recent national attention, the less than adequate STEM education system has received several pieces of legislation aimed at addressing the issue (Kuenzi, Rosin & Barondess, 2006).

A large body of research has been devoted to improving science, technology, engineering, and mathematics education in the United State's schools (National Center for Improving Student

Learning and Achievement in Mathematics and Science, 2007). However, it has been shown that such improvement has minimal likelihood of effecting long-term progress without the support of both site and district leaders (Petersen, 2009). School leaders must receive well-designed education and training to help them more effectively lead STEM education. The solution to the STEM problem rests on educational leaders' ability to create organizational capacity and in the end, effect instructional capacity.

Instructional capacity refers to an "organization's capacity is its potential to perform- its ability to successfully apply its skills and resources to accomplish its goals and satisfy stakeholders' expectations" (Petersen, 2009). Instructional capacity is the "ability to produce worthwhile and substantial learning by influencing the interactions between teacher, student, and material (Petersen, Sayre, & Kelly, 2007). As Petersen, Sayre, and Kelly's study points out, organizational and instructional capacity in schools hinges on roles played by all educational leaders in a school district, including the superintendent (Petersen, Sayre, & Kelly, 2007).

Rising to the challenge and addressing the need of students is a matter of national security and economic competitiveness. Legislation proposals have been drafted to address U.S. economic competitiveness in general through specific support of STEM education in particular (Kuenzi, Rosin & Barondess, 2006). The proposals, drawn from recommendations offered by the scientific and business communities were designed to improve output from the STEM educational "pipeline" at all levels (Kuenzi, Rosin & Barondess, 2006). The challenge to the United States now is to produce educational leaders capable of creating the organizational capacity needed to promote, support and sustain STEM education in today's schools.

*Leadership for STEM Reform*

The future of STEM education is dependent on the efforts of many individuals and groups. None more key than educational leaders. In their role, they will either promote or encumber the creation of school- and district-wide capacity for excellence in STEM education" (Petersen, 2009). According to Professor Gentilucci our educational leaders have demonstrated inconsistency with respect to the implementation of systemic and sustainable STEM education (Educational leaders have not yet identified STEM reform as a priority for policy initiatives, nor have they formed a collective vision for STEM education and much needed research. From these missteps, our educational leaders have failed to prioritize and allocate the resources necessary to develop systemic and sustainable STEM education. The United States must begin producing educational leaders who are capable of creating the organizational capacity to promote, support and sustain STEM education in today's schools. (Gentilucci, 2009).

The administrative leadership at the district level must understand how crucial it is to hire teachers who are specifically educated in STEM; for without strong leadership and guidance at this level, America will continue to lag behind its global competitors. Administrators must sustain and nurture that human capital by providing opportunities for all our teachers to participate in on-going professional development and professional learning communities (PLCs). Future educational leaders must make thoughtful and focused decisions towards creating an atmosphere of trust and support where teachers work together and strive to expand their individual capacity for excellence within a STEM-educated collective.

Educational leaders must re-think their roles and move from a "director model" to a "facilitator model;" a leader that draws connections creates collaborations, and supports the innovative initiatives teachers are taking. A leader who creates opportunities for shared decision making by distributing leadership roles throughout their organizations. Leaders who dedicate time for planning and learning, discussing instructional strategies with other teachers of how to better understand student thinking because they realize that is their most important material resource to expand instructional capacity. A leader who is capable of promoting individual growth is capable of generating renewable human resources; for by expanding the instructional capacity of the individual, he expands the institutional capacity of the whole.

Resources for STEM Reform

In order to create and sustain viable STEM programs, educational leaders must understand that STEM is not only an educational issue, but a political issue as well. In keeping Bolman and Deal's political frame in view, coalitions need to be formed by all the stakeholders to obtain the funding necessary for these STEM reform. The current state and national fiscal shortfalls are dramatically reducing school funding, there are limited resources being vied for by many. Funding for STEM initiatives must be undertaken with a voracious commitment to meet the immediate and future educational and economic needs of our state and our nation.

California is especially lagging behind in STEM educational achievement; this state needs leaders that will support STEM programs with more than words. It will be important that California taxpayers understand the need to support our STEM education reform with the necessary funds. Past trends reveal that it is very difficult to persuade voters to support additional funding for schools. It will be crucial to look beyond the well-known traditional sources for money. The National Science Foundation (NSF) has been a source of STEM funding; however, they alone cannot be expected to carry the financial burden. Of the 44,000 grant requests received by NSSF each year, only 11,000 are awarded. Additional financial support must come from outside conventional funding sources. Private industry is an obvious candidate for partnering, one that should be explored for all available resources.

Many private corporations are investing in STEM research by promoting science and math in schools. Technology-based companies, such as ExxonMobil are investing millions of dollars in company-sponsored programs. “Investing in STEM Education” is an outreach program sponsored by ExxonMobil that promotes science and math education by motivating students to learn and perform well in math and science courses. The program also provides professional development opportunities supporting the development of highly qualified math and science teachers (ExxonMobil corporation web site).

Bayer Corporation has also launched a new STEM Education guide aimed at forging business-education partnerships for grades K-12. General Electric, Intel, Lockheed Martin, Northrop Grumman, Rockwell Automation, and Autodesk have all made investments into STEM promotion and education. GE executives have characterized American's shortcomings in science and math as “incredibly serious.” He continues, “If innovation is to continue to be the principle contributor to American prosperity, we need to find and train more innovators.” (Reppert, 2008). STEM education has come a long way in a relatively short time, but time is not necessarily on our side. Cal Poly professor Dr. Shirley Magnusson says universities needs to work on creating a “STEM pipeline,” an environment in which new teachers are trained under the guidelines of STEM education in conjunction with scientific literacy (Magnusson, 2009).

If our schools were serious about meeting the needs of the future, it would behoove a district or school to employ a grant writer. Schools with Professional Learning Communities (PLC) would be able to assist the grant writer in choosing programs that would qualify for private grants monies. Toyota, W.K. Kellogg Foundation, Howard Hughes Medical Institute and the Coca Cola Foundation are just a few of the industries and foundations that could assist in the quest for STEM grant funds. Our nation's industry leaders know they have a vested financial and political interest in making sure that there are quality teachers in place who can direct future generations of students towards sustainable STEM industry careers.

While it is an uphill battle to procure funding from state, federal or private grants, it is our responsibility to our students and the future of this state and country. If the commitment to the future of this country's success is sincere, our leaders must be tireless in insuring that STEM programs are funded and supported so they may sustain and thrive.

*Teachers for STEM Reform*

Having a qualified staff is integral to a successful STEM program. Not only do the teachers need to be well educated in these areas, but the administrative leadership also needs to have a firm grasp on STEM concepts that facilitate and encourage the program to evolve. In order for a STEM program to succeed, the administration needs to be competent and ready for reform.

The optimal candidates for teaching these courses would professionals from the fields of science, technology, engineering or mathematics who then discovered or developed a desire to teach. These uniquely qualified researchers, scientists and mathematicians retain a wealth of real-world knowledge and innate curriculum content, while developing their teaching skills learned in a single subject teaching program, placing them in an essential, yet limited, recruiting pool. Making the decision to seek out and hire these "rare birds" would create a scientifically literate workforce; paying dividends in human capital to help pave the way towards creating a sustainable STEM-based environment.

As it stands now many districts, out of sheer need, are hiring teachers who may not have the best preparation or academic background to lead and teach STEM classes. This does not need to be. There are several programs at California Universities that are working towards repairing this issue. California Polytechnic State University at San Luis Obispo (Cal Poly) has a Learn by Doing Lab on its campus. This lab welcomes students in grades third through sixth to work with Cal Poly students on scientific experiments. The program encourages science majors at Cal Poly the opportunity to work with school-aged children. Many of them find they enjoy the experience and later decide to become teachers. This enthusiastic, motivated, and highly intelligent workforce is precisely what STEM courses need to get the students ready and eager to learn.

The Committee on Prospering in the 21st Century recommends a package for K-12 programs to recruit and train teachers. Among these recommendations are scholarships for science and math teachers. The four-year scholarship requires them to then teach for five years in a public school. To qualify, science, technology, engineering and mathematics departments would collaborate with colleges of education to develop teacher education and certification programs with in-depth content in education and subject-specific education in pedagogy. This is already happening at Cal Poly.

Another recommendation is to strengthen the skills of the teachers we already have. There are four parts to this program including: 1) summer institutes; 2) master's programs in science and math; 3) training for advanced placement and International Baccalaureate teachers; and, 4) the development of a voluntary national K-12 science and math curriculum.

Recruiting new teachers combined with strengthening the skills of the teachers we already have will ensure high quality, substantive instruction and education in STEM courses for our future scientists, engineers, mathematicians, and technologically advanced students. It would seem few factors are as important as this, if the United States is to successfully compete in the 21st century global marketplace.

## Conclusion

Simply put, our students' future success depends on the investments of our federal government, our states, our districts, our universities, school administrators, teachers, students and the communities across this nation all systemically working together towards the same goal. Commitment to excellence in STEM education requires a re-thinking of how our schools are organized. Our nation's educational leaders will need to prioritize STEM as a policy initiative, making focused investments of material, human and social capital towards that vision. If we are to receive dividends on these high-yielding investments, educational leaders and teachers must work together to better understand student learning, while building powerful collaborations aimed at continually improving and sustaining our nation's capacity for excellence in STEM education.

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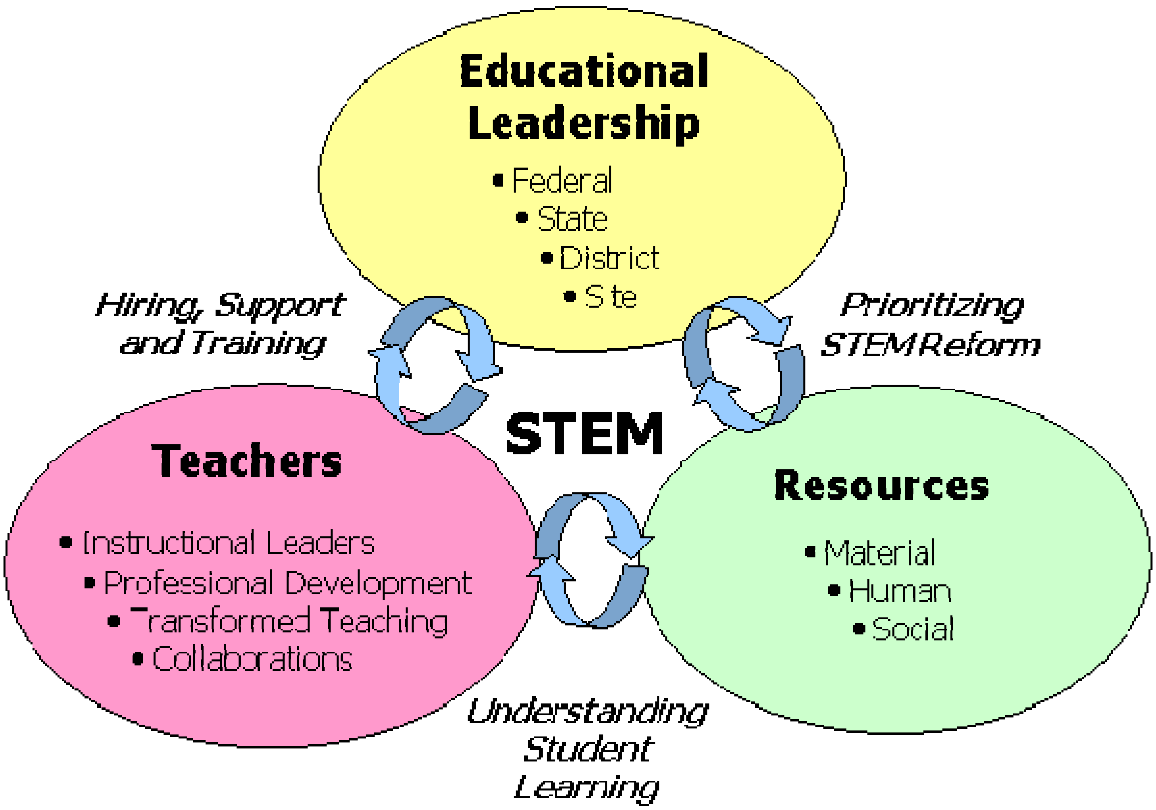
**Appendix A**

Model for Creating the Capacity for Excellence in STEM Education



# Spinning the Wheel of STEM Education

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**Keywords:** California workforce, STEM education, Federal and State Policy, Leadership, Professional Development

## Introduction

One of the main factors influencing California's future economic vitality is a well-educated workforce, and tomorrow's workforce is the population of students attending our public schools today (Rosin & Barondess, 2008). Therefore, science, technology, engineering, and mathematics (STEM) education should become a revolutionary movement that unites all Californians for change in public education. We should be reaching the common goal of achieving future economic success of the state through the intellectual products of STEM education.

In the search for variables that influence the improvement of STEM education in K-12 schools and colleges, one group of researchers has focused on the importance of inquiry based math and science education and designing of effective professional development (Carpenter et al., 2004; Youngs & King, 2002). The second group has identified the main components of organizational capacity (i.e., leadership, resources, teachers, and training) and multi-faceted challenges encountered while implementing STEM programs (Barab & Luehmann, 2003; Cohen & Ball, 1999; Kuenzi, Matthews, & Mangan, 2006; Petersen, Sayre, & Kelly, 2007).

To improve the STEM education, the provision of a variety of resources must be incorporated. For example, the material capital, in the form of money and supplies, need to be made available to improve science and math programs. Time for forming partnerships, developing new curricula, and teacher training for new programs must be provided. The social capital, in the form of trust and commitment of teachers and school administrators, needs to be established to enable a sharing of instructional materials and teaching experiences.

Moreover, leadership, partnerships, material resources, human resources, and social resources at schools and school districts all need to be addressed with vigor and detail (Spillane et al., 2001). These individual parts need to work together as one to create improved and superior STEM education that will address our nation's current concerns.

The proposed model of STEM education movement (see Appendix A) represents six key components (i.e., leadership, human resources, material resources, social resources, professional development, and partnerships) and six dimensions of sustainability (i.e., consistency, integration, integrity, inheritance, synergy, and linkage) that form capacity for excellence in STEM education presented schematically as a wheel. The success in STEM education requires California's educational system to have both the will and capacity to improve. 'To spin the wheel' of STEM education, leadership, budgetary concerns and constrains, media involvement, and educational policies at the federal and state level need to be reevaluated. Therefore, the model also identifies forces that would 'spin the wheel'.

**California's Future Workforce**

The California Employment Development department (EDD) projected the state's future workforce needs for the years 2004-2014 in jobs requiring mathematics, technology, and science-related knowledge and experiences. For example, jobs requiring a bachelor's or an associate's degree in technology (e.g., computer software engineers and network systems and data communications analysts or computer support specialists and health information technicians, respectively) will be among the most in demand. California will also need more medical scientists, biochemists, biophysicists, hydrologists, etc. that require a bachelor's degree, associate's degree or vocational training.

The research shows that "as California's technology and health care sectors expand, the demand for people who can use and maintain the new tools, processes, and information systems developed by the state's high-tech workers and researchers also expand" (EdSource, 2008, p. 3). Although California will have a large number of job openings in occupations that require less education and limited mathematics and science knowledge (e.g., waiters or office clerks), the research emphasized that these jobs will offer lower wages than the math- and science-related positions. Thus, the EDD projections make it clear that STEM education plays an important role in determining students' future opportunities and earnings and provide a foundation for students' learning of concepts and skills applicable in areas of adult life.

Although science and mathematics education are commonly cited together in research documents and discussions of future workforce competitiveness, the federal No Child Left Behind Act (NCLB) focuses teachers' attention on students' performance and achievements in mathematics and English language arts. Research shows that school districts increasing elementary instructional time in mathematics and/or English spend less time on science instruction (EdSource, 2008). Therefore, it remains unclear how STEM education as a movement would become more integrated into NCLB's measurements of schools' performance.

*Federal and State Roles in Promoting STEM*

Federal and state governments play an important role in promoting STEM education. For example, in 1984, the Eisenhower program was established. It funded professional development of science and math teachers through state agencies to school districts, institutions of higher learning or nonprofit. The goal of the U.S. Department of Education was to ensure that "a talented and dedicated teacher is in every classroom in America" (American Institutes for Research, 1999, p. 1). Creation of the National Science and Technology Council (NSTC) was the second step in coordination of STEM programs.

To increase the number of students studying in STEM fields and provide the quality of STEM programs, 207 federal educational programs were offered in 2004. About $2.8 billion was granted to several agencies (including but not limited to the National Science Foundation, the National Aeronautic and Space Administration, and the U.S. Department of Education) for provision of STEM-related programs. These programs had multiple goals (e.g., attract and prepare students at all educational levels to take courses in STEM areas, and ignite students' interest in pursuing STEM post-secondary degrees), provided multiple types of assistance (e.g., financial support for students and scholars, institutional support to improve quality of STEM education, and teacher and faculty development), and were targeted at multiple groups of students, teachers, faculty, scholars, and institutions.

However, a recent study conducted by Government Accountability Office (GAO) concluded that existing STEM programs are "highly decentralized and could benefit from stronger coordination" (Kuenzi, Matthews, & Mangan, 2006, p. 2).

STEM education emphasizes efforts to provide an effective curriculum as "a sequence of learning opportunities to students in their study of specific content" (Schmidt et al., 2001, p. 2**)** so they could succeed when they grow up and become the responsible citizens. Therefore, the government should provide a more direct impact on the development of STEM programs by allocating resources necessary for fulfillment of the potential capacity of STEM education.

"Today, business, media, and political leaders generally consider public education to be in crisis" (Fowler, 2009, p. 8). There is no doubt it needs some improvements, especially in STEM. Therefore, federal and state agencies should be involved in forming the public opinion about STEM education and its role in nation's welfare through the media and professional networks. Since the mass media, including print and broadcast media, wire services, online services, and the Internet, is an important actor in policy issues (Fowler, 2009), it should ignite and support a *public* political dialog about importance of STEM education. Providing information regarding: the changes in the future nation's and state's workforce; research findings in STEM education; and experiences of educators, businessmen, and ordinary community members, this dialog will form public beliefs in STEM education. As a result, assumptions would be made and policies would follow them on how to improve its quality.

Moreover, schools and school districts in California would be more successful in STEM education if they were to adopt the philosophy of engaging "the public in discourse that produces a vision for change, and built support for acquiring the resources necessary for change" (Kowalski, Petersen, & Fusarelli, 2007, p. 29).

*Creating capacity of STEM education in California*

In California, about 1,000 elected school boards, in unison with superintendents and other administrative leaders, make decisions that shape the local schools, school programs, and working environment for teachers and school administrators. They prioritize the programs, and provide a budget according to specific characteristics of each school district. The state Legislature and governor are the strategic apex of the educational system and they determine the mission and shape of the grand design focusing on the outside environment (Bolman & Deal, 2003).

Demanding state and federal expectations require that the system have both the will and capacity to improve. However, "years of reform efforts and the investment of billions of dollars have yet to create large-scale improvements in K-12 STEM education" (Gentilucci, 2008, p. 4).

The improvement of K-16 STEM education has not adequately progressed for several reasons. First of all, the implementation and sustainability of STEM programs require organizational and instructional capacities for STEM education, which are not built in all schools and colleges. Organizational capacity refers to the resources, knowledge, and processes employed by the organization; for example, financial resources, program and process management, and distributed leadership. Instructional capacity is a school's capacity to produce worthwhile and substantial student learning. It includes, but not limited to, teachers' qualifications and content understanding of material they teach. Both organizational and instructional capacities of public schools are in need of improvement. Second, capacity for excellence in STEM education must be both systematic and sustainable at all levels of the educational system.

## Dimensions of Sustainability

Capacity for excellence in STEM education must also be sustainable. Gamoran examined school sites where the educators were successful in teaching for understanding and identified four qualities of professional communities as dimensions of sustainability (National Center for Improving Student Learning and Achievement in Mathematics and Science [NCISLA], Fall 2002). One of the qualities "refers to trust, mutual expectations, and shared values that form the social resources necessary for a learning community" (NCISLA, Fall 2002, p. 7). This quality represents the *Integration* dimension of sustainability of STEM education. The second dimension is called *Linkage* and represents existing connections between the school professional community and the wider environment. This process allows members to integrate material and human resources.

Schools with coherence, competence, flexibility, and responsiveness to the change process have high organizational *Integrity* as another dimension of their sustainability in STEM education. Finally, *Synergy* dimension represents the relations between a school and community organizations in the alignment of STEM educational goals and efforts toward their achievement.

Thus, Gamoran has identified four dimensions of sustainability of STEM education (integration, linkage, organizational integrity, and synergy). However, analysis of the literature pertaining the science and math education has highlighted two more factors are substantial for sustainability of any initiatives (*Consistency* and *Inheritance*).

*Consistency of Efforts to Improve STEM Education*

Support for excellence in STEM education must be systematic and consistent throughout all levels of the educational system, i.e., federal, state, and local. The commitment to succeed in STEM education as a priority for school districts must start with the full support of the public, the federal and state governments. Consequently, school and district leaders must demonstrate their commitment to teachers' efforts in creating a statewide excellence system in STEM education.

*Inheritance of the Best Practices*

Best practices in the classroom, which work to excite students not just about STEM education but learning in general, are practices that need to be identified, highlighted, and copied throughout our schools. According to Barab and Luehmann (2003), best practices in sustainable education are not the same in every classroom or school. "The goal is not to develop teacher-proof curricula. Each classroom is a leg in the overall design experiment…[We should] not design some 'correct' version of curricula or assessment that will be implemented 'whole cloth' by willing teachers, but to develop flexible support structures that facilitate local adoption and ownership of each curriculum" (Barab & Luehmann, 2002, p. 456).

The most important structural change within the classroom is the transformation of the teacher from telling students about science, the traditional method, to guiding and facilitating students in exploring science. Teachers will be able to transform themselves by providing students with inquiry, project-based environments. Administrators at both the school site and district level can help to facilitate this change by designing teacher scaffolds that support and encourage teachers in making this adaptation. This will not look the same for every school, every district, or every classroom. Two examples of nation-wide programs for classroom adaptations include the Kids as Global Scientists Weather Program and Web-based Inquiry Science Environment (Barab & Luehmann, 2002).

*Human Resources*

The human resource frame is an essential lens to examine challenges facing STEM education. Carl Wieman, a Nobel Prize recipient in physics in 2001, believes America needs to produce technically literate citizens with the ability to problem-solve with ease. According to Wieman, educators need to transport student thinking from novice (pure memorization) to expert (deep thinking and problem solving). As a physics teacher, he has noticed that his students were becoming experts while completing projects. How do we approach teaching science so that our students become experts?

Science teachers need to be trained to require more than just the facts from their students. The traditional lecture needs to be enhanced with new pedagogical approaches that involve a more interactive engagement of students. Weiman (2007) suggested that new teaching methods must actively engage students, reduce their cognitive load, and address their belief system and misconceptions. Content is important, but not as significant as inquiry, which allows students to learn at the expert level.

In addition, teachers must be trained to stimulate and guide student thinking. Professional learning committees (PLC) need to be in place to create solid networks ensuring a sharing of materials and teaching practices. Current technology must be present to help students reach an expert level of problem solving. This allows them to strive to reach a deeper understanding of the content, and then appropriately apply their findings.

*Leadership*

Leadership is an essential piece of the mechanics of a successful 'spinning the wheel' (see Attachment A). It is defined as guiding and directing instructional innovations in schools (Spillane, Diamond, Walker, Halverson, & Jita, 2001). Spillane et al. (2001) conducted a four-year study focused on leadership at the elementary school level. Their aim was to improve science instruction. They studied school leadership and addressed the material capital (material resources including things bought, exchanged, disseminated or shared) and the social capital (trust and communication) needed for sustainable science education. Teachers were vital to this enterprise. When teachers have the expertise about curriculum and instruction the STEM fields and a passion for the subject, students learn at the expert level.

The research have also shown that "although science instruction is devalued in elementary education and resources for leading change in this instructional area are limited, some schools are able to successfully identify and activate resources to support leadership initiatives designed to transform science instruction" (Spillane et al., 2001,

p. 935). Moreover, Spillane et al. have concluded that teachers and educational leaders are at the apex of change in science education in elementary schools and consequently, in STEM education.

*Professional Development*

There is no single way to foster successful school reform. Increasing a school's capacity involves implementing several avenues of change. One such change involves promoting professional development to build school capacity. According to Youngs and King (2002) individual teacher competence is necessary for effective classroom practice. A school's capacity includes the skills and knowledge of individual teachers. "All teaching staff must be professionally competent in curriculum, pedagogy, assessment, and classroom management, and they must maintain high expectations for student learning" (Youngs & King, 2002). In addition to teacher competency, teacher collaboration in building school capacity must be present for effective change to take place.

Principal leadership influences professional development and school improvement. When principals' foster trust with their teachers and common goals are shared, change can take place. A principal can exert influence over teachers' work by

in providing: time for teacher collaboration; in-depth inquiry into assumptions, evidence, and alternative solutions to problems; shared goals for student learning; and opportunities for teachers (Youngs & King, 2002). It is the job of the principal to recognize the culture of his school site and to initiate appropriate changes toward shared common goals.

Moreover, research analysis of longitudinal data about Title II professional development also recognizes that professional development in STEM is effective when the teachers attend the trainings with longer duration of workshops (more than 3 days), specific content focus, collective participation, and active learning/inquiry based student activities (American Institutes for Research, 1999).

*Material Resources*

STEM education can thrive only when there are various types of financing available for new ventures. In California's current budget crisis, few dollars are currently available in the education sector for start-ups or new tools that are essential in STEM programs. Using existing public funds to encourage recipients to develop new STEM programs will be difficult; therefore, policy makers should create and sustain funding opportunities for all educational levels from kindergarten though high school as well as institutes of higher learning.

One such program that embodies the qualities of STEM education is the Templeton Biotechnology Institute (TBI) at Templeton High School. Created in part by Kristina Bolts, former science teacher at Templeton High School, the TBI is a cohort based science curriculum program for high school students that been named an "Exemplary Science Program" by State Superintendent of Public Instruction, Jack O'Connell. It was originally developed as part of the Specialized Secondary Program (SSP) that identifies teachers who have a passion for curriculum and is in its eighth year. A very impressive and important feature that has helped the program to remain sustainable is the TBI's fiscal independence from Templeton Unified School District, except for staff salaries and facilities cost. (Bolts, 2009). If California can support and encourage programs like the TBI around the state with start up funding, STEM education will have more opportunities to fulfill its mission of creating workforce competent in science and mathematics.

*Partnerships*

To improve STEM education, schools need to establish partnerships with businesses and communities. As Decker, Decker and Brown (2007) so astutely point out, educational partnerships take planning. To establish a partnership, the school must first formulate a plan defining immediate and future outcomes and goals (Decker et al., 2007). Then each partner's role in reaching the desired goals must be assigned in the plan of action along with a strategy to evaluate the implementation of the plan.

According to Decker et al. (2007), a successful partnership program requires five steps. These five steps include: 1) creating an action team; 2) securing funds to support costs incurred by partnership activities; 3) assigning the action team to evaluate the strengths in community and parental involvement programs; 4) develop a three year plan outlining goals and partnership committees, and a one year plan that explains the responsibilities of each committee; and finally, 5) implementing of the plans on an annual basis.

Educational partnerships can positively affect the quality of education if they are data driven, planned, and based on measurable objectives (Decker et al., 2007). In addition, when school leaders make partnerships a priority they can ensure success of STEM programs by communicating their importance to teachers, families and communities (Decker et al., 2007).

**Recommendations**

- Make STEM education a public concern by creating a grassroots movement from the parents of school children, participating educators, and leaders of business. State leaders have a critical opportunity to communicate their commitment to support promising STEM education, to inform the public and educators about the success and potential benefits of STEM education, and to provide a forum for addressing the barriers that hinder effective programs.
- Use public policy to encourage financing for STEM education.
- Query school districts. This process can be used to assess schools' and districts' openness to STEM education programs, evaluate educational and administrative practices, and eliminate outdated rules and practices that impose a barrier to maximizing the benefits of STEM education today.
- Engage partnerships and investors. Partners and investors can help jumpstart many STEM initiatives by providing seed funding and co-funding alongside the school financial system. Provide evidence to businesses and outside investors that STEM education will benefit them with a more skilled workforce.
- Provide a sustainable funding model for innovative STEM education projects. Don't just give one-time monies; teach programs how to develop outside funding sources. Self-sustainable projects are more likely to survive the budget crisis.

- Encourage administrators at the district and site level to provide leadership for professional development to build school site STEM educational capacity.

## Conclusion

We all know that our schools are vital to California's future. We believe that our educational ideology and culture shape our schools and that deliberate transformation of school policies has a place in that shaping. After receiving and analyzing information focused on California's economic future and STEM education initiatives, any reasonable individual would grasp the importance of STEM education more fully, would realize that more careful study of its capacity elements and components is needed, and would support the wise use of STEM education resources as a top priority in California's public education.

Constructing a model of STEM education movement, we focused on six key structural components and six dimensions of sustainability that define the capacity for excellence in STEM education. By exploring literature on decision making around the structural components, we verified research findings corresponding to four dimensions of sustainability of STEM education defined by Gamoran (In Brief, 2002) and identified two additional dimensions, i.e., inheritance of the best practices and consistency of federal, state, and local support for STEM education. By analyzing who makes decisions about each of the structural components, we defined forces that push the STEM "wheel" to reach its educational aims, goals, and purposes. Moreover, we differentiated each of the structural components in more detail to make our investigation more fine grained. As a result, we concluded that the lack of public interest in STEM education is the greatest constraint on successfully creating a systematic and sustainable capacity for STEM education.

A critical ingredient of the public interest – clear informational and statistical data that indicates how STEM education is important for the state's prosperity in the 21st century and how well STEM programs are working – is largely missing in the informational domain provided by the mass media.

By removing barriers to STEM innovation movement and by providing greater support for creation of systematic and sustainable capacity for STEM education, educators will be able to stimulate student interest, learning and understanding of science, technology, engineering, and mathematics, and therefore, to influence the future economic vitality of California.

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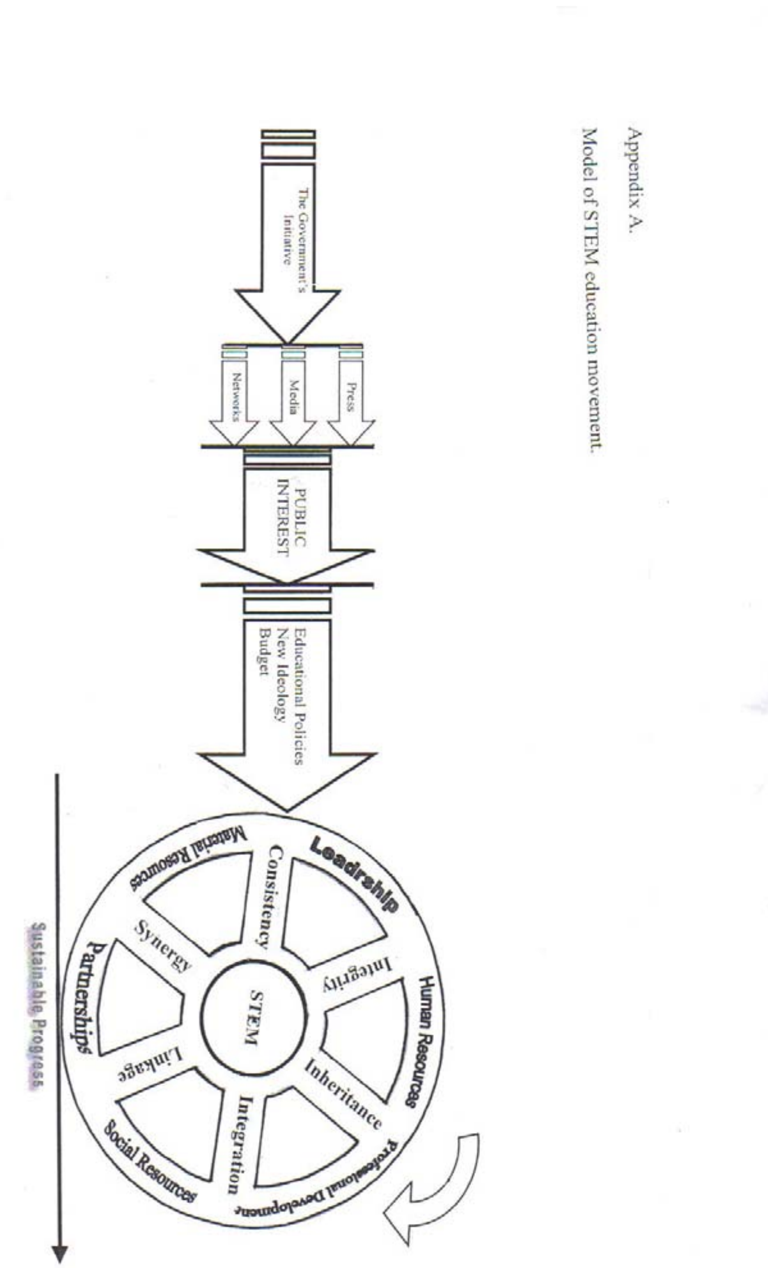
**Appendix A**

Model of STEM Education Movement



# Improving STEM Instructional Capacity: A Model for Educational Leaders

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**Keywords:** Four Frames, STEM Capacity, Professional Learning Communities, Instructional Practices

**Abstract**

The United States is facing a shortage of adequately trained professionals in the fields of science, technology, engineering, and mathematics (STEM). Modern economies are increasingly dependent on a sustainable STEM workforce, and the solution cannot simply be outsourced internationally due to concerns with national security. The STEM problem is relevant to educators at all levels, given that STEM instruction must improve in K-12 and higher education organizations for California's economy to endure. Much has been researched and written concerning STEM education deficiencies in America. Although leadership is a key component of building capacity for STEM education reform, it is consistently overlooked. The following analysis introduces a model for STEM reform which synthesizes the elements that have proven successful and that reoccur in the extant literature. The model is designed from the perspective of a K-12 school site leader, but elements of it can be applied to educational leaders at all levels.

## Introduction

According to Kuenzi, Matthews, and Mangan (2006), "there is growing concern that the United States is not preparing a sufficient number of students, teachers, and professionals in the areas of science, technology, engineering, and mathematics" (p. 1). This study and other literature about the state of STEM education in the United States present sobering statistics. Of the fastest growing occupations in California, four out of the top five are in computer-based fields and all of the top ten require some knowledge in science, technology, engineering, and mathematics (STEM) fields (Rosin & Barondess, 2008). Although the fastest growing fields require knowledge of STEM, many students in the U.S. are not pursuing courses of study that will prepare them to assume these jobs. In 2005, only 16.4% of degrees in the United States were awarded in STEM fields compared to Japan where 64% of degrees awarded were related to STEM (Kuenzi et al., 2006). In contrast, non-resident students are pursuing STEM degrees at American colleges and universities in substantial numbers. These students earned 46% of all advanced degrees in computer science and over 39% of all advanced degrees in engineering (Rosin & Barondess, 2008).

There are many ideas about why American students are not pursuing STEM degrees or entering STEM careers, but prevalent in the literature is the notion that public schools are not adequately preparing students for these career fields. Though some data indicate mild improvements on standardized tests in some STEM courses, data that compare students in the United States with those in other countries suggest U.S. students are falling behind students from other nations (Rosin & Barondess, 2008). In 2003 for example, U.S. students earned an average score of 483 on an international mathematics test. They scored lower than 23 of the 29 Organization for Economic Co-operation and Development (OECD) member states that participated and behind four of the 11 non-OECD countries. The average U.S. student scored 491 on science literacy, which was lower than 19 of the 29 OECD countries and behind three of the 11 non-OECD countries (Kuenzi et al., 2006).

Student performance is not the only concern highlighted in the research. According to Rosin and Barondess (2008), "there are large percentages of underprepared and out-of field teachers in [STEM] subjects due to shortages at both the middle and high school levels, especially in low-performing schools" (p. 4). Research done by The National Academy of Sciences (2007) indicates that in the United States, there is a 69% chance that a middle school student will not be taught math by someone who has a major in the subject and a 93% chance that a middle school student won't be taught physical science by someone who has a degree in the subject. In addition to the problem of underprepared teachers, the teaching of science curriculum is not a high priority, especially in elementary schools. For example, eighty percent of K-5 teachers report spending less than 60 minutes each week teaching science, and 16% of teachers are spending no time at all on the subject (Gentilucci, 2009).

These data suggest that educational leaders need to focus on bolstering instructional capacity for STEM education at all levels, but particularly in K-12 schools. Young and King (2002) define capacity as "the collective power of an entire faculty to strengthen student performance" (p. 645). The extant literature offer several solutions to the problem of increasing STEM capacity in K-12 schools, and the reoccurrence of particular solutions within the literature increases their level of significance when considering effective leadership.

**Findings from the STEM Symposium**

Carpenter, Blanton, Cobb, Franke, Kaput, and McClain (2004) claim that time is the most critical resource for improving STEM capacity. Time is necessary for teachers to engage in effective professional collaboration and reflection. The National Center for Improving Student Learning and Achievement in Mathematics and Science (NCISLAM) (2002) and Carpenter et al. (2004) also identified material and social resources (i.e., connections) as key components of STEM capacity in schools. Acquiring material resources in a time of economic scarcity can be challenging, but it can be done if leaders engage the social resources of their schools.  Kristina Bolts (2009), a successful STEM program coordinator, insists that leaders must become adept at managing reform with scarce material resources while taking advantage of external opportunities (e.g., grant writing).

A specific social resource mentioned often in the literature is the development of a professional learning community (PLC). The NCISLAM (2002) argues that a PLC encourages STEM sustainability by improving the likelihood that exemplary teaching practices will be shared. Youngs and King (2002) posit that PLC's enable leaders to create shared goals, to foster collaborative teacher input, and to develop a culture of inquiry-based understanding, all of which are necessary for building STEM capacity.

Staff and site leadership must create a reciprocal level of trust for a PLC to function legitimately. According to Chris Argyris (1991), professionals have difficulty functioning in a learning community. Professionals are successful individuals who struggle with reflecting on the effectiveness of their own practices. Learning is inhibited by defensive, blame-deflecting tendencies. Cohen and Ball (1999) make a similar argument by stating that site leaders must allow teachers to retain a level of autonomy when initiating reform due to their tendency to resist or reject alternative explanations for student performance. Reform requires taking risks, and risk is tempered by trust.

Capacity for STEM reform is also dependent on partnerships within the community, especially those existing with local universities. Cal Poly San Luis Obispo is a STEM leader in California. Commentary from professors Seth Bush and Susan Elrod as well as former student (and present K-12 teacher) Sarah Cameron (2009) highlight the usefulness of university partnerships. Bush, the director of the Learn By Doing Laboratory at Cal Poly, discussed the availability of workshops for teachers and students as well as the university's effort to recruit teachers from STEM fields of study. Cameron, a middle school science teacher, credits her ongoing training at Cal Poly for the improvement in her students' performance. Elrod, the director of the Center for Excellence in Science and Mathematics Education (CESaME) at Cal Poly, gave a promising report on a university program that is developing science teachers who actively participate in research.

Symposium panelist, Professor Shirley Magnusson (2009), claims a leader's best opportunity for creating STEM capacity is the professional development of teachers. This claim is supported extensively in the literature. Because there is a STEM deficiency in most traditional teacher preparation programs, it is necessary to provide experienced teachers with knowledge and pedagogical skills for STEM reform to be successful. Several STEM researchers discuss the benefits of professional development in creating systemic, sustainable reform, while providing effective models available to school leaders (American Institutes for Research, 1999; Carpenter et al., 2004; National Academy of Sciences, 2007; Youngs & King, 2002).

The success of STEM reform depends on teachers shifting from skills-based to inquiry-based instruction. Barab and Luehmann (2002) posit that sustainable science curricula require teachers to encourage participatory activities supported by technology in lieu of traditional lecture. Inquiry is a primary component of Achievement via Individual Determination (AVID), a program designed to build successful study habits in children traditionally under-represented in secondary education. Symposium speakers, Sarah Cameron and high school principal Ryan Pinkerton (2009), both cited AVID as being instrumental in the development of STEM capacity.

While daunting, the challenges faced by California are not insurmountable. The research indicates a collective wisdom is developing concerning the reform of California's educational system to meet the requirements necessary to support an economy and culture increasingly dependent on STEM. Collectively, this body of knowledge can be synthesized into a model that can be used by educational leaders as a guide for creating systemic and sustainable capacity for a robust STEM education.

## A Model for Educational Leaders

Research suggests that the role of educational leaders is often overlooked in STEM reform efforts (Gentilucci, 2009). Consequently, the authors of this analysis have created a model that places these leaders at the center of the reform effort in K-12 institutions (see Appendix A). School leaders who want to provide their students with rigorous and inspiring STEM education will need to view the issue through multiple lenses, including the lenses of structure, human resources, politics, and symbols (Bolman & Deal, 2003). There are at least four areas of reform that educational leaders can influence to bring about sustainable STEM education: PLC's, community partnerships, professional development, and instruction. The model shows the connections between the lenses and the reforms while also acknowledging the dependency of each reform on the others.

As the model suggests, all of these areas need to be viewed through each of the lenses to obtain a complete picture of the problem and possible solutions. For example, when an administrator plans to establish a PLC, he or she will need to examine the school schedule (structural lens), establish trust with leaders of the faculty (human resource lens), advocate with the district for additional resources (political lens), and ultimately need to show that the PLC represents a true priority (symbolic lens). This process should be repeated for community partnerships, professional development, and implementation of instructional strategies.

The interdependency of the four areas is also implicit in the model. A well designed PLC will give instructors a chance to collaborate and thus improve instruction. Community partnerships with local universities could provide opportunities for professional development. Additionally, professional development is needed in order to train teachers how to use research-based instructional strategies. Educational leaders must understand these connections as they strive to implement necessary changes.

Armed with a template for improving STEM capacity, the educational leader needs to understand how to implement each of the four areas of reform while keeping in mind the four lenses. What follows is a synopsis of the important details of these areas of reform along with recommendations for how school leaders can view these reforms through the four lenses mentioned above.

*Professional Learning Communities*

For school leadership to build STEM capacity, leaders must build collaborative relationships that are systemic and sustainable. The primary function of the collaborative relationship is trust. A culture of trust within the school community is imperative as leaders determine what is needed through a process of shared decision-making within the PLC model.

The PLC model flows from the assumption that the core mission of formal education is not simply to ensure that students are taught, but to ensure that they learn. This simple shift from a focus on teaching to a focus on learning has profound implications for schools (DuFour, DuFour & Eaker, 2006). When school staff takes this shift seriously, they can then determine the practices that have been most successful in helping all students learn.

NCISLAM (2002) notes that school leaders must establish and sustain a PLC in which teachers (1) share a sense of purpose, (2) focus collectively on student learning, (3) collaborate on ways to improve student learning, (4) engage in reflective dialogue on the nature and practice of teaching, and (5) make public their own teaching practice. Leaders wishing to sustain reform should encourage PLC's by establishing trust, mutual expectations, and shared values to enhance integration.

School personnel who are building a PLC must work together to achieve their collective purpose of learning for all and to create structures to promote a collaborative culture. The collaboration that characterizes a PLC is best described as a systematic process in which teachers work together to analyze and improve their classroom practice. Research by NCISLAM (2002) suggests that time is the most important material resource for supporting instructional reform. Leaders must provide teachers with significant time for collaboration.

Collaborative conversations encourage team members to discuss goals, strategies, materials, pacing, questions, concerns, and results. Every staff member is part of a team that is structured to improve the classroom practice of teachers both individually and collectively. School leadership must ensure that everyone belongs to a team that focuses on student learning. In contrast to the usual practice of working in isolation, a PLC encourages teachers to engage in reflective dialogue that focuses on student thinking and make their teaching practices public (NCISLAM, 2002). A PLC should be seen not only as an important tool for improving STEM education, but also as an effective method of improving student learning in all subject areas.

PLC teams should reach consensus on essential standards within each core content area and then develop inquiry-based lessons with common formative assessments. As teams examine student learning, strengths and weaknesses will emerge. The discussion should then focus on how the team can build on student strengths and address student weaknesses. There is no easy recipe for these intervention criteria, but effective leadership occurs when people strive to manage issues rather than to solve problems (Weick, 1996).

Intervention plans should be developed with the help of staff, parents, and community members. Using the relational communication model, the school communicates clear messages in a timely fashion, and the intervention occurs as soon as a student begins to struggle (Kowalski, Petersen, Fusarelli, 2007). Problems will occur in any school, but if there is a strategy for addressing them that has been communicated to all stakeholders, they can be kept from becoming unmanageable.

*Community Partnerships*

Instructional leaders who are passionate about STEM education must create and sustain community partnerships with state agencies, higher education, businesses, non-profit organizations, and community members to help their schools obtain scarce material, human, or social resources (NCISLAM, 2002). As communities see student STEM learning improve as a result of highly engaging and innovative partnerships, collaborating leaders should prioritize planning through policy and initiatives to further sustain STEM education. These activities require a balanced leadership approach utilizing the four lenses.

Partnering with universities to improve the preparation of teachers and leaders is a key component of needed STEM reform. During the Symposium, Elrod and Magnusson (2009) challenged instructional leaders at all levels to engage in this process. Both professors acknowledged that universities have a responsibility to model instruction appropriately as "they set the norms that pervade the education system regarding how science is taught and what it means to 'learn' science" (Wieman, 2004, p. 15).

Elrod (2009) reported that the Center for Excellence in Science and Math (CESaME) was founded in 2004 with a "vision to improve the STEM teacher pipeline" from preschool through graduate school. The Science Teachers as Researchers (STAR) program facilitates an eight week laboratory experience for current and prospective teachers and extends their learning by giving them opportunity to work in national laboratories.

*Professional Development*

The sustainability of STEM capacity is dependent on professional development. Professional development requires teachers to learn new content and to attain skills to ensure that content is successfully transferred to students. Instructional practices best suited for STEM education are based in inquiry, but traditional methods of teacher preparation and the pressure to increase standardized test scores have created a heavily skills-based approach to instruction. Consequently, teachers must be retrained for STEM education to improve.

Educational leaders cannot assume that professional development will work regardless of its structure and approach. Research has provided several elements of successful, meaningful professional development. Bernhardt (2004) offers a comprehensive definition: "Planned activities that help staff members, teachers, and administrators change the manner in which they work, i.e., how they make decisions; gather, analyze, and use data; plan, teach, and monitor achievement; evaluate personnel; and assess the impact of new approaches to instruction and assessment on students" (p. 281). Using this definition, the structure of professional development conducive to the sustainability of STEM best practices can be clearly discerned. Brock and Grady (2004) insist school leaders assume roles as facilitators. The principal encourages staff input in planning teacher education and provides consultation, time for collaboration and reflection, and evaluative progress reports.

The school leader must also ensure staff development coincides with the goals and values of its participants. The need to include teachers in the planning of staff development is reinforced by Kowalski, Petersen, and Fusarelli's (2007) warning that teachers will only implement change initiatives through retraining if they do not interfere with their core beliefs. Youngs and King (2002) provide evidence that internally planned staff development tends to be successful, and Blase and Kirby (2009) found that professional training is more effective when teachers are allowed a measure of discretion when implementing new practices. Perhaps the most productive means for ensuring teacher commitment to making STEM training more than symbolic is providing proof that it is beneficial to students (American Institutes for Research, 1999; Blase & Kirby, 2009; and Robinson & Lai, 2006).

Many researchers and authors agree professional development must be specific, focused, and delivered in limited settings. Robinson and Lai (2006) conclude that professional development is powerful when it is centered on contextual needs specific to individual classrooms. The need for student-specific adaptation is also listed by Carpenter et al. (2004) as a necessary requirement for STEM staff development. School leaders can and should determine individual need through classroom observation and formative supervision (Zepeda, 2007). Carpenter et al. (2004) posit that a long-term trajectory of student learning in math and science should guide STEM teacher training, but that site-specific adaptations would improve sustainability. Bernhardt (2004) believes "staff would benefit greatly from focused professional development on a *few* areas in small group settings" (p. 101, emphasis in the original). The results of a staff assessment of professional development as displayed in Appendix B support the need of limiting the setting. The NCISLAM (2002) would agree with Bernhardt, as it insists effective professional development is focused in specific subject areas. The NCISLAM also claims that effectiveness may improve by focusing staff development on a small group of teachers (i.e., increase quality of training by raising the money spent per participant).

The National Academy of Sciences (NAS) (2007) offer innovative models of professional development that would substantially address STEM deficiencies in public school systems. The committee reporting for the NAS recommends that 50,000 teachers a year be trained in federally and privately subsidized summer institutes. One such program, the Merck Institute for Science Education (MISE), has had positive results. Students of teachers who had participated in MISE significantly outperformed students of teachers who had not participated. The committee also recommends federal funding of incentive-based master's degree programs. Teachers would receive compensation in exchange for pursuing a master's degree in science or math education. The committee believes such programs would significantly improve the STEM skills of 50,000 current teachers in just five years.

*Instruction*

Professional learning communities, community partnerships, and professional development are not ends in themselves, but means to bring about quality instruction and improved student learning. Much of the research related to STEM education advocates a shift from traditional, lecture-based lesson design, to instruction based on active participation and inquiry (Barab & Luehmann, 2003). Bush (2009) claims focusing on content instead of inspiring by inquiry produces only short-term gains. Significant resources need to be directed to staff development that promotes inquiry-based learning. Instructors cannot simply be told to teach using inquiry. If inquiry is used poorly, the results are often worse than when skills-based instruction is used (Valentine, 2009).

Although research demonstrates that inquiry models are important for student success in STEM, teachers are presented with a significant challenge in the era of NCLB accountability when so many administrative decisions are based on test scores. According to Barab and Luehmann (2003), "implementing project-based science curriculum is challenging in the context of standardized tests, 45-min class periods, large class sizes, and the emphasis on individual grades" (p. 455). Science instruction can become less vital to educational leaders because it is not counted as prominently in the accountability matrix of the school. In some middle schools, teachers are told science is not important and the focus of instruction should be language arts and mathematics (Cameron, 2009). This difficulty highlights the need for professional development which helps teachers provide quality instruction, yet provides students with the principles to answer test questions even when some topics were not addressed in class (Bush, 2009). Cameron testified that the training she received at Cal Poly equipped her to teach using an inquiry-based model without neglecting the information needed to perform well on standardized tests.

It is imperative that educational leaders provide the training necessary to help instructors utilize inquiry-based methods. However, without formative supervision, much of the training given at professional development in-services will not be implemented. Some research suggests that many educational leaders do not have backgrounds in STEM and therefore do not feel comfortable observing STEM classrooms (Gentilucci, 2009). However, leaders must be willing to negotiate these barriers and provide the supervision that is needed to help make STEM teachers successful. Educational leaders should observe all teachers as often as possible, providing concrete and meaningful feedback. Ultimately, informal and formal observations should be linked to professional development so that educational leaders can see whether or not inquiry-based instruction is actually taking place and that such instruction is effective (Zepeda, 2007). Educational leaders who give meaningful, consistent feedback are cognizant of the human resource lens because they desire the improvement of those under their care (Bolman & Deal, 2003).

Educational leaders also need to view the issue of instruction through the other three lenses given in the model (Bolman & Deal, 2003). When examining the problem through the structural lens, administrators may notice that scheduling can become an obstacle to quality STEM education. Traditional secondary school schedules typically only allow 45 minutes for instruction, not enough time to conduct laboratory activities and still allow students to discover and be curious. Instead, a block schedule may give STEM instructors the time they need to use inquiry-based instruction without sacrificing the teaching of facts necessary for success on standardized tests.

## Conclusion

Educational leaders can build systemic and sustainable capacity by examining the issue of STEM education through four lenses: structural, human resource, political, and symbolic. Additionally, administrators should consider reforming their institutions by implementing PLC's, community partnerships, professional development, and inquiry-based instruction. Although the model presented in this research is from the perspective of a K-12 leader, the solvency of our nation's economy depends on consideration of STEM reform at all levels, including the university. Indeed, it is often the university that leads the rest of the educational system in reform, and STEM reform should be no exception.

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**Appendix A**

STEM Leadership Model:  A Guide for Educational Leaders