Cultivating STEM Identities

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Strengthening Student and Teacher Mindsets in Math and Science

Wendy Ward Hoffer

Foreword by Dr. Scott Sampson

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For my God-sent godfather,

Dr. William McNeamer Harvey,

who always reminds me of my true identity

The creation
of a thousand forests
is in one acorn.

—Ralph Waldo Emerson

Contents

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And lastly, you, dear reader: I am delighted that you care enough about our future to read this book. I hope that both your own and your students' STEM identities will prosper as a result.

Foreword

My elementary school backed up onto a forest, a green wonderland ideal for igniting young imaginations. One day after school in seventh grade, I was out bushwhacking with my buddy Tim when we happened upon an ancient, half-buried Coke bottle, the surface worn and opaque. We dug around and discovered more exotic items—an old can, a rusted chunk of metal, even a possible arrowhead. Our excitement skyrocketed.

The next morning we ran into the classroom, breathless to tell our teacher, Mr. Duncan, about this major discovery. After school he happily trekked with us to the "dig site," and spent some time poking around the cultural flotsam and jetsam. Eventually he declared, "I think you boys have stumbled upon some sort of old dumping ground. Great job!" Needless to say, Tim and I wore beaming smiles as we hiked back to the school.

The following week, Mr. Duncan announced that the entire class would be headed outdoors into the schoolyard to conduct a mock archaeological dig. We tumbled out onto a low, grassy hill around the flagpole to find several jumbled piles of objects—stuff like cups, bowls, burnt wood, and chicken bones. Each pile, or "site," was divided up into layers separated by paper towels or chunks of sheets.

We kids formed groups of three to "excavate" our archaeological site, carefully recording our findings, making diagrams, and analyzing the results. Eventually it became clear that each layer had different kinds of artifacts, and that we could use these patterns to generate hypotheses about the changing cultures that lived there long ago. Most of all, we were entranced by the joy of discovery.

Mr. Duncan was one of those rare gems of a teacher characterized by broad knowledge, high expectations, and a strong sense of caring. You worked to excel in his class because, well, the thought of letting him down was all but inconceivable.

This remarkable teacher also utilized hefty doses of creativity and hands-on activities, long before educators used terms like "experiential" and "inquiry-based learning." I had no idea at

the time (though I'll bet he did), that Mr. Duncan was helping all of us seventh graders forge our own "positive STEM identity"—growing the scientist in each of us.

Most elementary school teachers, then and now, take a more traditional, didactic approach to science teaching. And no wonder. The bulk of these teachers lack any formal scientific training. So it's natural to feel intimidated by the content, and unsure of how to present it. In such situations, the tendency to go into default mode and stick closely to the textbook is entirely understandable. Yet the result, too often, is unengaged learners who get turned off by science.

It is with great pleasure, then, that I welcome you to *Cultivating STEM Identities*. Within these pages, Wendy Hoffer offers up an antidote, an intervention, aimed at breaking the negative chain described above. Wendy is an education expert, particularly passionate about teaching STEM—science, technology, engineering, and math. Within these pages she provides you, the teacher, with easy-to-use tools that will enable your science teaching to be more creative, more engaging, and more experiential.

Also offered up is a provocative array of strategies aimed at building strong STEM identities in elementary school students. Wendy shows how key teacher beliefs (for example, "We are all scientists.") can cascade into teacher behaviors, which in turn directly impact the experience and, ultimately, the identity of the learner.

Assessment after assessment of formal education demonstrates that huge numbers of kids—with a strong bias toward girls, children of color, and those from lower income families—lose interest in STEM fields during the elementary school years. Tragically, that vibrant sense of wonder so prevalent in early childhood is all too often extinguished by the time adolescence arrives. As a result, many, perhaps most, of these children will forge a negative STEM identity that will have cascading effects throughout their lives.

Nevertheless, a large and ever-growing literature, much of it documented in this book, shows that educational interventions focused on quality STEM teaching can make a huge difference. In short, teachers have the power to turn this trend around and help foster the next science-minded generation. Doing so is critical not only for the health of children, but also for the places they live. Indeed, without such a profound shift, things look dire indeed.

We happen to live at arguably the most pivotal moment in 200,000 years of human history. Decisions made and paths taken over the next generation will have reverberating effects throughout Earth's biosphere for thousands, perhaps millions, of years to come (trust me on this; I'm a paleontologist). We desperately need to foster a generation that is science literate. Wrapped up in this idea is the notion of health literacy, environmental literacy, and sustainability literacy. Equally critical is keeping that sense of wonder alive and thriving.

So dig into this book. Then, dip back into it often, particularly when you need a new tool, a new approach, or just a little inspiration. You will quickly find that your confidence and competence with STEM gets a major boost, closely followed by that of your students. As an elementary school teacher, know that you are engaged in some of the Great Work of our time. Warm thanks for your efforts. And enjoy the journey!

—Scott D. Sampson

Introduction

Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. For its part, science education—meaning education in science, mathematics and engineering—should help students to develop the understandings and habits of mind they need to become more compassionate human beings able to think for themselves and face life head on.

—American Association for the Advancement of Science, Project 2061

Astronaut Mae Jemison, speaking at the Colorado Education Initiative's 2015 annual luncheon, described the need for diversity among medical professionals: not long ago, when oncology was predominated by men, the treatment of choice for breast cancer was radical mastectomy, and with limited success. Meanwhile the male-dominated field had virtually licked testicular cancer without a mention of castration as a treatment option. Now that more women have entered the medical profession, breast cancer outcomes have improved dramatically, and a patient with this diagnosis is far more likely to receive a lumpectomy and radiation than the more dramatic surgery of yore. Who our scientists are matters.

And yet even today, in the wake of the civil rights movement, the equal rights movement, Title 9, and a host of affirmative action efforts, most fields of science, technology, engineering, and mathematics in this country—a collection known by the acronym STEM—continue to be dominated by white men, and generally those from families of means. Don't get me wrong; I love white men. I gave birth to one. Still, all of us will benefit when the doors to opportunity in the STEM fields are flung wide open to all children, of all races, all sexes, all socioeconomic status levels. Just as there was a shortage of research on women's health when men significantly dominated the medical and neuroscience professions (Robert Wood Johnson Foundation 2011), we lack insight into

diverse economic, statistical, and scientific issues when the fields of professional mathematics and science are predominantly populated by folks of the same gender and ethnicity. Improving access to STEM careers for people of all backgrounds will not only increase their individual opportunities for economic advancement, offer off-ramps from cycles of poverty and underachievement, but also benefit our collective society by opening doors to new realms of creativity and problem solving.

Kids make up their minds early on—some researchers say by age eight—about their relationship with the fields of math and science, and so, as elementary educators, we are well poised to influence learners' opinions of themselves and these content areas (Weinburgh 1998). Each of us, by virtue of who we are and what we model for children, has the power to cultivate children's optimistic associations with math and science, as well as their positive perceptions of themselves as engineers and problem solvers.

What Is a STEM Identity?

We each have many identities—racial identity, professional identity, sexual identity, our role within a family—all these aspects of ourselves form who we are. Some components of our identity can bring us great joy, as in, "I love being a mom when you let me sleep past 5:30 a.m.," while others can cause us to struggle against discrimination or limiting beliefs, as in "Girls can't be astronauts." (Mae Jemison, of course, proves that wrong, but nonetheless, we swim among some challenging cultural beliefs about girls' opportunities in the STEM fields.) Our identities are informed by our upbringing, our experiences, and society at large, and can shift across time either unconsciously or through deliberate effort.

I have a friend who was not a morning person; in fact in college she had a bumper sticker that stated, "Not a morning person doesn't even begin to cover it." That was her identity when it came to sleep schedules; yet upon arriving in adulthood, with a real job that started at 8:00 a.m., she found the need to revise her identity. With improved sleep management and changes in diet and exercise, she intentionally reset her biological clock. She now relishes mornings and awakens each day before her children to enjoy the smells and sounds of dawn, an intentional identity change from night owl to morning person.

How you think of yourself as a scientist, technology user, engineer, or mathematician is your STEM identity. (We'll get into more detail about STEM identities and the factors that shape them in Chapter 1.) Whoever you are, wherever you came from, whether you love troubleshooting Internet access glitches or hate doing your own taxes, your STEM identity has a hold on you. Similarly, each of your students walks into your classroom each year with a STEM identity all her own, forged through her early life experiences.

What Is STEM?

The acronym STEM is employed in various circles with a range of definitions. Typically, it means merely the collection of the fields of science, technology, engineering, and mathematics. And it is a hot topic.

Some use the term to mean the intersection and confluence of two or more of these traditionally distinct areas of study; others refer to STEM as the application of knowledge from these fields to real world contexts, as in "problem-based" learning. In essence, each of these four STEM fields could be described as using knowledge to solve problems; this is their common denominator. For the purpose of this book, STEM means the content knowledge, as well as the habits of mind, employed by learners in each field.

Stop and Think

- How would you describe your STEM identity?
- How has your STEM identity impacted the trajectory of your life?

You work with young children. You know they are innately curious: they want to rip apart a broken blender to see what's inside, to watch a pair of crickets "do it," to stick their own finger in a mousetrap just to confirm that it will actually snap. Ouch.

"Why did that happen?"
"How did they make it do that?"
"Why does it hurt?"
"Why would you do that to a little mousey?"
"Why aren't you explaining faster?"
"Why?"

Their very nature is as inquirers: research reports that preschoolers ask their parents one hundred questions a day, while middle schoolers ask virtually none (Bronson and Merryman 2010). How can we shift this trend and ensure that all students sustain their innate inquisitiveness and develop identities as curious, productive problem solvers? STEM identities can be intentionally cultivated. This is a book about why they ought to be and how we each can serve learners collectively and society as a whole by creating opportunities for students to be and see themselves as capable and successful scientists and mathematicians. First, let's examine why we must.

Why STEM Identity Matters

The authors of the 2013 Federal Science, Technology, Engineering, and Mathematics (STEM) Education Strategic Plan based their efforts on a growing demand for a prepared STEM workforce, a need to increase our nation's international competitiveness, and the hope of creating a more just and inclusive society. Excellent rationale.

In addition to that committee's strong and familiar arguments about economic development and equality, I would like to add my own four reasons that we ought to prioritize engaging all children's deep investment in their own STEM education: health, opportunity, survival, and joy.

Strong STEM Identities Promote Good Health

While for our society as a whole, life expectancies continue to extend and opportunities for medical care expand, each individual's own health literacy is a significant predictor of her ability to maintain a healthy lifestyle, obtain health services, and comply with doctors' recommendations. According to the U.S. Department of Health and Human Services, only 12 percent of American adults possess proficient health literacy, and thirty million Americans have health literacy described as "Below Basic" (U.S. Department of Health and Human Services 2015). Individuals with limited health literacy—typically those with less than a high school education and folks with limited English proficiency, a disproportionate number of whom are people of color—are less likely to access preventative care, more likely to endure chronic conditions, experience high rates of hospitalization, struggle with low health status, and remain trapped in a cycle of shame that persistently limits their access to the care they need (U.S. Department of Health and Human Services 2015).

While medical professionals make increasing efforts to communicate in plain language and provide access to health care information in accessible formats, all of us are well served to believe in ourselves as capable of understanding the basic principles of human biology and disease. When an individual is met with an unexpected diagnosis, his stress will be less if he and his family members feel confident in their ability to communicate and understand conversations with health care providers. Like fresh water, a positive STEM identity is a basic ingredient contributing to the health of individuals and families.

Strong STEM Identities Open Doors to Opportunity

This is America. You can be anything you want to be, but what do you want to be? The futures children envision for themselves are limited by the scope of their creativity and confidence and the opportunities and encouragement provided by their communities. Given limited awareness, low interest, lax support, and/or lagging self-assurance, many of those traditionally underrepresented in STEM fields continue to sit outside. Statistics on both course and career selection indicate that we are far from achieving gender and racial parity in the STEM fields.

In addition to strong STEM backgrounds creating opportunities for individuals, diversity among the professionals in STEM fields creates greater richness and opportunity for society as a whole. As described earlier, when our scientists, engineers, and doctors fully represent all sectors of society, their research and development will explore the vast interest and needs of humanity's diversity, creating greater opportunity for the health and well-being of all.

Individuals' belief in themselves as capable STEM thinkers, learners, and problem solvers directly impacts the courses they choose and the careers they select.

Strong STEM Identities Increase the Odds of Our Species' Survival

The world is in a fix. Even the Pope is chiming in on climate change. While Dr. Scott Sampson, the paleontologist of "Dinosaur Train" fame, explains that we ought not to introduce apocalyptic topics before fourth grade (Sampson 2014), the reality is that our children are inheriting an imperiled earth.

With environmental challenges more complex than computer modeling can predict, consumerism depleting Earth's resources at an ever-increasing rate, and economic disparities widening the gap between the world's wealthy and those struggling to survive, the future will surely present our children with challenges requiring both STEM solutions and ethical judgment.

As Bill Bryson (2003) describes;

> *". . . if you were designing an organism to look after life in our lonely cosmos, to monitor where it is going and keep a record of where it has been, you wouldn't choose human beings for the job.*
>
> *"But here's an extremely salient point: we have been chosen, by fate or Providence or whatever you wish to call it. As far as we can tell, we are the best there is. We may be all there is. It's an unnerving thought that we may be the living universe's supreme achievement and its worst nightmare."*

Who Participates in STEM?

- The National Science Foundation's 2012 Science & Engineering Indicators showed that in K–12 settings, males are six times as likely to enroll in engineering courses (Figure I.1), and that significant achievement gaps in both math and science persist between different ethnicities and socioeconomic status levels: the achievement of black, Latino, and Native American students, and those from low-income families, was significantly below that of their Anglo, Asian, and more affluent peers (National Girls Collaborative Project 2015).
- According to the National Science Foundation's 2015 report, "Women, Minorities, and Persons with Disabilities in Science and Engineering," 57.3 percent of all bachelor's degrees were awarded to women, yet they received only 18 percent of those awarded in computer science, 19 percent of those awarded in engineering and 19 percent of the physics degrees. Only 11.2 percent of bachelor's degrees in all science and engineering fields were awarded to minority women, followed by a mere 4.1 percent of doctoral degrees in those same fields to minority women in 2011 (Figure I.2).
- Similar disparities follow in the STEM workforce: only 25 percent of mathematicians and computer scientists are women, and only 13 percent of engineers, according to the 2014 National Science Foundation Indicators. And Hispanics, blacks, and Indians/Alaskan Natives comprise only 10 percent of the workers in science and engineering fields, while they comprise 26 percent of the U.S. workforce (National Girls Collaborative Project 2015) (Figure I.3). Economic disparities follow: STEM jobs pay 26 percent higher wages than non-STEM jobs, on average. According to the 2012 census report, there were 7.6 million STEM workers in the U.S., representing one in eighteen workers (Langdon et al. 2011). These jobs are projected to grow by 17 percent from 2008 to 2018, compared to only 9.8 percent growth for non-STEM occupations.

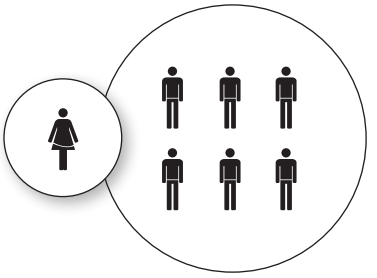

Figure I.1 Female/male enrollment in engineering courses in 2012

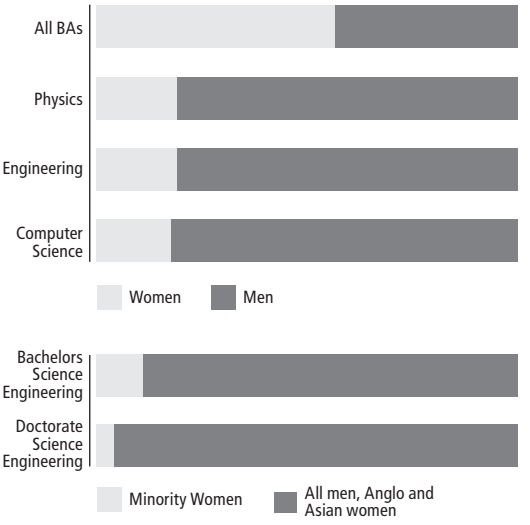

Figure I.2 Degrees awarded in 2011

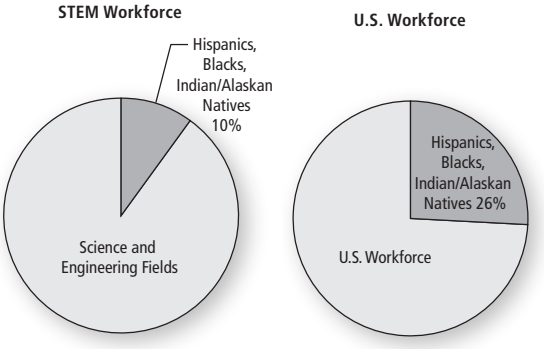

Figure I.3 Workforce disparities

We best equip our children to meet the unforeseen tests and respond to yet unposed questions by ensuring that each possesses a strong sense of herself as capable of making sense, weighing and making decisions based on STEM information as well as the dictates of her own conscience.

Strong STEM Identities Promote Joy

The authors of our Constitution believed in each individual's unalienable right to "life, liberty, and the pursuit of happiness," and to this third end, the pursuit of STEM can provide a prodigious pathway.

Health, wealth, and survival aside, STEM brings joy: marvel at a butterfly wrestling its way out of a cocoon. Watch a gathering storm as the clouds reorganize themselves above your head. Take heart in the magnificence of modern medicine capable of extracting by Cesarean a child who only a century ago would have lost his life and taken his mother's with him. Videoconference with someone on the other side of the world as though they were in the next room. Our children will take these wonders and innovations for granted unless we model for them an appreciation for the intricate beauty of the natural world and point out that our grandparents or great-grandparents had to wait weeks for letters from the front of World War II, to learn only after patient prayers that their loved ones lived.

Stop and Think

- What do you see as the benefits to having a positive STEM identity?
- What are your hopes for your students' STEM identities?
- How will you plant those seeds?

Technology is phenomenal. Nature is brilliant. Rushing through our lives, we can lose sight of the magnificence evident in each moment. A focus on STEM engages our curiosity, beckons us to marvel, to ask questions, to cultivate childlike wonder, and alongside that a pursuit to understand. This is the joy of STEM.

About This Book

This introduction invited you to reflect on why STEM identity is important. Chapter 1 asks you to consider your own STEM identity, the forces that crafted it, and your associated beliefs. From there, each chapter will introduce a productive belief about STEM and describe how that belief can be enacted through intentional teacher behaviors and student learning experiences to support learners' STEM identity development.

- Chapter 1: We Teach Who We Are
- Chapter 2: Beliefs: We Are All Scientists
- Chapter 3: Mindsets: Scientists Persevere
- Chapter 4: Community: Scientists Are Interdependent
- Chapter 5: Content: STEM Is Interconnected

- Chapter 6: Tasks: Scientists Grapple
- Chapter 7: Thinking: Scientists Are Thinkers
- Chapter 8: Workshop: Understanding Takes Time
- Chapter 9: Assessment: Scientists Share

While this book is about STEM identity, I use the shorthand "scientist" to refer to one who engages with STEM, since the fields of technology, engineering, and mathematics can all be collected under the banner of science. Science as the overarching heading for the complex and interrelated studies known as STEM was proposed by the American Association for the Advancement of Science's Project 2061 in their publication *Science for All Americans* (1989). This interesting resource, which offers an overview of the content and history of scientific endeavor, includes chapters on "The Nature of Science," "The Nature of Mathematics," "The Nature of Technology," and "The Designed World." So, with no intended disrespect for any of the discrete but interwoven STEM fields, for the purpose of this text, we will call the explorers of each "scientists."

As I worked to pull the content of this text apart into chapters, I felt as though I were trying to separate one big bowl of spaghetti into separate small portions: all the strands were connected, and when I tried to pull one out alone, I found it tangled up in the rest, all of which wanted to come along. The challenges for you, then, as a reader, will be to patiently savor each portion, or chapter, knowing that it is inextricably linked to all the others in the text. To illustrate this, cross-references are provided throughout, and I made an effort to avoid repetition and redundancy. The good news about this giant portion of spaghetti is that you don't have to eat it all at once: taking any concept in this book, any chapter, and working to implement those ideas into your planning and instruction will have a ripple effect across all other aspects, catalyzing adjustments at a number of levels. The Appendix in the back offers you some resources that may be helpful as you move forward. Be gentle with yourself as you consider change; begin with something bite-sized, and soon learners' whole experience might shift.

About Me

I had the good fortune to come into this world as the daughter of a British scientist. From the time he was fifteen, my dad spent 80 percent of his time studying chemistry, physics, and math and knows more science than anyone I have ever met. He raised us on the beliefs that science was interesting, problem solving was fun, and it is cool to know a lot of obscure information by heart. That was before the Internet.

As I made my way in the world, I learned and taught math and science in many contexts, inside the classroom and out. Most notably, I worked as a specialist for elementary-level classrooms as a garden-based science teacher (as you will read in Chapter 5). Later, after receiving my master's degree in science education, I taught math and science in two of Denver's Expeditionary Learning (EL) schools at a time when EL meant breaking and remaking the mold of public education. With abundant freedom and quite a few tears, I learned by trial and error

what does and does not support student engagement and understanding.

For more than a decade, I have enjoyed working with the Denver-based non-profit Public Education & Business Coalition (PEBC), where I now serve as Education Senior Director. My work includes playing the roles of staff developer for schools and districts throughout the nation; math and science methods instructor for our pre-service Boettcher Teacher Residency; workshop designer and facilitator of our Science Institute, Math Institute, Numeracy Institute, and other offerings; as well as author of books for educators about teaching for understanding. Most recently, I have had the opportunity to work closely with a number of inspiring elementary level STEM classroom teachers, PEBC's STEM Mentors, as they honed their craft and reflected on their and their students' STEM identities. Much of the learning I share in this book is a product of that project.

In my work supporting pre-service and in-service teachers, I have struggled to find literature that is both research based and accessible and that merges what we know about science as a way of knowing, teaching for understanding, and content-area literacy for a STEM teacher audience. In response, this is the fourth of my books on pedagogy; my previous works include: *Science as Thinking* (Heinemann 2009), *Minds on Mathematics* (Heinemann 2012), and *Developing Literate Mathematicians* (National Council of Teachers of Mathematics [NCTM] 2016). Though each of these texts targets a unique audience and aspect of instruction, together they stand on common principles:

- We and all of our students are capable mathematicians and scientists.
- Every child deserves high quality STEM education that respects, generates, and challenges thinking.
- Teachers are the best-hearted and hardest-working segment of our population and deserve to be honored and supported as such.

Whatever your STEM story up until now, I am delighted that you picked up this book. I know you became a teacher because you want the best for every child, and yet your plate is full. I am right there with you. Yet cultivating STEM identities does not need to be one more thing to cram into your already overloaded days. It can be the red thread that runs through them, the fuse that sparks student engagement, makes learning experiences meaningful, and inspires delight for all.