# A Practice-based Model of STEM Teaching

## STEM Students on the Stage (SOS)™

Alpaslan Sahin

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*STEM Students on the Stage (SOS)™*

*Edited by*

**Alpaslan Sahin**
*Harmony Public Schools, Houston, USA*

SENSE PUBLISHERS
ROTTERDAM/BOSTON/TAIPEI

A C.I.P. record for this book is available from the Library of Congress.

ISBN: 978-94-6300-017-8 (paperback)
ISBN: 978-94-6300-018-5 (hardback)
ISBN: 978-94-6300-019-2 (e-book)

Published by: Sense Publishers,
P.O. Box 21858,
3001 AW Rotterdam,
The Netherlands
https://www.sensepublishers.com/

*Printed on acid-free paper*

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MARGARET J. MOHR-SCHROEDER

# FOREWORD

> It's easy to come up with new ideas; the hard part is letting go of what worked for you two years ago, but will soon be out of date.
>
> — Roger von Oech

Teachers today are being asked to think "outside of the box" in order to prepare their students for a career and a life that is largely unknown due to the warp speed changing needs and desires of society today. While many teachers today happily accept the challenge and are driven by curiosity and motivation to succeed, it can become a very daunting and overwhelming task. The STEM SOS™ (Students on Stage) model, and this book in particular, helps to bridge that gap between daunting and overwhelming to doable and successful. While much literature exists regarding project-based instruction, no book or article has provided such a comprehensive look and guide to successful (and what success looks like!) implementation of interdisciplinary STEM project-based instruction, through the STEM SOS™ model, as Dr. Alpaslan Sahin has done here with this book.

While I was trained as a mathematician and mathematics educator, I also had a deep passion for the life sciences. I dreamed of becoming a neonatologist when I was growing up, but I also had a deep passion for teaching and helping people understand mathematics and science. In the end, that passion for learning and teaching won out and I eventually ended up in my current position as a teacher educator at a major research university. As a budding STEM enthusiast, my research and work over the years led to the creation of the first ever major in STEM Education in the United States. It was through this work that I reconnected with Alpaslan and his grass roots interdisciplinary STEM school efforts.

I first met Dr. Sahin while doing my doctoral work at Texas A&M University. As a fellow doctoral student, Alpaslan and I were deeply entrenched in a multi-million dollar research project that involved lots and lots of video coding and analysis. You always knew when we had a deadline coming up – one would walk into our office room and we all would be sitting in our cubicles, headphones on, huddled over our monitors, furiously tallying away. It was in these moments that Dr. Sahin and I's conversations about connections and interdisciplinarity began. Dr. Sahin has always had a deep curiosity for mathematics content and how it was taught and presented in the United States. I remember during our video coding sessions, he would always wonder and discuss why United States teachers were always so focused on teaching a particular concept, instead of focusing on the application and interconnectedness of a concept, skill or generalization. He would share stories about how he had seen and experienced mathematics as a student. As someone who had been discouraged from majoring in mathematics and biology in college because they were so “dissimilar”, I was fascinated with Dr. Sahin’s knowledge and passion about applications and connections.

While I took a more traditional “professorial” route after graduation, Dr. Sahin continued pursuing his passion of helping people understand the importance of applications and connections, especially through the lens of interdisciplinary, project-based instruction. Through his work as a research scientist at the Aggie STEM Center at Texas A&M University in College Station, Dr. Sahin was an integral part in building and nurturing the foundation for innovative STEM schools in the area. This work springboarded him into the Harmony Public Schools where he has carefully studied and helped teachers and administrators implement and embrace the STEM SOS™ (Students on the Stage) model. Over the past several years, he has studied, designed and trained STEM teachers of STEM academies, with his work appearing in a variety of books and journals.

The STEM SOS™ model has been shown to improve student knowledge and conceptual understanding, and STEM interest, and other important 21st century skills including self-confidence, communication and collaboration, ultimately improving students’ college and career readiness. In this book, Dr. Sahin’s work shines through in codifying and telling the story of the STEM SOS™ model. While there have been books and articles published affirming the positive effects of project-based instruction, none have presented it in a ready-made curriculum, making this an essential go-to book to have in your library. Not only does it set a foundational stage for integrating project-based instruction into classrooms, it also contains examples of what the STEM SOS™ model looks like at the classroom level and at the school level; its connections to standards; and even contains appendices of full lesson plans, teacher resources, authentic assessment samples, etc.

This book tells the story of that implementation and how you - whether a teacher, an administrator, a teacher educator, a scientist, an engineer, or even a STEM enthusiast – can regularly, actively engage students in STEM, through shared work in collaborative and social settings, in order to help them see STEM as a socially desirable and attractive profession for them to consider in their futures.

*Margaret J. Mohr-Schroeder*
*Associate Professor of Middle/Secondary Mathematics Education*
*STEM Enthusiast*
*Department of STEM Education*
*University of Kentucky*

# PREFACE

The purpose of this book is to describe the Harmony STEM approach called the *STEM SOS Model* and its components, from creation to assessments to teacher training. This book describes an easy-to-use project-based learning (PBL) model and classroom-ready materials that help make implementation as simple and seamless as possible. At its heart, however, this book provides useful information about STEM education, including its history, current PBL models and their similarities and differences, and most importantly, detailed information about the STEM SOS model and implementation strategies.

The STEM SOS model was developed by Harmony Public Schools with the goal of teaching rigorous content in an engaging, fun and effective way. In the book, you will find that the STEM SOS model is not only helping students learn STEM content and develop $21^{st}$-century skills, but also helping teachers improve their classroom climate through increased student-teacher communication and a reduction in classroom management issues.

This is an innovative book in at least two ways: First, you will find student videos and websites associated with QR codes. Readers can use their QR readers to watch student videos related to the content in the chapter and see student e-portfolio samples at their Google sites. This provides readers with the opportunity to see that what is discussed in the book actually happened, either within a classroom or in outside activities. Second, the book is not about a theory; it is an actual implemented model that has evolved through the years and has been used in more than 25 schools since 2012. Every year, the model continues to be improved to increase its rigor and ease of implementation for both teachers and students. In addition to using the book as a classroom teacher resource and/or guide, it can also be used as a textbook in Master's level mathematics, science and/or STEM education programs. Curriculum and instruction and/or educational leadership programs may also benefit from the explanations, research and discussion around the implementation, development, and sustainability of a STEM teaching model from scratch. Therefore, STEM educators, leaders, pre-service and in-service teachers, and graduate students may all benefit from reading this book.

Appendices will be one of the favorite aspects of this book for teachers who are constantly looking for ready-to-use student and teacher handouts and activities. Full handouts, including formative and summative assessments materials and grading rubrics, will provide an opportunity for teachers and curriculum directors to understand the ideas and secrets behind the STEM SOS model. Lastly, STEM directors will find one of the best STEM teaching model examples on the market due to their ability to either adopt or revise the model to make it their own.

*The Editor*

# ACKNOWLEDGEMENTS

Many individuals contributed to this book through their encouragement, ideas and examples and it is not possible to thank all of them due to space constraints. However, there are some specific individuals who have given their time, support and wisdom to whom I wish to express my gratitude and appreciation.

I would like to thank the following authors who contributed chapters for the book: Margaret J. Mohr-Schroeder, Maureen Cavalcanti, Kayla Blyman, S. Enrico, P. Indiogine, Niyazi Erdogan, Todd Dane Bozeman, Namik Top, Ozgur Ozer, Ismail Ayyildiz, Nickola Esch, Pam Srinivasan, Freda Husic, Cynthia Sargent, Robert Thornton, Kerri Bell, Burak Yilmaz, Eugene Kennedy, Tevfik Eski, Ulvi Celepcikay, Soner Tarim, Bulent Dogan, Bernard Robin, Farjana Yasmin, Kadir Almus, Steven Busch, and Angus J. Macneil.

Dr. Ozcan E. Akgun, Assistant Professor in the Department of Computer and Instructional Technology, Sakarya University, was with me when I was working on this model. His inspirational ideas and support helped me develop the name of the model, "STEM Students on the Stage."

Levent Sakar, HPS Physics Curriculum Director and STEM Activity Coordinator and one of the developers and advocates of the STEM SOS model, contributed valuable insights and provided sample STEM SOS lessons, assessment materials and rubrics for the book. He also answered all my questions without showing any signs of weariness while I was working on codifications of the model. Likewise, Ishmael Ayyildiz, Director of Curriculum-Secondary and ISWEEEP Program Director also provided valuable insights during the project. Dr. Ozgur Ozer, Chief Academic Officer and Associate Superintendent of Harmony Public Schools, supported the idea of writing and codifying the model as well as helping me determine the content of the book.

I would also like to thank Margaret J. Mohr-Schroeder, Associate Professor of Middle and Secondary Mathematics Education in the College of Education, University of Kentucky, who agreed to write the foreword for this book even though she has been swamped with her own projects and responsibilities.

Meredith Takahashi, Editorial Assistant, reviewed the book multiple times for grammar and format. This book is better as a result of her meticulous efforts.

And, finally, it is without reservation that I acknowledge my debt to Dr. Soner Tarim, Professor Robert M. Capraro, Mr. Zekeriya Yuksel, Dr. Kadir Almus and Professor Gerald Kulm for their exceptional leadership and support during this endeavor. Thank you!

Alpaslan Sahin, Ph.D.
Houston, TX
October 2014

# SECTION 1
# LITERATURE ABOUT STEM EDUCATION

How did STEM education start? What made STEM education important? Do we really have problems educating students in STEM fields? Are there any differences between ethnic groups in mathematics and science achievement? Section I helps you assess your preparedness for STEM education and increase your readiness to appreciate the variety of STEM learning models.

MARGARET J. MOHR-SCHROEDER, MAUREEN CAVALCANTI, AND KAYLA BLYMAN

# 1. STEM EDUCATION: UNDERSTANDING THE CHANGING LANDSCAPE

This chapter provides a brief history of Science, Technology, Engineering and Mathematics (STEM) education in the United States, including key movements that have helped shape it and have kept it sustainable. This chapter is foundational to understanding the context of STEM education and its interdisciplinary nature.

## INTRODUCTION

It is well-known that the today's youth are tomorrow's innovators and leaders. They are our *Generation Z* or *Post-Millennials* (Horovitz, 2012). They are our most diverse population cohort yet and are considered to be digital natives. Yet they are amidst a STEM "crisis." Research, legislation, media and even infographics (see Figure 1 for an example) everywhere point to the dire need for educational reform in STEM (Kelly et al., 2013); for creating a *STEM literate* workforce (National Research Council, 2009, 2014a; National Academy of Engineering, 2008; Varmus et al., 2003); for more women and people of color in STEM fields (National Science Foundation, 2013); and for more individuals in general to be interested in STEM careers (Carnevale, Smith, & Melton, 2011; Langdon, McKittrick, Beede, Khan, & Doms, 2011; National Science Board, 2014). Additionally, employers today believe that *all* people, especially young people, need some form of technological and STEM literacy in order to become productive citizens, even if they never intend to enter a STEM-related career (National Academy of Engineering and National Research Council, 2014).

There have been multitudes of reports published in the last 30 years that call for major changes, expansions, opportunities and improvements in STEM education (e.g., AAAS, 1990, 1993; Council on Competitiveness, 2005; NGA, 2007; NRC, 1996, 2007a, 2012a; NSB, 2007; PCAST 2012). Major changes and initiatives have emerged from these calls to action, including, but not limited to:

- The Common Core State Standards for Mathematics and Literacy in the Sciences (CCSSO, 2010);
- A Framework for K-12 Science Education (NRC, 2011) and the subsequent Next Generation Science Standards (NGSS Lead States, 2013);

*A. Sahin (Ed.), A Practice-based Model of STEM Teaching, 3–14.*

- Assessment consortia aiming to create assessments aligned with the new standards (e.g., PARCC, Smarter Balanced Assessment Curriculum);
- STEM-focused schools; and
- STEM partnership networks (e.g., STEMx, Ohio STEM Learning Network, iSTEM, Washington STEM).

These initiatives have led to a renewed focus on the exact definition of STEM education, what constitutes effective teaching in STEM and a general overall


*Figure 1. Example STEM need infographic (Washington STEM, washingtonstem.org).*

knowledge of STEM and the development of a STEM literate population. This chapter will provide a brief history of STEM education and its influences and present a framework and definition of STEM education that will set the stage for the model presented in this book. Here, we aim to present a model that will help teachers operationalize STEM education through interdisciplinary instructional practices. Doing so will provide support for teachers transitioning to STEM teaching and learning and make content accessible and meaningful to students, both within and across disciplines (Basham, 2010). The need to develop curricula that operationalizes STEM education has been studied (Wang, Moore, Roehrig, & Park, 2011), but the models themselves are still being developed. This book aims to fill this gap in a way that connects research, perception and practice.

## A BRIEF HISTORY OF STEM EDUCATION

Almost 60 years ago, on October 5, 1957, the launch of the Russian satellite *Sputnik* caused a deep stir in the United States, one that was fueled by fear (of falling behind) and the United States' competitive nature. In President Eisenhower's famous speech after the launch of *Sputnik*, he challenged Americans and called for action:

> The Soviet Union now has – in the combined category of scientists and engineers – a greater number than the United States. And it is producing graduates in these fields at a much faster rate . . . We need scientists in the ten years ahead. They (the President's advisors) say we need them by thousands more than we are now presently planning to have. The Federal government can deal with only part of this difficulty, but it must and will do its part. The task is a cooperative one. Federal, state, and local governments, and our entire citizenry must all do their share.

Very quickly thereafter, the National Aeronautics and Space Administration (NASA) was formed in 1958. Through the rapid growth and success of the space program, the United States soon emerged as the world leader in the number of students attaining engineering degrees, graduating about 80,000 per year in the mid-1980s, according to the Engineering Workforce Commission.

As an incentive to continue the reform efforts, including those focused on developing more critical thinking and problem-solving skills rather than rote memorization and facts, the Reagan Administration's National Commission on Excellence in Education published *A Nation at Risk* (1983). Shortly after, in 1985 - the year Halley's Comet passed near earth – the American Association for the Advancement of Science (AAAS) created *Project 2061* – the year we will see the return of Halley's Comet (for a more complete history, see http://www.aaas.org/program/project2061/about). Project 2061 set out to identify factors that would create a science literate population, which led to the 1989 publication of *Science for All Americans* and the subsequent *Benchmarks for Science Literacy* that are still widely cited and utilized today.

Although the call to action in STEM heightened after the 1957 Sputnik launch, the United States has had an extensive history of recognizing the importance of scientific issues, phenomena, and research, dating as far back as the First Congress (1787, www.TeachingAmericanHistory.org) and President George Washington's First Annual Message to Congress on the State of the Union on January 8, 1790, at which time he called upon Congress to promote scientific knowledge:

> Nor am I less persuaded that you will agree with me in opinion that there is nothing which can better deserve your patronage than the promotion of science and literature. Knowledge is in every country the surest basis of public happiness. In one in which the measures of government receive their impressions so immediately from the sense of the community as in ours it is proportionably [sic] essential.

The drive to be competitive and outpace our international partners continues today. Fifty-two years after Sputnik and 219 years after President Washington's State of the Union speech, Congress and the American people are still being called upon to be innovative and achievers in science and mathematics. President Obama called on Americans to renew that charge of almost 60 years ago in his 2009 State of the Union Address:

> We will not just meet, but we will exceed the level achieved at the height of the Space Race, through policies that invest in basic and applied research, create new incentives for private innovation, promote breakthroughs in energy and medicine, and improve education in math and science. … Through this commitment, American students will move… from the middle to the top of the pack in science and math over the next decade – for we know that the nation that out-educates us today will out-compete us tomorrow.

*Policy*

While one can see that policy has played a pivotal role in the history of STEM, its role over the past 10 years has significantly impacted how we view and what we call STEM today. During his tenure as president, Barack Obama and his administration has passed two specific initiatives to improve STEM teaching and learning. They first launched *Educate to Innovate* in 2009, followed by *Change the Equation* in 2010. Change the Equation was a specific call to action for the business community to become more involved in STEM education, which was also one of the goals of Educate to Innovate (http://changetheequation.org/). Additional goals of Educate to Innovate include increasing diversity within STEM fields and careers, improving STEM teacher quality and having the government invest more in STEM at the federal level. One way President Obama has worked towards a more effective and diverse STEM workforce for the future of the United States has been to invest in improving undergraduate STEM learning in order to positively impact future generations (http://www.whitehouse.gov/issues/education/k-12/educate-innovate).

Before President Obama, President George W. Bush passed the *American Competitiveness Initiative* (2006), which had similar goals to those of President Obama.'s initiatives. The American Competitiveness Initiative had a goal to improve mathematics and science performance in the United States in the interest of making the United States a world leader in the STEM fields. This call to action specifically addressed training more highly-qualified mathematics and science teachers, increasing the number of people involved in innovation and providing additional grant money to schools to encourage them to more readily adopt and implement research-based mathematics curricula and interventions (http://georgewbushwhitehouse.archives.gov/stateoftheunion/2006/aci/index.html#section2).

*Curricula*

While presidential initiatives come and go with changes in administration and tend to be nothing more than "calls to action," actionable change happens at the local level through the use of innovative curricular methods such as the one described in this book. While continuous, collaborative and interdisciplinary STEM education remains a dream and goal of many teachers, the realities of current classrooms and the cultural climate of accountability testing can bring an innovative project to a halt before the idea even gets off the ground. However, the passion and drive that teachers and educators bring to the STEM content areas have helped overcome these barriers through grassroots efforts. While there are many that have helped shape STEM as we know it today, two engineering education projects have become nationwide projects and these two programs highlight the interdisciplinary nature and project-based instruction framework we propose in this book.

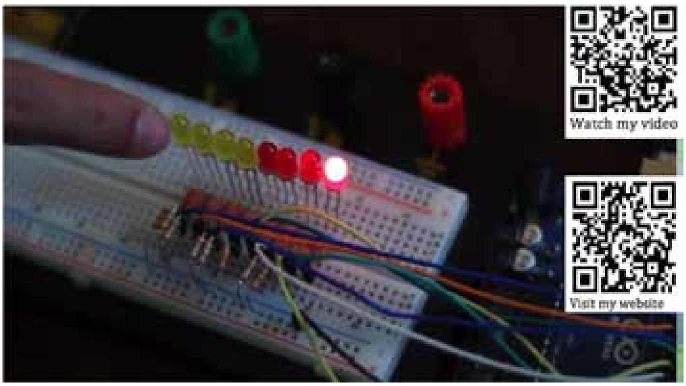


*Figure 2. A student demonstrating his Level II project. (Please use your QR reader to scan the QR code to watch the video).*

*Project Lead The Way.* The steps towards the birth of this widely successful program began in 1986 when a high school teacher named Richard Blais began teaching basic engineering to his students. In 1997, the project was funded to expand beyond Blais' school by the Charitable Leadership Foundation. Over the years, Project Lead The Way has continued to grow with partnerships, grants and endorsements from many notable government programs and Fortune 500 companies. Because of the support the project has received, it has managed to expand beyond the initial goal of educating K-12 students about engineering while encouraging them to consider a career in and/or majoring in an engineering-related major in college. Today, Project Lead The Way's curricula are more wholly inclusive of STEM, while working toward a broader mission of "[preparing] students to be the next generation of problem solvers, critical thinkers, and innovators for the global economy" (https://www.pltw.org/).

*Engineering is Elementary.* Another such project is Engineering is Elementary. This project was founded by the National Center for Technological Literacy (http://legacy.mos.org/nctl/), which was launched by the Museum of Science, Boston, in 2004. While it is not as widely known as Project Lead The Way, Engineering is Elementary has a more narrow focus for its audience. Specifically, Engineering is Elementary targets elementary school students and teachers with a mission to "[support] educators and children with curricula and professional development that develop engineering literacy" (http://www.eie.org/). While the project has expanded to include middle grades materials through the Engineering Everywhere curricula and to high school with the Engineering the Future course, its expansion to other STEM fields remains limited; however, they have expanded geographically and now have their curricula used in all 50 states. (http://www.eie.org/).

### *The Pivotal Role of the National Science Foundation*

Throughout the history of STEM education, several Presidents and their administrations and hundreds of various organizations have impacted STEM as we know it today and as it is being formed for future generations. However, it can be argued that none have had more of a pivotal impact than that of the National Science Foundation. While World War I, the subsequent Great Depression and World War II took many resources from the American people, those events became test beds and discovery zones that focused on scientific advances related to wartime needs. For example, cyanoacrylates, aka, superglue, were discovered in 1942 while searching for materials for clear plastic gun sights for World War II (MIT, 2010). Duck tape (or duct tape) was developed during World War II for use in sealing ammunition cases (Gurowitz for Johnson & Johnson, www.kilmerhouse.com). Wanting to continue with the scientific advances even though the war was over, President Franklin D. Roosevelt called upon Vannevar Bush for help. Bush's solution, presented to the President in 1945, was a "National Research Foundation." The "National Science Foundation" – a name suggested by Senator Harley Kilgore of West Virginia

– was introduced as a series of bills in 1945 and passed by Congress in 1947. However, President Truman vetoed the bill because he was not allowed to name the director of the agency. Finally, in 1950, the bill passed, creating the *National Science Foundation* (NSF), with Alan T. Waterman as the first director and an initial appropriation of $225,000 (equivalent of about $1,875,000 in today's dollar). (For a more complete history of the NSF, please see http://www.nsf.gov/about/history/overview-50.jsp#1940s.) Although the NSF began funding educational innovations as early as 1954, it did not see significant amounts of funding until after the launch of Sputnik, when Congress more than tripled its education funding in 1958.

While there were several calls for a renewed focus on science education throughout NSF's history (e.g., 1971, 1972, 1980), it wasn't until 1989 that we saw the beginnings of the calls for multidisciplinary research through the Small Grants for Exploratory Research program. This call for multidisciplinary, innovative research was originally coined *SMET* – Science, Mathematics, Engineering and Technology. Although the history of the acronym SMET is largely unknown, it did appear as early as 1993 in NSF 93-143 Guide to Programs documents:

> One major NSF goal is to improve the quality of the Nation's science, mathematics, engineering, and technology (SMET) education.

Additionally, congressional hearings in 1997 in the Committee of Science show the use of the SMET terminology as well. However, in 2001, Judith Ramaley, then a director at NSF, decided that the words needed reordering to show a more interdisciplinary emphasis:

> I did so because science and math support the other two disciplines and because STEM sounds nicer than SMET. The older term subtly implies that science and math came first or were better. The newer term suggests a meaningful connection among them. (Chute, Feb. 10, 2009)

The term is wildly popular today, long surpassing analysts and critics who thought it was just a trend or fetish. Despite its growing popularity, the definition of STEM and, more specifically, the definition of STEM education, remains very broad and open to various interpretations amongst its stakeholders (Breiner, Harkness, Johnson, & Koehler, 2012).

## DEFINING STEM EDUCATION: AN INTERDISCIPLINARY APPROACH

In defining STEM education, the current state and focus of that education must be considered. There is an increased focus on college and career readiness with the recent release of the Common Core State Standards and the Next Generation Science Standards, including a new focus on integrating engineering into science classrooms. Add into the mixture literacy across the disciplines, STEM literacy and 21st century skills, it has become a very broad field with a great deal of overlap. Across the literature, although STEM education consistently focuses on a more holistic approach where sense-making is essential, the starting point for doing so varies (Labov, Reid, & Yamamoto, 2010). For example, the NRC (2003) advocates for effective STEM instruction to foster "inquisitiveness, cognitive skills of evidence-based reasoning, and an understanding and appreciation of the process of scientific investigation" (p. 25). However, one of the first integrative STEM education programs in the US suggests starting with engineering so as to focus on the application of the field (Sanders, 2009). Regardless of the starting point, the most important thing to consider is that the context in which we conceptualize STEM education impacts our definition. For example, Breiner et al. (2012) surveyed faculty members at a public Research I institution concerning their conceptions of STEM. While 72% possessed a relevant conception of STEM, they did not share a common conceptualization. This disjoint in conceptualization is likely due to their various academic disciplines and/or the impacts of STEM on their daily lives.

Therefore, for the purposes of this book, we sought to define STEM education that (a) took into consideration a common context for our conceptualization of STEM education (namely, project-based instruction); (b) considered the application of STEM to real-world settings within the project-based instruction environment; (c) rooted itself in an interdisciplinary approach (described later); and (d) led to the STEM literate society. Tsupros, Kohler, and Hallinen's (2009) definition of STEM education most closely met our criteria:

> STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy.

*Interdisciplinary* and *integrated* are two terms commonly used to describe theoretical and instructional approaches to STEM education. Perceptions of these terms have the potential to carry different meanings and may, in fact, lead to misapplications of prior experiences by novices as they try to apply theory to practice (NRC, 2014; Rivet & Krajcik, 2008). Our focus on supporting the practice of STEM education will be best accomplished in this book by further defining *interdisciplinary* as it is applied to incorporating STEM teaching and learning in educational contexts. Specifically, there should be a focus on depth of content knowledge within a specific [STEM] discipline while engaging in learning across two or more [STEM] disciplines. As depicted in Figure 3, we can visualize the interdisciplinary nature of STEM education in which goals, outcomes, integration and implementation are clearly defined within the disciplinary expertise, and practice within and across STEM are essential (Mohr-Schroeder, Jackson, Schroeder, & Wilhelm, in press). Note that we are not advocating for a single model of cross-sector collaboration, but rather a variety of different models that are relevant to the communities they serve and reflect cultures, environments and stakeholders.

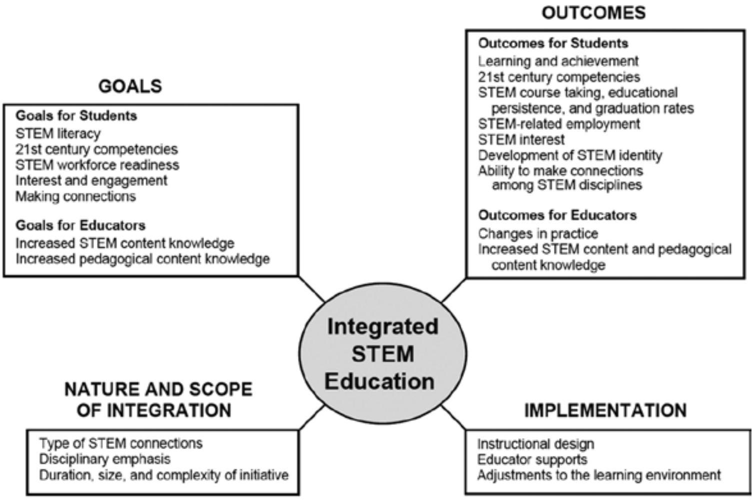


*Figure 3. Interdisciplinary STEM education framework (National Academy of Engineering and National Research Council, 2014).*

For example, let's explore what it means to be *STEM literate* using our idea of interdisciplinary STEM education. We can consider literacy as defined in terms of STEM compared to literacy as it is defined for individual disciplines. Literacy has become increasingly more specialized (Shanahan & Shanahan, 2008). The misconception of literacy as a concern limited to the English Language Arts is being corrected as the concept of disciplinary literacy gains traction and the experts are increasingly those within a given discipline. We can apply a common definition of disciplinary literacy to the four STEM disciplines, both individually and then more holistically. A frequently cited definition of *disciplinary literacy* addresses the context of a discipline, the unique practices used by those within a discipline and how the knowledge and abilities possessed by those in a discipline are used to create, communicate and use knowledge to engage in the work of that discipline (Shanahan & Shanahan, 2008, 2012). Applied to the STEM fields, experts in individual STEM disciplines could identify those unique tools related to engaging in that discipline. The commonalities across the disciplines, as previously described in defining a transdisciplinary approach, create yet another unique tool set and ability to create and use knowledge that we classify as STEM literacy. Novices can become experts as they learn how to create, communicate and use knowledge within and across STEM fields.

## FULL STEM AHEAD

The perspectives held by teachers and students help shape the implementation of STEM education. In this chapter, we sought to present a brief history and a framework that will help teachers operationalize STEM education through transdisciplinary instructional practices such as the STEM SOS model on which this book focuses. Professional development and supplemental materials such as this book that are geared toward STEM education practices are necessary to effectively meld perception and practice in the classroom. While teachers today know and understand the value of inquiry-based instruction, such as that of project-based instruction, without proper training and support, they tend to revert to traditional instruction that is rooted in the work of the Harvard Committee of Ten (NEA, 1894) that placed an individual focus on subject areas. While discrete subjects are important, that focus challenges today's call for 21st century skills, critical thinking and application, and making cross-disciplinary connections that industries desire (NRC, 2014).

> Imagine an education that includes solving hundreds of such challenges over the course of the 13 years of schooling that lead to high school graduation – challenges that increase in difficulty as the children age . . . Children who are prepared for life in this way would be great problem solvers in the workplace, with the abilities and the can-do attitude that are needed to be competitive in the global economy. Even more important, they will be more rational human beings - people who are able to make wise judgments for their family, their community and their nation. (Alberts, as quoted in NRC, 2014, p. 10-11)

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S. ENRICO P. INDIOGINE

# 2. THE ACHIEVEMENT GAPS IN MATHEMATICS AND SCIENCE

## INTRODUCTION

The purpose of this chapter is to discuss and outline the findings from studies on the achievement gaps (AGs) in science and mathematics. I also review the interventions that have been implemented to mitigate or overcome those gaps.

I begin this analysis by (1) looking at the background of AGs by investigating the meaning and origin of AGs and discussing the several types of AGs. Then (2) I examine the relevance of AGs to the lives and prospects of the students and our nation, asking "What is the economic and strategic impact of the AGs?" (3) I then present the results of research on the causes of AGs, and (4) examine the outcomes of interventions to address AGs that have been implemented by the schools and school districts.

## BACKGROUND

In a contemporary society where universal education has become a reality, the focus of attention has shifted from the availability of public education to its quality. There is a widespread perception in the United States that K-12 public education is not at the level it should be. This issue is thought to have a number of negative effects, ranging from the narrowing of career opportunities for students all the way to reducing national competitiveness in an increasingly competitive global economy. Many attempts have been made to quantify the quality of education in our public schools. Looking at the several available metrics, including graduation rate, funding per student, time in school and educational levels of teachers, it comes as no surprise that the preferred metrics are test scores, preferably from standardized tests. This can be seen in the following quote by Maloney and Mayer (2010, p. 333).

> The phrase "achievement gap" in education and political circles signifies the long-term and steady score gap between white, black, and Hispanic/Latino youth on standardized tests. Using the National Assessment of Educational Progress (NAEP) and SAT scores, researchers have shown that this gap, first recognized in the 1960s, fell by 20% to 40% (depending on the estimate) in the 1970s and 1980s, but then began widening in the late 1990s. (Lee 2002; English 2002; Haycock 2001)

*A. Sahin (Ed.), A Practice-based Model of STEM Teaching, 15–28.*

The NAEP scores are computed at the national level and disaggregated by ethnic and racial group by the National Center for Education Statistics, an agency of the U.S. Department of Education. The SAT is administered by the Educational Testing Service on behalf of the College Board.

In other words, at the national level, there are persistent and significant differences between ethnic/racial groups in which students of Asian and European descent have significantly higher scores than Native American students and students of African or Hispanic descent. Concurrent with these differences in achievement scores based on race/ethnicity are the differences in wealth. The effect of disparity in income on educational outcomes is at least as incisive as the previous differences. This phenomenon has been called the "racial, ethnic, income, or national achievement gap" (NAG).

The national achievement gap is not a phenomenon that is restricted to the public school system in the U.S. It also exists in private schools, although less is known about the NAG in private schools. However, it seems that the NAG is narrower in private schools (Coulson, 2005; Neal, 1997). Similarly, little is known about the NAG in home-schooling but there again, it seems that the gap is narrower if not eliminated (Home School Legal Defense Association, 2001, pp. 4-5).

Test scores have also been aggregated according to nation by the International Association for the Evaluation of Educational Achievement, administrator of the Programme for International Student Assessment (PISA), and the Organization for Economic Cooperation and Development, which offers the Trends in International Mathematics and Science Study (TIMSS). In these international rankings, the U.S. usually places at the middle to bottom among developed countries. This phenomenon is often called the "international achievement gap" (IAG).

The IAG is defined and understood in slightly different ways by various authors. The general concept is that there is a disparity between the proficiency of students in U.S. and other countries that are considered its "peers." A recent author on the subject, Wagner (2008), defined this gap as the disparity between the "new skills" needed in "today's highly competitive global knowledge economy" and what students are taught in class) (p. xxi).

A more prosaic understanding of the IAG is simply about the ranking of the U.S. in international studies. However, this is a very crude way of understanding the issue. Ranking is often misleading because the differences in score points are not statistically significant. For example, the document that in a certain sense started it all, *A Nation at Risk* (National Commission on Excellence in Education, 1983), was later reanalysed and much less threatening results were found in the data. According to Carson, Heulskamp, and Woodall (1993), Simpson's paradox made several trends appear to go in the opposite of their actual direction. This type of paradox occurs when the statistical data of distinct groups are pooled, i.e., each group may exhibit a positive trend, but when combined, the overall trend becomes negative. However, according to Stedman (1994) there were still reasons for concern even though the situation was not as dire as generally portrayed. The standardized tests themselves

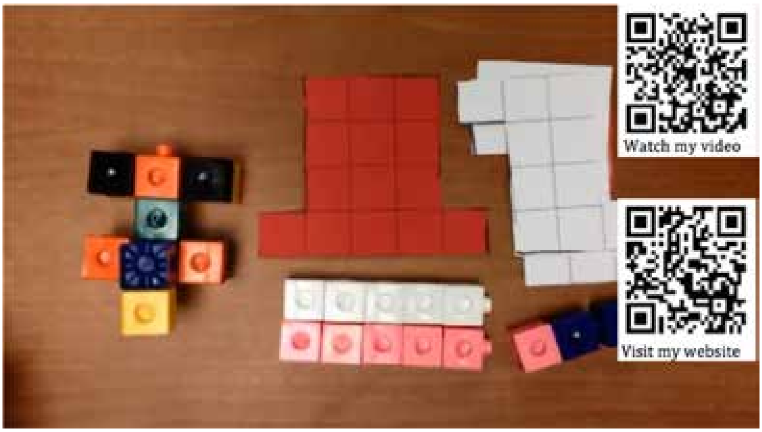


*Figure 1. A student demonstrating her Level II project.* (Please use your QR reader to scan the QR codes to watch her video and/or see her e-portfolio website.)

have been subjected to extensive criticism. For example, a simple renorming would make any idea of trends meaningless. Others such as Downey, Steffy, Poston, and English (2009) have a more nuanced view:

> The first important step to take in confronting the achievement gap problem is to abandon the idea that one single thing, or even a few things in combination, will crack this apparently baffling educational conundrum. And the first factor to confront is that there is no single "achievement gap" but many kinds of gaps. (p.1)

Using a national educational longitudinal data set, Carpenter, Ramirez, and Severn (2006) found "not one, but multiple achievement gaps, within and between groups" (p. 120) and that "gaps between races may not be the most serious of them" (p. 123). The gender AG has received less attention because the gender imbalance in public schools has swung in favour of female students and has only remained relevant in advanced placement (AP) courses in the STEM fields where female students are typically underrepresented (e.g., Robinson & Lubienski, 2011).

## RELEVANCE

Although schools teach a wide variety of subjects, the focus of attention has primarily been on English language and mathematics and, more recently, science. These fields of knowledge are considered vital for national security and prosperity. Of these subjects, the preeminent one has been English, which is the "unofficial official" language of the nation. The latest wave of immigration into the U.S. distinguishes itself from the previous ones by its members being less eager to relinquish their native languages in favour of English. However, more recent harsh economic realities have shifted the spotlight to the teaching and learning of mathematics and science. These academic subjects are considered to be critical for the formation of a workforce capable of participating and succeeding in a competitive and technologically advanced economic system that now spans the entire planet.

The achievement gap is now an indelible part of the public discourse on education at all levels. There are two major markers of this phenomenon. The first was the publication in 1983 of the previously mentioned report, *A Nation at Risk* (National Commission on Excellence in Education, 1983), and the second was the passing of the "No Child Left Behind" Act of 2001 (NCLB). The topic is closely intertwined with burning issues of the U.S. social life such as de-industrialization, globalization and the disappearance of "well-paying jobs" for those having a high school degree or less.

A recent example of the popularity of this subject is an article that appeared in *The New York Times*, written by Garfunkel and Mumford and dated August 24, 2011.

> There is widespread alarm in the United States about the state of our math education. The anxiety can be traced to the poor performance of American students on various international tests, and it is now embodied in George W. Bush's No Child Left Behind law, which requires public school students to pass standardized math tests by the year 2014 and punishes their schools or their teachers if they do not.

## DESCRIPTION AND CAUSES

The majority of the research on AGs has been conducted without specific reference to math or science. Most of these studies focused on identifying the causes of the underachievement of African American students. Among these studies are Chambers (2009) who detected a "differential treatment by school personnel as early as elementary school'' (p. 1). The study by Rowley and Wright (2011), based on the Educational Longitudinal Study of 2002, confirmed the Black/White gap, but also made the statement that among its causes is "discrimination based on race" (p. 1). However, the paper itself did not offer any substantiation of racial discrimination, but rather pointed to the inequity of the U.S. public school system. This is an almost uniquely U.S. phenomenon based on the preponderance of local funding of schools in the United States.

A relatively recent trend in AG studies is the focus on Hispanic students. The term Latino/a is also used. Among those studies are those of Reardon and Galindo (2009), Heilig, Williams, and Jez (2010), and Madrid (2011).

Gill (2011) conducted a study in which both ethnic groups, Black and Hispanic, were taken into consideration. The author did not find any statistically significant differences in the Virginia "Standards of Learning" scores between those two groups, but both had scores that were statistically different from the group of White students.

An additional item on the topic of study is the socioeconomic status of the families (SES). However, Condron (2009) studied both and, surprisingly, found that schools widen the Black/White disparities, but narrow the social class gaps. He concluded that school factors affect the racial AG and non-school factors drive the income AG. Later, Burchinal et al. (2011) obtained the same type of result in a longitudinal study of elementary school students.

Among the studies about the causes of AGs, a topic of research is school and class size (McMillen, 2004). There is a policy aspect to the size of schools and classes because it is determined by policy and funding. McMillen stated that:

> The number of public schools serving the secondary grades in the U.S. has largely held steady between 23,000 and 26,000 since 1930. During that same time, however, the number of public high school students in the U.S. nearly tripled, from approximately 4.4 million to over 13 million. As consolidation trends have created larger schools, the issue of school size has become of great interest to educators and policymakers alike. (p.)

Cultural aspects of AGs were discussed by Cholewa and West-Olatunji (2008) and Demerath, Lynch, Milner, Peters, and Davidson (2010). These researchers discussed the AGs in light of the "wave theory." The first wave was the primordial hunter-gatherer culture; the second wave consisted of the agrarian civilization; the third wave was the industrial society; and the fourth is the post-industrial society. The author noticed how in a fourth wave society, such as the U.S. of today, "[a]dvanced literacy and numeracy skills are absolutely essential for competing within the 4th wave workforce" (p. 15). Adams (2005) showed how differences in habits between racial/ethnic groups impact academic success, such as hours spent watching television, time dedicated to homework and parental expectations.

The gap between the culture of the teachers, the majority of whom are of European descent, and those of who do not share this culture creates what Cholewa and West-Olatunji (2008) called "cultural discontinuity" (p. 1). The authors considered this phenomenon to be a major cause of the AGs. A different approach was taken by Demerath et al. (2010), who pointed out that "we need to decode success, rather than continue the autopsy of failure" (citing Hilliard, 2002, p. 2937). The authors analysed how children from middle and upper-class backgrounds are able to extract from schools the best they have to offer to better compete in society.

A more focused analysis of the various immigrant groups was performed by Han (2006), who took into consideration the number of generations after immigration as well as the ethnic origin of students and concluded that "[c]hild and family characteristics were the most important factors to these [immigrant family] young children's academic achievements" (pp. 313-314). Basically, some ethnic groups scored higher (e.g., East Asian) than the U.S. average, while others (e.g., Mexican) scored lower. Schwartz and Stiefel (2006) similarly found that countries of origin were important. For example, Russian children scored above average and children from the Dominican Republic scored lower. However, on average, immigrant students did better than native students in New York. Konstantopoulos (2009) performed a rigorous correlational statistical analysis of the achievement of Asian American students and confirmed what is considered common knowledge. The Asian-White AG is clearly in favour of Asian American students, even though it is smaller in reading than in mathematics. However, Pang, Han and Pang (2011) showed in their study of this group of students in California that we should not consider all Asian American students as a homogeneous group, but rather need to disaggregate between subgroups. Briefly, Asian Americans can be divided into a group of above-average achievers, corresponding to North East Asians (Chinese, Koreans, and Japanese) and South East Asians (Filipinos, Cambodians, Pacific Islanders, etc.), who achieve below average. Some studies on the achievement of immigrant students are even more granular. Simms (2012) studied the effect of educational selectivity of parents. This term denotes how the education level of parents compares with the average in the country of origin. The author found that educational selectivity had more explanatory power than SES. Related to immigration is the issue of how language has an effect on achievement (Han, 2012). The author described how mixed bilingual students were able to close the AGs, but non-English dominant bilinguals and non-English monolinguals did not. Halle, Hair, Wandner, McNamara and Chien (2012) studied the effects of the grade at which English proficiency was attained and the AGs. Their study found that the sooner that proficiency was attained, the sooner the gap was narrowed or closed.

A minor, but still important, area of research is the comparison between public and private schools. Usually, the private schools are Catholic because they are (1) a large system, and (2) unlike many private schools, not for the nation's elite, but for all groups of students. Hallinan and Kubitschek (2010) provided an example of this kind of study. The authors compared Catholic schools to public schools in Chicago with regards to the influence of poverty on student achievement. This study showed, not surprisingly, that poverty hampers achievement, but that this effect was mitigated in Catholic schools.

Some studies are fairly technical and critique the statistical measurement of the AGs themselves. For example, Verdugo (2011) studied the effect of dropouts on the AGs. Because the academically weakest students are those who typically are the most likely to leave the school systems, the achievement scores looked better than they actually were.

Considerable research has been done on the causes of the mathematics AG. The typical study of this type involves a detailed statistical analysis in which several factors are considered: race/ethnic group, SES, parental involvement, teacher, class and school size, and knowledge of English. See, for example, Berends and Penaloza, (2010), Braun, Chapman, and Vezzu (2010), Georges and Pallas (2010), Abedi and Herman (2010), and Riegle-Crumb and Grodsky (2010).

Among the most interesting types of statistical analysis is the longitudinal study. The efficacy of NCLB on the closing of the AG was examined by Braun et al. (2010) who found a modest impact.

Berends and Penaloza (2010) added an historical dimension to their study of the AG and showed that, between 1972 and 2004, the mathematics Black-White and Latino-White AGs increased. The authors attributed this phenomenon to the increase in segregation during that period.

Kelly (2009) studied the mathematics course taking of Black students and found that they were disproportionately enrolled in lower-track courses, a difference that could not be entirely explained by individual or family factors. Similar results were found by Long, Iatarola, and Conger (2009) in a study that focused on the need for remedial mathematics courses in Florida in relationship to the number and level of math courses taken by high schools students in that state.

Some studies have focused on teachers and their effect on mathematics scores. Hines (2008) found that students of teachers with low self-efficacy had lower mathematics test scores. In addition, Desimone and Long (2010) found that lower-achieving students had teachers who spent less time on instruction. On the other hand, Georges and Pallas (2010) found that teaching practices had little influence on mathematics scores and, at any rate, had uniform effects for all students.

Lee (2012) studied the effects of AGs on the possibility of obtaining a 2- or 4-year post-secondary degree, finding "large disparities between actual and desirable math achievement levels for college readiness at the national level" (p. 52).

While most research is focused on the problem of mathematics AG, a few, such as Stinson (2008), studied successes. That author conducted a participative study with four African American male students who were academically successful in mathematics.

The mathematics AG is often associated with educational inequity (Hines, 2008; Long et al., 2009). Ruiz (2011) stressed the social aspects of the mathematics AG, using her personal experience to discuss the importance of motivating Latino students in Algebra I. Most of the ELL students in the U.S. public school system are Latinos; thus, cultural and linguistic issues are often connected. Several studies have targeted the relationship between the language skills of Latinos and the mathematics AG (e.g., Abedi & Herman, 2010).

The most popular type of research on the subject of IAG is the statistical study of data from TIMSS (e.g., Chudgar & Luschei, 2009; Heuveline, Yang, & Timberlake, 2010; Wang & Zhu, 2003), or PISA (Perry, 2009). Hierarchical linear modeling is often employed for analysis of TIMSS data (Heuveline et al., 2010; J. Lee & Fish, 2010).

An interesting study was performed by Chudgar and Luschei (2009), who looked at differences between and within countries with respect to the SES of families. This study found that, in most cases, the schools are less important than the family situation in explaining student achievement. Similarly, Lee and Fish (2010) found that the international AG gap is due to school factors, but family factors explain differences between states in the U.S.

Perry (2009) did an in-depth statistical study that focused on equity and found that (1) academic selectivity in school admittance policies in compulsory education

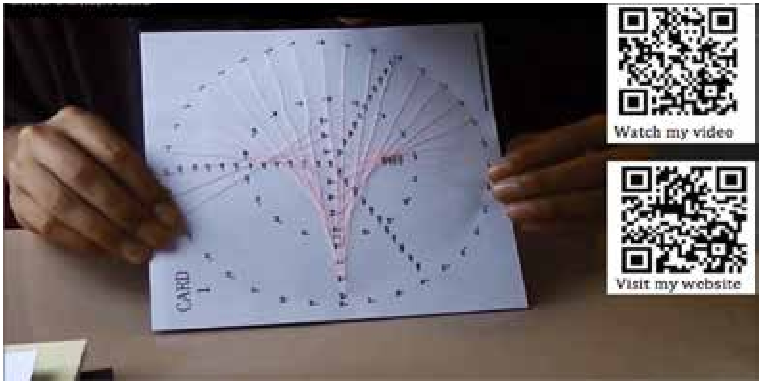


*Figure 2. A student demonstrating his Level II project.* (Please use your QR reader to scan the QR codes to watch his video and/or see his e-portfolio website.)

is strongly associated with inequitable outcomes, but not necessarily overall performance; (2) selective schooling does not always reproduce social status; (3) high levels of privatization and choice are not necessarily incompatible with educational equity, although they may diminish it; and (4) income inequality within the larger society does not appear to be strongly associated with equitable math achievement in OECD countries.

Heuveline et al. (2010) studied the relationship between family structure and mathematics achievement. As expected, children in single parent households scored lower. However, in the U.S. this gap was larger than in 13 other countries.

## INTERVENTIONS

Several projects were implemented with the aim of reducing or even eliminating the AGs. These were implemented at various levels, including single schools (Beecher & Sweeny, 2008), school districts (Burris, Wiley, Welner, & Murphy, 2008; Lopez, 2010), and even larger geographical areas (Konstantopoulos & Chung, 2009; Smith, 2012). Common to all the successful interventions are the considerable amount of resources, the adoption of interactive whiteboard technology (Lopez, 2010), a complete restructuring of a school (Beecher & Sweeny, 2008), group counseling (Bruce, Getch, & Ziomek-Daigle, 2009), more advanced classes such as International Baccalaureate (IB) courses (Burris et al., 2008), class size reduction (Konstantopoulos & Chung, 2009), and summer programs (Smith, 2012).

The main objective of NCLB was to eliminate the AGs. Lee and Reeves (2012) performed a longitudinal study using hierarchical linear modeling of NAEP data to determine the impact of NCLB on the reading and mathematics AGs. Their results aligned with the previously mentioned research in that school resources were more influential than the instruments of reform law, accountability, data tracking and standards.

Can instructional practices reduce the mathematics or science AGs? To answer this question, Wenglinsky (2004) performed a hierarchical linear modeling study on a national sample. He found that instructional practices could make large differences even after the personal backgrounds of students were taken into consideration. Similar results were obtained by Crosnoe et al. (2010), Clarke et al. (2011), Santau, Maerten-Rivera and Huggins (2011) in science, and by Boaler and Staples (2008) in California. Other types of school interventions have met with success, such as "ethnic matching" of African American students with African American teachers (Eddy & Easton-Brooks, 2011).

However, supplementary programs were also found to have a positive effect (Lee, Olszewski-Kubilius, & Peternel, 2009). Similarly, the use of computers as both in-school and extra-school activities was able to narrow the mathematics AG, according to a national longitudinal study (Kim & Chang, 2010).

With the relatively recent influx of immigrants with low English language skills, an often used strategy in the closing of the mathematics AG is to act on the English language skills, after all almost all standardized tests are written in English (Kim & Chang, 2010; Santau et al., 2011). Sometimes, teachers receive English language learners (ELL) training or use special instructional practices targeted to ELLs (Pray & Ilieva, 2011). NCLB provides exclusions and deferrals for English ELL students.

Alson (2006) presented a personal case study, which, however interesting, has the limitation that it is not reproducible, even though most studies in education at a certain level share this limitation.

It seems that very few programs have been implemented to narrow the International AG (IAG). Tabernik and Williams (2010) studied the effect of teachers' professional development in Ohio on the international mathematics achievement gap.

Very little research has been done on whether project-based learning (PBL) can reduce or eliminate the AGs. Recently, Halvorsen et al. (2012) implemented a PBL series in low and high-SES schools in the subjects of social studies and reading and writing to learn content (content literacy). They found no statistically significant differences between high- and low-SES students at the end of the intervention. In other words, the researchers had, supposedly, closed the AG for these subjects. However, the study did not establish the presence of an AG before the intervention; it was simply assumed. There was no common pre-test across differing SES schools, only a post-test.

In their study, Lieberman and Hoody (1998) reported the results of the implementation in 40 schools of a framework that employed the environment as an Integrating Context for Learning (EIC). This approach provided "hands-on learning experiences, often through problem-solving and project-based activities" (p. 1). In addition to math and science, the academic subjects covered included social studies, reading and writing. The document states that EIC "holds great promise for helping 'close the achievement gap' in reading, writing, math, science, and social studies"

(p. 11); however, no data are shown to support this statement. Nonetheless, the study has shown improved academic performance in most schools that have implemented EIC.

In our discussion of interventions geared towards the elimination of the AGs, we need to mention the charter schools. Briefly, a charter school is a type of school that receives public funding, but operates independently from local school districts, even though it is subject to the same curriculum standards and state achievement testing as traditional public schools. Many have suggested that, due to the independence and flexibility of the charter schools, the movement is able to implement innovative academic activities and structures that can overcome the AGs (Read, 2008; Department of Education & WestEd, 2006; Ladner et al., 2010).

It is regrettable that the students who would most benefit from learning math and science are most often disinterested in these subjects. Technical, health, and engineering careers are wonderful opportunities for upward mobility because they do not usually require the presence of a network of connections as careers in law and management do (Sahin, Gulacar, & Stuessy, 2014). Hence, any means of eliciting the interest of the students in science and mathematics and thus their academic achievement should be fostered.

The Harmony charter schools have implemented a project-based STEM teaching called the STEM Students on the Stage (SOS)™ model to improve the mathematics and science achievement of students of all subgroups (Sahin & Top, in press; Sahin, Top, & Vanegas, 2014; Sahin et al., 2013; Sahin et al., 2014). Studies of the SOS model at HPS have shown that student are profoundly engaged, interested in STEM subjects and learning skills relevant to the workplace as well as getting ready for college and life. (Sahin & Top, in press; Sahin, Top, & Vanegas, 2014),

In the presence of promising preliminary results of PBL implementation and the results from research on the efficacy of PBL at Harmony Public Schools, we have reason to be optimistic.

## CONCLUSION

During the last years, we have seen a certain decrease of the emphasis on the achievement gaps. However, there is also no indication that the AGs problem has been resolved. All but four states have obtained or requested a waiver from the U.S. Department of Education for failing to close the achievement gap as requested by NCLB. The public discourse on the achievement gaps has changed from the high hopes of ESEA and especially of its re-enactment as NCLB to the tacit and implicit admission of failure that these waivers denote. It is the understanding of the author that because of inherent contradictions build into the legislation aimed at resolving the achievement gaps, primarily NCLB and the more recent "Race To The Top" (RTTT), the AGs will not be solved within the current legislative framework (Indiogine & Kulm, 2014), even if localized interventions are able to mitigate if not resolve the achievement gaps.

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# SECTION 2
# DESCRIPTION OF STEM SOS MODEL

As you explore a brand-new project-based learning (PBL) method to prepare your students for the 21st century, Section II first helps you understand the differences between different PBL models, including the new STEM PBL model titled, STEM Students on the Stage (SOS)™. The next chapter presents a research study about the codification of the STEM SOS model and describes the STEM SOS model and its components. The final chapter in Section II discusses the way in which the STEM SOS model accomplishes PBL in a standards-focused world. After reading these chapters, you will have initial and broad understanding of the new STEM PBL model and how easy it is to implement.