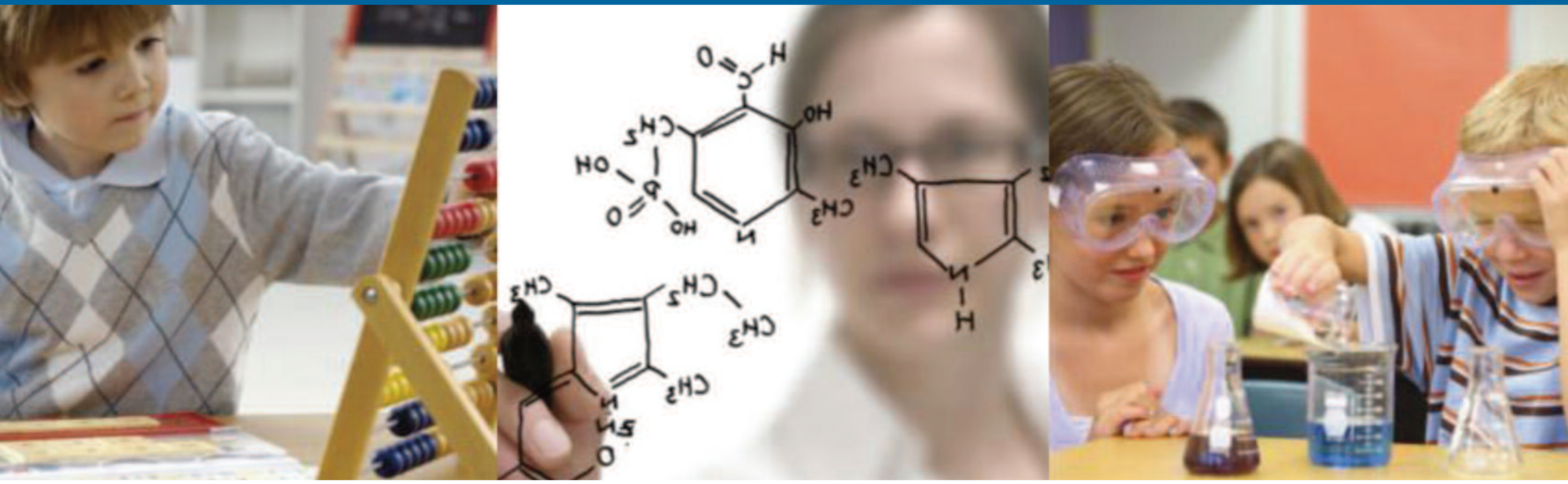
# STEM Summit 2010:

## Early Childhood Through Higher Education



NATIONAL ACADEMY OF ENGINEERING

Samueli FOUNDATION

UCIRVINE

10 YEARS Children & Families Commission of Orange County

WHITE HOUSE WRITERS GROUP

# Acknowledgements

It took many different kinds of leaders to make this STEM Summit: 2010 conference such a success, from the event host and sponsors, to a core group of volunteers and staff.

Host: This Summit would not have been possible without the National Academy of Engineering, and in particular, Proctor Reed and Greg Pearson. The NAE assisted us in securing the Beckman Center facility, while Greg helped us to define our Summit objectives.

Sponsors: The conference content was created with the help of: The University of California, Irvine's Henry Samueli School of Engineering; the University of California, Irvine's Department of Education; and, the Orange County Children and Families Commission. Special thanks go to the Dean of U.C. Irvine's Henry Samueli School of Engineering, Rafael Bras, and U.C. Irvine's Chair of the Department of Education, Deborah Vandell, for their tireless effort in defining the agenda, securing the speakers and setting the overall tone of the conference. Their efforts in securing the best in the STEM fields made this Summit such a success.

Michael Ruane, Executive Director of the Orange County Children and Families Commission, offered his hard work and advice in developing content. He also provided key staff to oversee and manage the logistics of the conference itself.

Kristen Thompson and Linda Clinard, on behalf of the Commission, played integral roles in ensuring that the conference planning was effectively implemented.

Thanks also go to Eileen Doherty, Adam D'Luzansky and Mark Davis from the White House Writers Group for assisting with conference development and planning and in developing this Summit report.

Staff: I want to personally thank Maggie Scherer and Francisca Baldwin-Petek for their true dedication to this effort and to supporting me throughout this process.

Visionaries: Of course, special appreciation goes to Drs. Henry and Susan Samueli, founders of the Samueli Foundation, for their vision and support of this conference. The Samuelis saw a need for gathering STEM leaders into one comprehensive forum—a Summit worthy of the name. The result was a look at the continuum of STEM learning and education where best practices could be shared, breaking down one silo after another to bring about positive systemic change.

Finally, our thanks go to all who volunteered their time and all who attended for making this a Summit success.

Gerald Solomon,
STEM Summit Chairman
Executive Director
Samueli Foundation

# STEM SUMMIT 2010:
## Early Childhood Through Higher Education

**A Discussion: Feb. 18-19, 2010,**
**University of California**
**The Arnold and Mabel Beckman Center**
**Of the National Academies of Sciences and Engineering,**
**Irvine, California**

### Host

**National Academy of Engineering**

### Sponsors

**Samueli Foundation**

**UC Irvine**

**Children and Families Commission of Orange County**

## **S**cience, **T**echnology, **E**ngineering and **M**athematics

"*Children only have one chance for an education. And the youth who are in school now need a better education today if they are to thrive and succeed tomorrow. Ensuring that our nation's children are excelling in the STEM field is essential. The participation and participants in this Summit have important work to do.*"

Message from U.S. Secretary of Education, Arnie Duncan

# EXECUTIVE SUMMARY

## America's STEM Crisis

Many of the great names of America are synonymous with invention—Franklin, DuPont, Bell, Edison, Wright, Ford, Salk, Gates and Jobs.

From the start, leadership in **Science, Technology, Engineering and Mathematics (STEM)** has been America's path to national greatness. In the 21st Century, these STEM-driven high-tech industries, from integrated circuits, to biotech, to aerospace, remain bright spots for a U.S. economy that has seen advantages in heavy manufacturing and other industries steadily erode.

Science and its pragmatic sibling, engineering, also remain the nation's prime generator of jobs. In fact, one scientist or engineer can generate enough new wealth to sustain a multitude of jobs, which, in turn, can enable a whole new industry. Little wonder that we still see invention and innovation as being at the core of a vibrant and strong American economy.

But is that red-hot core in danger of going cold?

The United States is producing a declining share of the world's science and engineering papers, a declining share of scientific citations, and a declining share of the world's STEM-related Ph.D.s. Unfortunately, there does not appear to be any momentum to arrest, much less reverse, this decline.

More than half of those with science and engineering degrees in the workforce are forty years of age or older. Lockheed Martin reports that it will need 90,000 American engineers by 2016. Will there be anyone to fill these valuable positions? The numbers now enrolled in STEM subjects in college today cannot possibly meet the future need of businesses such as Lockheed and its peers.

U.S. business leaders are increasingly asking: How much longer can U.S.-based global firms continue to pay American scientists and engineers at competitive rates when comparable talent is on tap at one-third the cost in India and China?

There is also concern about the STEM education some Americans are receiving. Are the scientists and engineers that we are producing broadly educated enough to assume leadership roles for their teams and active roles in the governance and management of their companies? Do all adults, including those with liberal arts degrees, have enough technological literacy to understand the STEM challenges of our times?

In such an environment, talk of American exceptionalism runs the risk of sounding delusional. If our scientific and technological edge continues to deteriorate, the United States will likely lose competitiveness, let alone its global leadership.

## Start Behind, Stay Behind

With these concerns in mind, a Summit was held at The Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering adjacent to the University of California, Irvine campus, Feb. 18-19, 2010, that brought academic experts in child learning into dialogue with business leaders, professors in STEM fields, university chancellors and presidents, and Foundations that fund in the STEM fields, to examine how to improve U.S. STEM education from Pre-K to higher education.

At the heart of this discussion is a paradox. For all the lack of interest in STEM careers, newly minted engineers reap large starting salaries and face better career opportunities in the United States than graduates in nearly every other discipline.

Why do good careers go begging? There seems to be a decline of interest in the rigors of STEM careers as the nation grows more affluent. As one discussant put it: "The abstract nature of applied science has a limited appeal for youth that are obsessed with social relevance and social networking through Facebook and Twitter."

Worse, huge segments of the population are excluded from sharing in the high income and fulfillment that STEM careers can bring. One Fortune 500 corporation, whose workforce is 75 percent engineers, reports that less than 10 percent of its employees are women, that less than 1.5 percent is Hispanic, and less than 1 percent is African-American.

Why does our educational system produce so little diversity in these fields?

Women face an external (and perhaps internalize) expectation that STEM careers are not for them. This belief represents a tragic loss in the face of empirical evidence that gender similarities, not gender differences, are the rule in math performance. In college, women earn about half of the Bachelor's degrees awarded in mathematics. And yet only 18 percent of engineering Ph.D.s goes to women.

Inflated claims about gender differences in math performance cost the nation by discouraging half of our talent from engaging STEM careers.

What about under-represented minorities?

Researchers have found that the biggest gaps of all correlate not with race, but with socioeconomic status, with the children of all races in the lowest income quintile facing diminished prospects in STEM learning.

This socio-economic gap is perhaps the most troubling of all. Millions of children from low-income homes are poorly prepared for math learning when they enter school. And yet the acquisition of these early math skills is highly predictive of their later achievement.

- Children with persistent math problems are less likely to graduate from high school or to attend college.
- Surprisingly, early math skills are more predictive of later reading achievement than early reading achievement itself.

In short, those who start ahead, stay ahead. Those who start behind tend to stay behind.

These are just some of the many negative trends driving America's diminishing ability to attract STEM-capable workers. These range from growing disinterest, to the cultural belief that females have a math deficit, to the lack of participation by underrepresented minorities and those from low-income backgrounds in the early STEM learning needed for a career.

And yet, there is reason to take heart.

The good news is that we know what works.

We know what to do.

## From Preschool to College, Learn by Doing

Perhaps not-surprisingly, engineers and other STEM professionals turn to a pipeline metaphor in describing pre-K to12 education as the source for STEM workers. The Summit revealed a surprisingly strong potential in the youngest children who enter that "pipeline."

Current research goes against the grain for many who work in early childhood education. They often believe that young children cannot handle the abstract thought that enables mathematical learning. And yet a powerful and growing body of research refutes this popular view. Evidence shows children can become adept at the mathematical thinking that underlies future success in STEM careers at shockingly young ages. In fact, children can prepare for early math and science well before they enter kindergarten.

For this reason, throughout the Summit, participants strongly endorsed the recommendation of the National Academy of Sciences Committee on Early Childhood Mathematics, which calls for: "*A coordinated national early childhood mathematics initiative should be put in place to improve mathematics teaching and learning for all children, ages 3 to 6*."

To make the most of early childhood education, young children need intentional teaching, a planned curriculum, and activities to explore. This is not a matter of flash cards and rote learning, but of experiential learning. To cite one example: Young children's mathematical abilities can be measurably cultivated by the use of board games (like "Chutes and Ladders") that combine visual, spatial, kinesthetic, auditory and temporal clues about counting and the relative values of numbers. Children also strongly benefit from "math talk" and mathematizing—converting informal and intuitive knowledge into formal and organized ways of thinking and representation.

When it comes to science, very young children—naturally inquisitive learners who ask an average of 76 questions an hour—bring surprising abstract abilities to the task of learning. Even in preschool, children can make predictions, check them, and use them to make inductions and deductions. At later ages, they can use the scientific method to discern nature's deep principles—and describe what they see in concise words and mathematics.

Children can best learn about engineering not as a separate discipline, but as a platform on which to build their understanding of math and science.

Interestingly, in learning engineering, what works best in elementary school seems to work best all the way up through higher education. That method is to learn by doing. If interest and motivation are key obstacles to enticing young people into STEM fields, then learning by doing—mastering engineering projects in teams—can transform abstract principles into actual devices that are as fun to operate as they are to devise.

In college, such engineering projects are a great way to enliven the curriculum, while learning to adapt science and engineering fundamentals. It also instills the business fundamentals of managing costs, resources and people that are so fundamental to the real engineering profession.

What about drawing under-represented groups and children from low-income homes into STEM learning?

A growing national movement is yielding heroic results from low-income children by combining high expectations with support for the needs of the total child. Typified by the Harlem Children's Zone, great results are being reaped from no-excuse schools combined with a "conveyor belt" of social programs designed to mimic the often invisible cocoon of support and nourishment that middle-class and upper-middle class children expect as their birthright.

What about enticing young women to go into STEM fields?

One very real difference, perhaps culturally-based, is that men prefer to work with things and women prefer to work with people. STEM careers, and engineering in particular, may draw more women simply by rethinking how these professions are portrayed. Is engineering about transistors, transformers and transducers? Or is it about fields, like biomedical engineering, that help people? Reframing the opportunity is critical.

## A Matter of National Will

To make a leap in quality STEM education, from early childhood to higher education, this nation is going to have to thoroughly rethink how we teach these subjects. We are also going to have to be willing to come up with new approaches, change the conversation and paradigm, and invest new and significant resources, if we are going to remain a competitive leader in this world, and effectively educate our children.

- We need to make dramatic investments in digital access. One example: The State of Maine, which gave each of its middle-schoolers a laptop.

- Teachers of younger children—many of who are "math-phobic"—must be re-trained and instructed in the consequence and fun of mathematizing problems with children. It is not about memorization, but rather about the skill sets and thinking patterns one develops.

- At the high school level, two-thirds of students studying chemistry and physics are taught by teachers with no major or certificate in the field. We must cultivate STEM knowledgeable educators to teach our children from an inquiry-based project-based approach, and reward them appropriately.

- Schools, especially those with stretched resources in states ravaged by budget crises, must look to supplement their students' learning in informal venues, from out-of-school time, to after school time, to summer programs, to science museums, universities and non-profits, and to look to philanthropy as a true partner.

- And in higher education, we must end the almost exclusive focus on research at the expense of teaching as the path to tenure. Without compromising standards, the mark of a good teacher should not be pure research at the university level, or teaching to testing for K-12, but rather how successful the teacher has been in making the material exciting enough to capture young and ambitious minds.

These are the ways to turn around America's STEM crisis.
Again, we know what to do.
Do we have the will to make these changes that are in our ultimate national interest?

# CHAPTER ONE

## "The Need for STEM Professionals"
## The View from an End-Customer of STEM Education

*Dr. Henry Samueli,*
*Founder, Broadcom*
*Chairman of the Board, Samueli Foundation*

I will speak today from the perspective of a high-technology business leader, the end-customer for the product of our great universities. That product is the (STEM) Science, Technology, Engineering and Math-educated young man or woman—a person whose development starts in early childhood, all the way through undergraduate and graduate school.

After twenty years of education, we hope there's a good match between what a business customer like Broadcom needs and what the universities, high schools and below are producing.

This is vital, because innovation in the STEM fields is the only way we can maintain our nation's standard of living. Since the founding of this country, our nation's wealth has been built upon an innovation economy that creates new industries at the forefront of the world. These industries not only create the highest-paying jobs, they generate wealth spread across our entire economy.

For example, America has the largest players in the semiconductor industry because we were first to invent this technology. I truly believe that this invention of the integrated circuit has probably had more impact on society than any invention in the last 100 years.

Technology can explode unbelievably fast if you're in the right place at the right time with the right technology. Broadcom is a case in point. It was founded in 1991 by two UCLA graduates—Henry Nicholas and myself. Today, we are a Fortune 500 company with 2009 revenues of $4.5 billion. We have a broad portfolio of more than 12,000 patents, and a workforce of 7,500—75 percent of them engineers. So who do we hire to do our engineering work?

- 60 percent of Broadcom's engineering workforce has advanced degrees.
- Almost 90 percent of our engineering workforce is male.
- 26.1 percent of our engineering workforce is white, 53.4 percent Asian, 17.8 percent undeclared—and yet, only 1.5 percent Hispanic, and 0.7 percent black.

These are frightening statistics. Women and minorities are not participating in some of the highest-paying jobs in our economy. This shortage of STEM professionals among women and under-represented minorities is a social issue with negative, long-term social implications.

And yet we can only hire engineers that the system produces. When you look at the low percentages of women and under-represented minorities, it is clear that we need to do something to increase those numbers—and pretty soon.

This dearth of female and under-represented minority engineers is not for a lack of financial incentives. We have all the incentives in the world for students to want to go into engineering. The salaries for engineering graduates are truly among the highest of any college field. A Bachelor's in Engineering at Broadcom can expect $70,000 a year; an MA can expect $80,000 a year; and a Ph.D. can expect $100,000 a year.

**We have all the incentives in the world for students to want to go into engineering.**

And we will pay up to $130,000 a year for the best and the brightest.

So clearly, money is not the problem. Something else needs to be fixed to deal with this issue of encouraging more Americans to go into engineering and STEM subjects.

If you look at India, comparable engineers make $33,000. In China, they make almost $30,000 a year. In South Korea, it's a little higher and in Singapore higher still. But if you look at India and China, with the world's two largest populations, people are working as hard as they can. They are also working much harder at educating their young people. They're producing many more graduates in the science and engineering fields. They're creating new companies.

Not only has China taken away our manufacturing jobs. They are now very quickly trying to push up the food chain to create innovation companies as well—to achieve an innovation economy. The Chinese are working very hard at this with very strong government support and subsidies. Their whole culture is just focused on it.

If we don't watch ourselves, we are going to get steamrolled very quickly. Our standard of living is going to collapse closer to that number in China rather than the other way around—a slippery slope.

**If we don't watch ourselves, we are going to get steamrolled very quickly. Our standard of living is going to collapse closer to that number in China rather than the other way around—a slippery slope.**

As I said, Broadcom will hire the best and brightest in the U.S. for $130,000 a year. But if, all of a sudden, we find the best and brightest in India and China who are willing to work for a quarter or half the salary, we are going to hire them, too. We have to survive as a company. We can't just hire people here and put on blinders and let Chinese companies then hire their $30,000 graduates and then compete with us and enjoy four times the productivity.

Something's got to change. So either we work harder to become more innovative or our standard of living is just going to drop.

Let me sum up.

- Innovation in the STEM fields is the only way the United States can maintain our standard of living. We have to continue to push these subjects up that food chain and stay at the top of the innovation economy. If we lose our edge, we lose our prosperity.

- U.S. high-tech companies in particular cannot survive without an elite STEM workforce.

- Today, a significant percentage of this talent is acquired via foreign graduates of U.S. universities. The U.S. has historically been a magnet for the best and brightest international students.

- As STEM opportunities increase overseas, the pool of elite international students will naturally decrease and therefore must be replaced by U.S. students. Otherwise, companies will simply expand in international locations to acquire the talent.

- We are not tapping into this huge, potential talent pool in America. There is a severe shortage of females and under-represented minorities in the STEM fields. This has very negative long-term social implications since the STEM fields have much higher than average salaries.

- And yet, high salaries alone are clearly insufficient to stimulate interest in the STEM fields.

Clearly, we need a cultural transformation to make science and technology a field that everybody wants to get into.

In my work with Broadcom, I get to see other cultures. I see how Asian parents interact with their kids, how they push to get them to go into science and technology fields. That culture is not present here in the United States.

That is the topic we have to talk about today: How do we transform our culture to push more students into the STEM fields and to create more excitement about the STEM fields?

The rewards are there.

The salaries are there.

The jobs are there.

We just need to motivate young people to see the opportunity and adventure a STEM career can be.

# CHAPTER TWO

## The Need for STEM Professionals: An Aerospace Perspective

*Rafael Bras (Facilitator), University of California, Irvine*
*Henry Samueli, Founder, Broadcom; Chairman of Board, Samueli Foundation*
*Ray Haynes, Director of the University Strategic Alliances, Office of Technology Development at Northrop Grumman Space Technology*
*Ray Morrison, President and Principal Consultant, ACETS (Associates for Continuing Education in Technology and Science); Lockheed Martin, retired*
*Richard Miller, President, Olin College of Engineering*

At a time when the United States is struggling to maintain its competitiveness in so many fields, aerospace remains a bright exception. But for how much longer? The U.S. aerospace industry faces unique constraints in attracting a STEM-capable workforce.

First, aerospace engineers must have U.S. citizenship.

Second, the annual data report of the National Association of Colleges and Employers (NACE) confirms that engineers face better career opportunities in the United States than graduates in nearly every other discipline. And yet, as in other affluent countries, the demand for engineers—with commensurate compensation, is not enough to lure more students into this very difficult field.

**The abstract nature of applied science has a limited appeal for youth obsessed with social relevance and now social networking through Facebook and Twitter.**

"The abstract nature of applied science has a limited appeal for youth obsessed with social relevance and now social networking through Facebook and Twitter," says Dr. Richard Miller, President of Olin College of Engineering.

Third, there are questions beyond the sheer quantity of STEM leaders.

"Do we have the right quality?" asks Dr. Ray Haynes of Northrop Grumman. "Do we have the students who can think, who can actually do something when they come to work, or do they have to be retrained for several years before they actually take an active part in the governance and management of the company?"

The National Academy of Engineering's recent report, *The Engineer of 2020*, identifies a set of attitudes, behaviors and motivations essential to effective technical leadership—a skill set that must include the ability to communicate.

"I'm not talking about taking an English course," Dr. Miller says. "I'm talking about teamwork and effective leadership, as well as creativity and inventiveness, entrepreneurial thought and action, and global cultural awareness. Knowledge, even scientific knowledge, is rapidly becoming a global commodity, but vision, creativity, leadership, initiative and entrepreneurship are not. That's what this country does best."

Ray Morrison, who had a long career at Lockheed Martin, asks if we are producing engineers who are capable of innovation and taking leadership roles.

**Do we have the students who can think, who can actually do something when they come to work, or do they have to be retrained for several years before they actually take an active part in the governance and management of the company?**

Should we shift the center of gravity of our educational paradigm toward direct student engagement to become engineers rather than learning about engineering? Wouldn't students be energized if schools asked them to attack and solve real-world challenges?

This is already happening at Olin College, which requires all students to work on teams to solve real problems. Students are required to stand and deliver to a professional audience at the end of every semester. Finally, they must start and run a business as a requirement for graduation.

"These requirements have resulted in very high levels of student engagement, high four-year graduation rates, a can-do attitude—along with what I'd call entrepreneurial disease, starting their career with a passion to make a positive difference in the world," Olin's Dr. Miller says.

U.S. industry faces a dire lack of STEM professionals. We have the tools ….But do we have the national will to change our programs and use those tools?

# CHAPTER THREE

## The Long-Term Effects of Early Childhood Experiences: What Does the Research Evidence Tell?

*Deborah Vandell (Facilitator), University of California, Irvine*
*Greg Duncan, University of California, Irvine*
*Margaret Burchinal, University of California, Irvine*

A growing body of research suggests that not only can very young children benefit from exposure to math and science, but such exposure is critical to their future success. While early reading and math achievement are highly predictive of later achievement, early math skills are particularly predictive to success K through 12, as well as in later life.

**Early math skills are particularly predictive of success in K through 12.**

Dr. Gregory Duncan of the University of California, Irvine, offers what he calls "rather scary statistics" on academic gaps in kindergarten, drawn from a large national representative survey of children who entered kindergarten and were followed through the fifth to eighth grades.

Looking beyond the expected racial and ethnic differences in children's academic performance, researchers were surprised to find that the deepest academic gaps were between children at higher and lower levels of Socio-Economic Status, or SES. In fact, these SES gaps were twice as big as the racial and ethnic gaps.

This SES gap "is huge and it's not shrinking over the course of elementary school," Dr. Duncan observes. "So not only do we need to be thinking about racial and ethnic gaps, but we also need to think about gaps in terms of socioeconomic status where white kids are included in the lower quintile with African-American kids and Hispanic kids."

### What Does Early Achievement Look Like?

Very young children can learn to succeed in three domains: Achievement, Attention and Mental Health.

What happens when researchers develop a causal association between these three domains and children's later success in school? Interesting and counterintuitive results emerge.

"It turns out that antisocial behavior and the mental health differences in kindergarten are completely unpredictive of later achievement," Dr. Duncan says.

What about attention skills? Their predictive ability is fairly modest.

It is, in fact, reading and math that are the most predictive of later achievement.

"What was really surprising here is how important early math skills are relative to early reading skills," Duncan says. "Early reading skills are rather unimportant for later math achievement, but if you switch that . . . it turns out that early math skills are *just as predictive of later reading achievement as early reading achievement is*."

**Reading and math are the most predictive of later achievement.**

In fact, Dr. Duncan reports that persistent math problems drop the chance of high school graduation by about 12 percentage points.

When it comes to college attendance, children with persistent math problems in elementary school have about half the college attendance rate of those who do not.

"In summary, early math skills (controlling for IQ and family background) have surprising power to predict future school achievement," Dr. Duncan says. Persistent math problems in elementary school are quite predictive of later outcomes very important to completing high school and college.

**If we're wondering about where to focus our efforts in elementary school . . . if we want to increase a child's chance of graduating from high school . . . avoiding persistently low math achievement is the most powerful factor.**

"So if we're wondering about where to focus our efforts in elementary school . . . if we want to increase a child's chance of graduating from high school . . . it seems avoiding persistently low math achievement is the most powerful factor," Duncan says.

## The Role of Child Care

The NICHD Study of Early Child Care and Youth Development, conducted at ten sites covering more than 1,300 children, yielded many disparate and interesting results. The relationships that leapt out to Dr. Margaret Burchinal of the University of California, Irvine, were between childcare experiences and the early development of the academic skills, especially math skills.

In the NICHD study, children were given a battery of tests at four-and-a-half years—language achievement, as well as social and behavior problem assessments. These test results were related to child care experiences, including the quality of the care, how responsive and sensitive caregivers were to that child, the amount of care, on average how many hours per week did the child attend child care, as well as the quality of the parenting within the home environment. Data from the NICHD study showed that children who were given higher-quality care started school with stronger academic achievement. Some of these effects in this longitudinal study were measured up to age 15.

The Cost, Quality and Outcomes study also found a correlation between the quality of child care and child outcomes through the second grade (though the magnitude of the childcare effects was found to be smaller than the magnitude of the parenting effects).

"Parenting is still a much stronger predictor of the kind of skills children are starting school with than child care, but both seem to be making a difference," Dr. Burchinal observes.

The bottom line?

The evidence suggests that children who experience higher-quality care will see substantially stronger outcomes. Children who experience average levels of child care don't see those associations.

Dr. Burchinal found similar evidence across other studies.

"So we conclude that child care experiences seem to be making a difference," Dr. Burchinal says. "Parenting, perhaps, matters even more, but both are making a difference in early childhood in terms of the kinds of skills, especially math skills, that children are bringing when they enter school and that those elements predict later outcomes."

**Child care experiences seem to make a big difference in later outcomes.**

## IQ and Parenting

What about the old debate between nature and nurture, genetics and environment? Is it just that smarter parents have smarter kids? Or it could be that it's what the parents are doing that's making a difference?

To tease apart these elements, Dr. Burchinal turned to a recent French adoption study that followed children four- to five-years of age whose IQs were between 60 and 80. The court removed these children from their biological parents because of abuse or neglect, and placed them into lower-class families, middle-class families and upper-class families.

When one looks at the children's IQs when they were with their biological parents at four to six years of age against their average IQs when they were eleven to fourteen, all the children scored higher. But the magnitude of gains over time was a function of the Socio-Economic Status (SES) of the family.

IQs rose much higher for children cared for by wealthy parents than with those adopted to lower-income parents.

"It's not just the genetic relationship that makes the difference," Dr. Burchinal says. "It is what parents are doing with their children in the household that is making a difference [in IQ], but also in terms of the kinds of skills that children bring to school."

This is just one more bit of evidence that shows that early childhood is a sensitive period of academic achievement. To build better science, technology, engineering and math skills, especially among children from a broader economic and ethnic background, quality efforts in early childhood will be needed.

"A strong home environment clearly contributes to the development of these skills—activities like having parents talk frequently and reading frequently with their children and ensuring that homes have stimulating activities," Burchinal says. "High-quality programs can also compensate to some degree for less stimulating home environments. "As we try to address these issues of achievement gap within STEM, we really want to think about the degree to which early childhood development needs should be considered with programs like pre-kindergarten, Head Start and home visiting programs."

# CHAPTER FOUR

## Paul Tough, New York Times reporter, Author of Whatever it Takes: Geoffrey Canada's Quest to Change Harlem and America

When I started reporting in Harlem in 2003, I was drawn to the Harlem's Children's Zone by the personal story of Geoffrey Canada, its founder and CEO. His story is a classic American tale. Geoff grew up impoverished in the South Bronx, one of four children being raised in a cramped tenement by a single mother. He was a troubled street kid, but he managed to turn his life around. He escaped the inner city, attended college, and went to graduate school at Harvard.

Geoff then returned to New York, using his credentials to save kids in trouble—kids like the ones he'd grown up with, most of whom were either dead or in prison. By the early 1990's, he was running a multi-million dollar, non-profit organization in Harlem. He was saving hundreds of kids each year from violence, keeping them in school and away from drugs. So as life stories go, it's pretty inspirational, right? Despite his success, Geoff felt like a failure. When he looked around Harlem in the mid-1990's, he realized kids in his program were doing pretty well, but there were thousands more who were failing—falling behind in school, dropping out, having babies too young, going to jail. For every child he saved, 10 or 20 more were slipping through his fingers. He wanted to help greater numbers of Harlem kids beat the odds. So he invented the Harlem Children's Zone.

It started about 10 years ago as a 24-block neighborhood in central Harlem and it has since grown to cover 97 blocks. HCZ provides a comprehensive network of educational and social programs that follow disadvantaged children living in the zone from birth through college. Now, about 8,000 neighborhood kids take part in one or more programs annually.

The zone is motivated by two basic ideas. First, poor children in Harlem face so many disadvantages that it doesn't make sense to take on one or two and ignore the rest. The second is market penetration—a tipping-point idea. If 5 to 10 percent of neighborhood kids are enrolled in the programs, then the kids who try to better their lives are seen as oddballs. But if 40, 50 percent, or 60 percent of neighborhood kids enroll, then the tide turns: involvement is normalized while negative behavior begins to seem strange. Geoff refers to this process as "contamination." The word usually carries negative connotations, but he uses it positively to describe the way that aspirational values can spread like a virus through a family, a housing project or a neighborhood.

**If 40, 50 percent, or 60 percent of neighborhood kids enroll, then the tide turns: involvement is normalized while negative behavior begins to seem strange. Geoffrey Canada refers to this process as contamination.**

The gaps separating the lives of poor children from the lives of their middle-class peers are wide and numerous. Poor children are more likely to be raised in a single-parent home, to have a parent suffering from high levels of stress or mental illness, to encounter violence, and to go to foster care. They're less likely to own educational toys or children's books, to have a parent who graduated from college, to be enrolled in high-quality preschool or childcare.

**The gaps separating the lives of poor children from the lives of their middle-class peers are wide and numerous.**

These differences lead to an achievement gap that opens very early. One study found that 80 percent of children from the highest socioeconomic level are able to recognize the letters of the alphabet on the first day of kindergarten—and just 30 percent of children at the lowest socioeconomic level can do the same. For most kids, this achievement gap doesn't disappear once school starts. In fact, it often widens, extending into adulthood. By age 24, three-quarters of people from well-off families in the U.S. have earned a BA. Just 9 percent of those who grew up in the poorest families have been able to do the same.

The gaps are clear in the research, but, for me, they didn't really hit home until I talked to poor children and their parents about life in Harlem. I attended a nine-week parenting class called Baby College. There I met Shantelle Jones. She was 32, single, and pregnant with her fifth child. New York City's Department of Child Services had taken away her first four children. She was poorly educated, never had a steady job, and had always lived in public housing. Shantelle's daughter, whom she'd already named Treasure Lee, was due in a few months. On paper, a child like Treasure Lee is almost certain to fail because of her parents and her neighborhood. She is statistically a good candidate for foster care, substance abuse, poorer school performance, welfare, and prison.

What would it take for Treasure Lee to follow a different path—to graduate from college, to postpone pregnancy until marriage, to avoid drugs and legal trouble, to have a stable family and a steady job, the basics of middle class life?

Until recently, it seemed that it would take a miracle for just one child out of 1,000 in Treasure Lee's circumstances to make it. The best public policy or philanthropy could do for Treasure Lee, we believed, was to cushion the blows, increasing the likelihood that Treasure Lee might be the lucky one to survive and to thrive. And, until recently, the debate was about what Shantelle needed—was it job training, a husband, financial assistance? Now, the discussion focuses more on Treasure Lee's needs. What interventions might provide her with the skills she needs to succeed, in spite of her circumstances?

**Until recently, it seemed that it would take a miracle for just one child out of 1,000 in Treasure Lee's circumstances to make it. The best public policy or philanthropy could do for Treasure Lee, we believed, was to cushion some of the blows that she might face, increasing the likelihood that she might be the lucky one to survive and to thrive.**

Looking nationally for programs that work to improve low-income kids' skills with real results, the best ones share a common quality: They start working with kids and parents very early, sometimes before children are born. The nurse-family partnership sends trained nurses to visit and counsel poor mothers during and after their pregnancies. Bright Beginnings, a pre-K program in North Carolina, enrolls four-year-olds who score lowest on cognitive ability screening tests and brings most to grade level by kindergarten.

To improve outcomes for disadvantaged children, starting early is ideal. However, even reaching kids well into their academic careers can have a big impact. Some of the most dramatic success stories come from charter middle schools.

Interestingly, charter middle schools have demonstrated more success improving math skills than English skills. Look at the reading and writing scores from some of the most successful middle schools; you find that, after a few years of intensive education, kids who began far behind are moving closer to where they should be, but in math especially, they're hitting it out of the park.

Take Roxbury Prep, a charter middle school in Boston, where two-thirds of the student population is poor, 100 percent black and Hispanic, and lottery chosen. Two years ago, the school's eighth graders had the highest percentage of students out of any Massachusetts school scoring advanced or proficient on the state math test. Ninety-four percent of students hit that mark compared to 90 percent at Boston Latin, one of the state's oldest and most prestigious schools. There are similar success stories all over.

**To improve outcomes for disadvantaged children, starting early is ideal. However, even reaching kids well into their academic careers can have a big impact.**

Problematically though, such programs are isolated, scattered across the country, and often they're only directed at a few years of a child's life, meaning that their positive effects tend to fade once the intervention ends.

This is exactly why the Harlem Children's Zone is such an important model. It is neither isolated nor scattered. It combines an extensive, no-excuses charter school with what Geoff calls a conveyor belt of social programs designed to mimic the invisible cocoon of support that follows wealthier children.

The conveyor belt begins with Baby College, the parenting program where I met Shantelle Jones. Baby College works with 500 or 600 parents a year, encouraging them to choose alternatives to corporal punishment and to engage more with their children.

The conveyor belt next stops at the three-year-old journey: Parents are taught more sophisticated strategies to boost further their children's vocabularies and cognitive abilities. Kids proceed from the three-year-old journey into Harlem Gems, an all-day pre-kindergarten, which leads directly into the Promise Academy, a K-12 charter school that runs on an extended day and year and where teachers and principals pledge to get every child to college. Along the way, children have continuous access to community supports like family counseling and a health clinic. The goal is to endow children with the character and the abilities to survive in a poor neighborhood and to graduate from college.

Geoff's conveyor belt is already producing measurable results. In the last two years, the first students to enter the Promise Academy in kindergarten reached the third grade—where they took their first statewide-standardized tests. Despite coming from one of the poorest Harlem zip codes and having mostly young, single, uneducated parents, 94 percent of students scored on or above grade level in English and 100 percent of them scored on or above grade level in math. They outperformed kids from some of New York State's best schools and they're just getting going.

**We already know how to raise kids to succeed… The question is do we want to give children in low-income neighborhoods those same opportunities to succeed? Do we want to use this new research to make a difference not for just a few disadvantaged kids, but for millions of them?**

Last year, Congress approved $10 million in planning grants to help cities and nonprofits prepare applications to become the first Promise Neighborhoods. The Department of Education will likely issue those grants to 15 or 20 cities this spring. Groups will have a year to work on their plans, the first pilot cities will be chosen and the first Promise Neighborhoods will be created in early 2011…

We already know how to raise kids to succeed. We do it all the time in middle class and upper middle class neighborhoods. The question is do we want to give children in low-income neighborhoods those same opportunities to succeed? Do we want to use this new research to make a difference not just for a few disadvantaged kids, but for millions of them?

Are we willing to do whatever it takes to level the playing field for real?

# CHAPTER FIVE

## Early Learning In Mathematics

*Deborah Vandell (Facilitator)*
*Robert Siegler, Carnegie-Mellon University*
*Herbert Ginsburg, Columbia University*

With the importance of early childhood learning in math established, Deborah Vandell of the University of California, Irvine, asks: What kinds of experiences do children need to have at home and in school to foster these early math skills?

There are many strategies already known to educational researchers on how to stimulate mathematical learning in children. Knowing this, however, is not enough if we fail to convince teachers and other early childhood workers that mathematical learning is important—and show them how to teach it.

Robert Siegler of Carnegie Mellon University brings perspectives to these questions from performing applied research, as well as participating in the learning processes group of the National Mathematics Advisory Panel (NMAP). He offered two conclusions of interest from NMAP as partial answers to Dr. Vandell's questions.

First: "Encouraging results have been obtained for a variety of instructional programs developed to improve the mathematical knowledge of preschoolers and kindergarteners, especially those from low-income backgrounds. There are effective techniques—derived from scientific research on learning—that could be put to work in the classroom today to improve children's mathematical knowledge."

Second: "Children's goals and beliefs about learning are related to their mathematics performance . . . When children believe that their efforts to learn make them 'smarter,' they show greater persistence in mathematics learning."

What are some of the effective techniques NMAP pointed to? Dr. Siegler drew on his experience in developmental psychology to discuss representations of numerical magnitude.

### The Centrality of Numerical Magnitude Representations

What do we mean by numerical magnitude representations? An example: Twenty is twice as big as 10, and 10 is twice as big as 5.

"We think, well, of course, anyone who could count would know that 10 is twice as big as 5 and 20 twice as big as 10," Dr. Siegler says. "The fact is that this knowledge is actually rather hard won. It doesn't necessarily stem from counting. You can count just fine and have no idea that 10 is twice as big as 5, or even know that 10 is bigger than 5.

**We think, well, of course, anyone who could count would know that 10 is twice as big as 5 and 20 twice as big as 10. The fact is that this knowledge is actually rather hard won.**

"So, when we ask kids questions like this, preschoolers are often wrong," Dr. Siegler says. "It's also the case that when you get into bigger numerical scales, much older kids, second-graders, third-graders, fourth-graders, often make similar mistakes. So, they won't know for example, where 650 should be on a 1 to 1,000 number line, or where 12 should be, or where 868 should be."

Empirical research indicates that linear representations linking number symbols with their magnitudes are crucial for a variety of important outcomes in mathematics learning.

Researchers also examined children's proficiency at measurement estimation, as well as numerosity estimation (in one test, children were shown a beaker on a computer screen with 1 dot, and another with 1,000 dots. They are told to hold down the mouse until they had about 374 dots, then to 657 dots.)

**Understanding the magnitudes of numbers is neither automatic nor is it a kind of side show. It's really a central aspect of being good, at least at math, through the eighth grade.**

The results? In both the second-grade and fourth-grade levels, researchers found strong correlations between the linearity of their estimates across these tests. More importantly, researchers found substantial correlations between the children's linearity of estimates on each task, and their overall math achievement test scores.

"So, the point here is that understanding the magnitudes of numbers is neither automatic nor is it a kind of side show," Dr. Siegler says. "It's really a central aspect of being good, at least at math, through the eighth grade."

What do these findings mean for improving the math learning of low-income preschoolers?

"Kindergarteners' numerical knowledge predicts later mathematical achievement, through elementary school, middle school and in another study, through high school," he says. "*So, you start ahead, you stay ahead; you start behind, you stay behind* . . . This is where the theoretical work and the practical problem of low-income kids' mathematical knowledge come together."

**So, you start ahead, you stay ahead. You start behind, you stay behind.**

The research shows that counting experience is likely helpful, but insufficient. Children can count from 1 to 100 a good year to a year-and-a-half before they know that 57 is bigger than 39. They can count to 10 a similarly long period before they know that 6 is bigger than 4.

If counting is insufficient, then what else in children's real world experience would lead them to understand numerical magnitudes in a sense that they could form a linear representation if it?

## Board Games and Numerical Knowledge

"An answer we started thinking about was playing board games," Dr. Siegler says. "Now, board games aren't designed as far as I know to promote numerical knowledge. Their main purpose is to promote pleasant and rich interactions between parents and peers, and between the children. But they also provide rich experiences with numbers."

He points to a prototypical board game, "Chutes and Ladders." The greater the number a token reaches, the greater the distance the child has moved the token. Move it from 4 to 8, and the child has moved it twice as far from the origin.

"The greater the number of discrete hand movements the child has made along the way, the greater the number names the child has spoken, goes with the greater the number of times spent by the child playing the game," Dr. Siegler says. "So, together, this very simple board game provides visual, spatial, kinesthetic, auditory and temporal cues to the link between the numerical symbol of the word 'Eight' and how big it is." (The game must, however, be linear. Circular board games do not show the same result.)

In a study performed by Dr. Siegler and Geetha Ramani of the University of Maryland, the goal was to investigate whether playing the number board game improves a broad range of numerical skills and concepts.

The results? Children scored significant and substantial increases in numerical magnitude comparison and counting, number line estimation and number identification from playing a number board game.

A follow up study also showed that linear representations of numerical magnitudes help children master arithmetic problems.

Dr. Siegler sees this as bolstering a key finding from the National Mathematics Advisory Panel—that teachers and developers of instructional material sometimes incorrectly assume that children need to be a certain age to learn certain mathematical ideas.

"A major research finding is that what is developmentally appropriate is largely contingent on prior opportunities to learn," Dr. Siegler says. "Claims that children of particular ages cannot learn certain content because they are too young have consistently shown to be wrong.

**Claims that children of particular ages cannot learn certain content because they are too young have consistently shown to be wrong.**

"Children in China, Japan, Korea, Singapore and a number of European countries . . . learn a lot more math at very early ages than kids in the U.S.," he says. "Presumably our kids could do the same thing. There's no reason they couldn't if they receive the relevant experience.

"When children believe that their efforts to learn make them smarter, they show greater persistence in mathematics learning," he says. "This issue of motivation is tremendously important in math learning. One of the problems I think that we face and that limits both the quantity and quality of graduates in STEM fields is that these fields require hard work; they require a lot of dedication."

**When children believe that their efforts to learn make them smarter, they show greater persistence in mathematics learning.**

## The Power of Intentional Teaching

The National Academy of Sciences Committee on Early Childhood Mathematics reinforces research and recommendations of other bodies, finding that:

"*When given the appropriate learning opportunities, young children can become competent in mathematics.*"

The committee recommended:

"*A coordinated national early childhood mathematics initiative should be put in place to improve mathematics teaching and learning for all children, ages 3 to 6.*"

**A coordinated national early childhood mathematics initiative should be put in place to improve mathematics teaching and learning for all children, ages 3 to 6.**

Herbert Ginsburg of Columbia University adds an important caveat.

"Young children at those ages can benefit from intentional teaching," he says. "It's not an issue of simply letting them play, or giving them exciting activities to explore. They need teaching. They need a planned curriculum—a series of activities designed to go in sequence over a period of time."

This should include:

- An extensive focus on numbers and geometry
- A planned curriculum that promotes not only procedures and facts, but also concepts, mathematical thinking, "math talk," and mathematizing—converting informal and intuitive knowledge into formal and organized ways of thinking and representation.

The workforce that can accomplish these activities is, of course, made up of the early childhood teacher.
Who are they?
What do they need?
How can we help them to become good educators at the preschool level?

## The Early Childhood Teacher

The early child workforce is made up of 2.3 million workers.

- 24 percent are in centers like Head Start.
- 28 percent are in family daycare.
- And 48 percent are informal family, friends, neighbors.

What are their levels of education among pre-K teachers?

- 73 percent have a Bachelor's Degree, usually employed by a public school system where some other state or city-run agency that can impose these criteria.
- In Head Start, only 36 percent have Bachelor's Degrees or higher.
- 30 percent of center-based workers have Bachelor's Degrees.
- 11 percent of home-based have Bachelor's Degrees.

Compensation for the early childhood worker is significantly lower than K-12, with the average preschool teacher's salary about $25,800. The average childcare worker's salary is $19,670, and the average Head Start teacher's salary is $24,608. Many Early Childhood teachers do not receive health insurance.

**Compensation for the early childhood worker is significantly lower than K-12, with the average preschool teacher's salary about $25,800.**

"Why, then, would talented people want to go into a field like this?" Dr. Ginsburg asks. "It's the selection effect—that's who gets into early childhood education. Not only that, but they are poorly prepared. They very seldom get extensive and appropriate math education training. In fact, I think you can say that the colleges give the least training to these people in the subject with which prospective teachers need the most help."

Another barrier to early childhood learning in math is the prevailing belief "that children cannot learn abstract math. They say kids are too concrete."

Worst of all, Dr. Ginsburg adds, many early childhood workers "don't understand the math themselves. Some of the mathematics taught in preschool, although it involves basic numbers, shapes, and other things, is very difficult precisely because it is so basic. The foundations of mathematics are what are involved in early childhood math."

**Worst of all, many early childhood workers don't understand the math themselves.**

Many teachers also believe that social/emotional development and play should be emphasized above all else.

"They tend to put math people in the category of being against social/emotional development and play," Dr. Ginsburg says.

"That's not true. We love social/emotional development and play, but we think that's not all there is to education. They tend to believe that teaching and curriculum are what they call developmentally inappropriate.

"There is the general, I think kind of a vague, romantic view, that if you put your kids in a stimulating environment, they will learn everything there is to learn," Dr. Ginsburg says. "They don't really need the adults there, and you do not need a plan such that they ought to be doing this activity this week and maybe another activity next week."

**Early childhood teachers teach math badly, if they do teach it at all.**

In short, early childhood teachers teach math badly, if they do teach it at all.

There is a final barrier—an emotional one.

Dr. Ginsburg adds that many teachers, academic colleagues and graduate students—highly selected individuals—often say, 'Math has always been a dreaded subject for me. I have yet to think of math in a positive way. In fact, I have to take a math course in my New York Certification, and I'm trying my hardest to find a way around it.' He also hears: 'My previous history as a poor math student makes me fear teaching math to young children in the future, that being partially my reason for choosing early childhood education.'

"So, what do they need to learn?" Dr. Ginsburg asks. "One thing is to get over their fear and appreciate the importance of math. And just as kids need to get over their fear of math, so do those teaching it. They really need to understand the ideas that they are attempting to teach.

**Teachers need get over their fear and appreciate the importance of math. And just as kids need to get over their fear of math, so do those teaching it.**

"With National Science Foundation support, we've created a model course in this area that has several features," Dr. Ginsburg says. "Of course, it's only one approach. We need more. But I want to give you a very concrete illustration of what needs to be done, I think, at the college level."

That model course is Video Interactions for Teaching and Learning, or VITAL. It has four components.

- A course syllabus.
- New technology and pedagogy for "clipping" video information.
- Higher education classroom pedagogy.
- A digital library.

"So, we have a traditional syllabus, weekly readings, on this new approach to early childhood through early mathematical thinking," Dr. Ginsburg says, adding that instruction includes understanding a mathematical environment, early numbers through geometry, patterns, algebra, rational numbers, and then teaching with manipulatives.

He offers an example of an assignment. After viewing a video clip of a teacher instructing a child, Olivia, the student-teacher is asked: In what ways does Olivia understand or not understand addition? What mistakes did the interviewer make in interviewing her? Given what you saw, what would you do to teach her addition?

Student-teachers go on to review the literature, videotape their own teaching of that lesson, and videotape a clinical interview of a child before and after the lesson. Then they write an essay embedding the key video evidence and analyzing their teaching as their final project.

What about in-service professional development?

"Teachers already in the system are also poorly trained and in general, they have avoided math teaching for many, many years," Dr. Ginsburg says. "So, they are a harder group to deal with because they will tell me anything I recommend is developmentally inappropriate based on their experiences."

The key components to in-service professional development is that training must be tied directly to the use of a curriculum.

"It's fine to help teachers understand how kids learn," Dr. Ginsburg says. But unless they can relate that to their curriculum and their classroom, it's not going to have a great effect.

He adds, "The weakest link is the teacher. We've done a terrible job of preparing them and supporting them. I'm not teacher bashing. I'm not saying these are bad people. I'm saying we in the universities and the public school system are at fault. We've done a very bad job preparing teachers, supporting them, with society not paying them. So, we need extensive professional development at all levels for professors of early childhood math education, for prospective teachers, practicing teachers."

**We in the universities and the public school system are at fault. We've done a very bad job preparing teachers, supporting them, with society not paying them. We need extensive professional development at all levels for professors of early childhood math education, for prospective teachers, for practicing teachers.**

# CHAPTER SIX

## Early Learning in Science

*Deborah Vandell (Facilitator)*
*Rochel Gelman, Rutgers University*
*Kathleen Metz, University of California, Berkeley*

Children are strong and natural explorers. Dr. Rachel Gelman of Rutgers University says that studies show that young children ask on average 76 questions an hour (including, as any parent knows, asking the same question over and over again).

Cognitive development and educational psychology are converging on important conclusions that address policy concerns about STEM illiteracy. All show that we can teach science in a meaningful and better way, much earlier than we have—and that even preschool children have some relevant abstract abilities.

Are young children truly capable of learning about science and the scientific method? And if they are, what are some of the learning principles that foster such scientific thinking in preschoolers?

## Scientific Principles for Preschoolers

The truth is that very young children can handle far more than we imagine. Children can learn that the methods of science are interrelated with its contents. They can learn to try to make neutral observations. Preschoolers can also learn to make predictions, check their predictions, and use them to make inductions and deductions. "They should learn it is also extraordinarily important to record and date your work," Dr. Gelman says. Children also need to be taught how to compare and contrast, which is, after all, the underlying idea of an experiment. They can work out of their existing knowledge to search for deep principles of biology and inert physics, as well as to explore the energy sources that affect both of those domains. Numbers and mathematics also come into play—a child, after all, must be able to count to make simple summaries.

**The truth is that very young children can handle far more than we imagine.**

"We can encourage kids to tell us what they know," Dr. Gelman says, showing one lesson in which preschoolers differentiate between living objects (like the photo of a panda) and non-living objects (like the photo of a stuffed panda). After a little instruction, children are asked: Which of these can go up and down a hill by itself?

From such humble beginnings, children learn about causality while making distinctions between animate and inanimate objects. Is the energy source for a subject biologically created within its internal structures? Or is it an inanimate object dependent on sources of energy from external agents that are either manmade or inert?

**Preschoolers can learn how to make predictions, check their predictions, and use them to make inductions and deductions.**

From here, children acquire an awareness of unique biological concepts—that living things grow and change over time; that individuals maintain their identity over time; and, that offspring are of the same species as their parents.

When it comes to the relationship between parents and offspring, young children already have an intuition that offspring will resemble their parents.

## Building Organized Knowledge

By five years of age, however, most children know that plants and animals share many biological capacities, from growth, to reproduction, to death.

At the beginning of a preschool program, children are asked in 'group time' to pass around an apple. Each child is asked to make and record one unique observation. They are asked to predict the insides of the apple—observe—and record what they find. In this way, they learn to build a prediction on an observation, and then to test that prediction with another observation.

**After the preschoolers built an irrigation system, they were asked how the water would move when they pulled up the gate.**

Dr. Gelman offers examples of building organized knowledge, taking deep concepts across the curriculum in one preschool in Los Angeles that used a "Sunflower House" to teach science.

The preschoolers planted sunflower seeds, and then measured and recorded the budding plants with a ruler. After they put in an irrigation system, they were asked how the water would move when they pulled up the gate.

"So there was a bit of engineering built into this, and they're predicting whether it will work or not," Dr. Gelman says. The children learned to date stamp their work. Most importantly, they named their plants and systematically followed and recorded one variable (light, water, etc.) at a time, learning why one plant is healthy, while another is unhealthy.

For a healthy plant, one preschooler responded: "They have more leaves than the other ones, and they have everything they need." For an unhealthy plant, one preschooler responded: "And this is green but it has little yellow spots."

Experiments like these reinforce that mature awareness that living things grow and change over time; that plants, like animals, are living things; that individuals maintain identity across changes; and offspring are the same species as their parents.

Preschoolers can go on to do actual science—if they build on what they know, using their exploratory, questioning minds instead of treating science like a fact memorization task.

**Preschoolers can go on to do actual science—if they build on what they know, using their exploratory, questioning minds instead of treating science like a fact memorization task.**

## Rethinking Science in the Primary Grades

What about science for children in primary grades? Kathleen Metz of the University of California at Berkeley offered two assertions that were similar to Dr. Gelman's.

"First of all, the primary grade kids are much more capable than current curricular practices reflect," Dr. Metz says. "And secondly, a reshaping of primary grade science, based on a Learning Progressions tactic, could lead to a radically more powerful science for young children, and a fundamental shifting of the ground on which middle school and high school teachers can build."

Learning Progressions build on a child's existing knowledge with a strategically designed curriculum. This is real science, a very different approach than the traditional model of what is "developmentally appropriate" in elementary school science.

Can young children handle this kind of real science?

It often has been pointed out that research indicates that there are limits on the intellectual development of students in grades three to five. For example, students often confuse theory (explanation) with the evidence for it. They have trouble making logical inferences.

To this research, Dr. Metz offers an important caveat from the American Association for the Advancement of Science:

" *. . . the studies say more about what students of this level do not learn in today's schools than what they might possibly learn if instruction were more effective.*"

## Evolution and the Progressions Approach

Dr. Metz proposes the teaching and learning of evolution from this Progressions approach, an incremental understanding of an increasingly complex topic. Evolution, after all, is central to the understanding of biology. There are certainly broad shortcomings in the understanding of evolution at the end of K-12 schools and beyond. And conceptual challenges in the understanding of evolution are continuous across all ages.

How then, asks Dr. Metz, can we scaffold the conceptual underpinnings of evolution across the second and third grades to support understanding and application of some facets of the theory, as well as to position students to achieve a deeper understanding of evolution at subsequent grades?

The current science standards for elementary school in California include teaching "facts and terms." Dr. Metz finds this insufficient. After all, facts and terms themselves have little explanatory power.
"If we assume that kids can't consider anything abstract, then I'm concerned about the impoverished position to engage kids in really thinking through questions of interest," she says.

Dr. Metz describes the design of one program that worked with 180 children over a two-year span, in the second and third grades. Over this two-year span, children revisit the same conceptual terrain in the study of animals and their behavior, and in the study of botany.

Children in this program performed research on the rain forest and the desert, created scientific illustrations and photographs of plants in the desert, and made green-scale comparisons between the plants in the rain forest and the desert. Along the way, they learned about chlorophyll and its function in photosynthesis.

Back in the classroom, children use their data and their scientific illustrations and plant photos to consider how the plants in these two environments are different from each other, and the different ways the plants are adapted to where they live. Students learn a progression of ideas:

- Organisms live where they belong.
- Organisms live where they get what they need.
- Organisms live in all kinds of places with limiting factors.
- Differences in the same structure help organisms get what they need where they live.

In later grades, children start to build the abstraction of adaptation in mid-curriculum. Children learn about the survival value of a species trait. They also learn:

- How these differences can determine which individuals have the best chance to survive and have offspring that survive.
- How inherited traits that help organisms' chance to survive and reproduce where they live become more common over time.

- How the process of natural selection leads to organisms that are well-adapted to where they live.

"So we begin by giving every child a little magnifying box with two aster seeds and asking them how are these different from each other?" Dr. Metz says. "And then we ask them to discuss which of these traits do you think might make a difference for how far they float on the wind?"

From this simple question, the children design an experiment, beginning with an empirical investigation—how are these seeds different from one another? Which trait do we predict will help them travel far on the wind?

Students use color-coded yarn to measure and collect data on how far the lighter, smaller seeds travel when compared to the heavier seeds. They organize their data in terms of case magnitude plot, and then analyze that in terms of range and medium, with data supporting their conclusions.

Then they are asked to perform a thought experiment: A storm blows some of these seeds out to sea to land on an island. What happens to the seeds?

One child answered: "What I think will happen is most of the heavy seeds will fly to the water because the heavy seeds won't travel that far and the light[est] seed would fly too far to reach the island."

They are faced with another set of problems: Once some seeds are landed on the island, predict how the distribution of seed traits on the island will change across subsequent generations. Explain which trait you think would be an advantage and why. Predict the distribution after many generations on the island and then compare your predictions to what the scientists actually saw.

"We're trying to build the idea of survival value of a species' traits, that individuals even of the same kind, living in the same place, are not the same," Dr. Metz says. "They learn that inherited traits that help the organism's chance to survive and reproduce where they live become more common over time."

**Those who care about middle school, high school and college should care about early learning in science.**

Dr. Metz concludes:

"Those who care about middle school, high school and college should care about early learning in science. Powerful early learning in science opens up the possibility of attaining a much more powerful scientific understanding at a higher grade."

# CHAPTER SEVEN

## Fostering Diversity and Inclusion in STEM Education

*Deborah Vandell (Facilitator)*
*Janet Hyde, University of Wisconsin*
*Walter Secada, University of Miami*
*Milton Chen, Executive Director, George Lucas Foundation*

In fostering STEM education, we must deal with the gaps—the glaring lack of participation of women in some STEM careers, as well as the lesser participation of minorities in STEM careers, and children from lower-income backgrounds in STEM learning. How do we measure these gaps? How do we address them without unintentionally diverting resources to create other gaps? Is the new digital technology one powerful way to bring more children onto a STEM learning track?

### The Data on Psychological Gender Differences

A *Newsweek* cover story in the 1990s, "Guns and Dolls," purported to make the scientific case that boys and girls have very different aptitudes. When the mass media portrays such gender differences in psychology, it often reports that these differences have biological causes, confirming for many that certain "deficits" come with gender.

One of the most common beliefs about these "deficits" is that girls are stronger on verbal skills and that boys are stronger in mathematical and spatial skills. In short, the view is widespread that boys are born with a much greater aptitude for the skills needed for STEM careers.

**48 percent of Bachelor's Degrees in math go to women.**

"So it's not only that girls and boys are different, but girls are deficient," says Janet Hyde of the University of Wisconsin. Dr. Hyde used a quantitative technique, meta-analysis, to synthesize vast amounts of research on psychological gender differences. She performed a quantitative literature review on 100 or more studies on gender differences.

What do the statistics say? When Janet Hyde asks a group of STEM educators and professionals to guess the percentage of Bachelor's Degrees in Mathematics that go to women, a common estimate she gets is 28 percent.

The correct answer is that 48 percent of Bachelor's Degrees in math go to women.

"That's about as close to 50/50 as you're going to get," she says.

Researchers contacted the Departments of Education in all 50 states to put gender comparisons to the test with a meta-analysis in 2008 mandated by No Child Left Behind. Dr. Hyde received responses from 10 states, compiling data for a very large sample size of 7 million children.

What does Dr. Hyde's meta-analysis show? The overall supposed gender gap was close to zero.

**Girls have reached parity with boys in math performance at all grades. We don't have gender differences. We have gender similarities in math performance today in the United States.**

"Girls have reached parity with boys in math performance at all grades," Dr. Hyde says. "We don't have gender differences. We have gender similarities in math performance today in the United States."

"The problem here is not girls' math performance or women's math performance," Dr. Hyde says. "It's the stereotypes that women can't do math. Even today, if you have parents rate the math ability of their sons and daughters, they will rate the math ability of their sons higher."

Former Harvard president Dr. Lawrence Summers had famously addressed the question of male dominance of the upper tail of the distribution curve in math talent (those who are exceptionally talented). How can there be differences in this upper tail of distribution favoring boys, when there are no average differences? One answer is the Greater Male Variability Hypothesis, originally proposed over 100 years ago—holding that men are much more apt than women to have exceptional talent in math.

**The problem here is not girls' math performance or women's math performance. It's the stereotypes that women can't do math.**

At first glance, the data seems to back up the Greater Male Variability Hypothesis, with twice as many males as females in the exceptional category.

"However, that would mean that if math was the only thing that you needed to succeed in engineering, even with 2-to-1 ratio, you'd still have about 67 percent males and 33 percent females," Dr. Hyde says. "But only 18 percent of engineering Ph.D.s goes to women. That's a male-to-female ratio of 4.5. So there's something going on here besides just pure mathematical talent."

To gain more perspective, Dr. Hyde examined this phenomenon historically. She found that the percentage of U.S. Ph.D.'s in mathematics awarded to women changed wildly decade-by-decade.

"Interestingly, even back in the 1890's, 11 percent of the math Ph.D.'s were going to women," Dr. Hyde says. "And you see, it got up to about 15 percent in the 1920's and 1930's, the first wave of the Women's Movement, I think not coincidentally. Then, it drops back dramatically to only 5 percent in the 1950's and 6 percent in the 1960's. Why is that? Well, it was the 1950's, right? I mean, need I explain more? The men came home from the war and everybody went out to the suburbs and had lots of children, women were supposed to stay home.

**If it's not gender difference in math ability that is to account for engineering being an overwhelmingly male profession, then what is it?**

"However, in our most recent decade, it's gone up to 30 percent, about that 2 to 1 ratio," Dr. Hyde says. "So that's 30 percent of women who are capable of, and actually getting, Ph.D.'s in mathematics and certainly would be well qualified to undertake careers in related areas like engineering."

This lack of participation by women in STEM areas is not insignificant. There are real costs to inflated claims about gender differences—costs our nation pays for in lost talent and social inequity. So, if it's not gender difference in math ability that is to account for engineering being an overwhelmingly male profession, then what is it?

One factor might be that of interest.

Research shows that on average men tend to prefer working with things, while women tend to prefer working with people.

"Now, I don't believe this difference is hard-wired into the brain, I don't think it's got anything to do with testosterone or estrogen," Dr. Hyde says. "Women and men have different roles, but it's there.

It's there and it's big. So, what do we do with that?"

Dr. Hyde recognized Dr. Sheryl A. Sorby from the Department of Engineering at Michigan Tech for suggesting that to get more women into engineering, we should rethink how the profession portrays itself.

"Is engineering about things, calculations, electrical circuits, and the like, or is it about helping people in fields like biomedical engineering?" Dr. Hyde asks, stressing the importance of motivation to go into STEM fields.

**Is engineering about things, calculations, electrical circuits, and the like, or is it about helping people in fields like biomedical engineering?**

## Addressing Inequality

Walter Secada of the University of the Miami wants educational researchers to question their assumptions about STEM performance.

"Why do we care about inequality in the STEM professions?" he asks. There are many reasons, he says, ranging from socially enlightened self-interest, to meaningful participation in our democracy, ideals of fair play, remedy of historical injustices, and the utilitarian need to make the most of America's talent.

How do we define achievement in STEM subjects?

Achievement is measured by performance on standardized tests, the SAT and "the usual alphabet soup of tests" he says. One can measure by course grades, by course taking (tracks) in high school, by college major and course taking, by careers that require math and science, by careers of mathematicians and scientists.

**The fact is that many distinctions are socially constructed.**

One might get, however, high achievement by one metric (courses taken), however, without getting it in other (grades). There are other distinctions to be made in research on learning.

"In this country, we accept social class like it's a given," Dr. Secada says. "I invoke social class and people say, 'yeah, what do you expect'? Try to put the word gender in there and see if you get the same nod of acceptance. And why is it that social class is just so easily accepted in this country, where as in other [countries] it's not?"

The fact is, Dr. Secada says, many distinctions are socially constructed.

"A white woman from an upper middle-class background is not just a woman," he says. "She has a privilege based on background, on class, and on race. Not all inequalities are equal."

He notes that in the Program for International Student Assessment (PISA) of 15-year-olds around the world, females do better in 11 countries for reading and literacy by a proficiency level. In the remaining 21 countries (including the United States), they are less than half a proficiency level ahead.

What about in STEM subjects?

Males do better in math in only half of the countries. In science, males do better in three countries, and females do better in three—*with no gender differences in science in the United States.*

In fact, females now enroll in and complete post-secondary education in greater numbers than males in the United States. Given PISA results, the real gender question is why are so few females entering (non-life, non-social) sciences?

We need to look at other, structural sources of inequality, Dr. Secada says, for once again "not all inequalities are equal."

"The interactions of race and ethnicity, with gender and social class is more complex than one would believe based on looking at either single-groupings, or at one or another grade, or at one or another subject," he says.

Another difficulty is that innovations targeted for low-income children often end up restricted from them.

"Many people forget that Maria Montessori lived in slums when she created the Montessori Schools for poor kids. Find a poor kid in a Montessori School right now," Dr. Secada says, provoking laughter from a STEM audience.

Another set of distinctions must be made between malleable versus non-malleable determinants. "By the time a child enters school," Dr. Secada says with a smile, "it's too late for that child to choose his parents more wisely . . . Social policy is often unable or unwilling to tackle (let alone change) long-standing practices."

Still, there are some obvious steps we can take.

"If I was to say where I'd put my money, as a policy maker, I would try to reduce the size of schools, I'd try to get teachers and high schools to take more responsibility—a reasonable kind of responsibility—and I'd try to narrow the curriculum," Dr. Secada says. "These are clear policy interventions, clear policy things that are doable.

"If we want to create more kids who will be math and science literate, then we need to look at whether that's what we're trying to accomplish," Dr. Secada says. "I come at this from a closing the gap perspective. I think that it's part of our responsibility to say, if we evoke the gap as a reason why we're engaged in these things, at some level the true test is whether we can actually close it."

**The clearest research result measured by the Educational Testing Service was that children who watched more Sesame Street, learned more, regardless of social background.**

## Multimedia Learning

What role can media play in drawing children into STEM subjects?

Milton Chen, Executive Director of the George Lucas Educational Foundation and former director of research for PBS's Sesame Street, notes that a prime purpose of Sesame Street was to make sure children had kindergarten-ready skills—knowing letters and numbers when they got to school.

The clearest research result measured by the Educational Testing Service was that children who watched more Sesame Street, learned more, regardless of social background.

**George Lucas hit upon this idea that if we could use film to show what it looks like, then light bulbs will begin to go off.**

"The question was getting them more exposure," Dr. Chen says, adding that when adults, parents and preschool teachers helped them learn from the program, there was a leveraging effect on outcomes.

It is revelations like these regarding the power of media to make big differences in academic achievement that inspire the work of the George Lucas Educational Foundation, a media-making organization founded by the legendary director in the San Francisco Bay area.

"George Lucas hit upon this idea that if we could use film to show what it looks like, then some of the light bulbs will begin to go off," Dr. Chen says.

Dr. Chen makes three seemingly simple points.

"The first point is that it's time to give every student the tools of digital learning," Dr. Chen says. "The second point has to do with the creation of new settings and places where kids can learn in schools, but also beyond school. And the third point is helping people with special needs."

**It's 2010 and we're still discussing this issue of digital equity and the digital divide. We are very slow as a nation to provide our students with the tools that they need to do this kind of work.**

## A Civil Rights Issue

Dr. Chen says that guaranteeing digital equity is more than an educational issue. It is a civil rights issue.

"I just find it amazing that it's 2010 and we're still discussing this issue about digital equity and the digital divide," Dr. Chen says. "We are very slow as a nation to provide our students with the tools that they need to do this kind of work."

It only costs $275 per student, per year, to digitally connect a student. And yet only one state has shown the political will to do so—Maine.

"You can walk into that state and every middle school student has a laptop computer," Dr. Chen says. "Angus King, the former Governor of Maine, is the one who made the laptop program there an essential part of his platform. He ran as an independent rather than seek the endorsement of teacher's unions for his education platform.

"It's a great statement of vision and anticipation of where we want the education system now to move," Dr. Chen says. "We need governors and other leaders to anticipate that and say that things like this are critical to creating a 21st Century system."

## New Settings for Learning

Dr. Chen says that it is critical to realize the extent to which technology is already enveloping the school, enabling 24/7-365 learning.

A critical area of focus must be to provide learning environments that enable kids to use technology for learning about STEM subjects; and not just in the regular school day—but afternoons, evenings, summers.

"The role of universities is critical," Dr. Chen says. "I encourage all universities to have closer ties with school districts to create lab schools, to create the kinds of schools where you can actually show what this should look like."

He notes that California, where 12 percent of the country is educated, is a state with a crumbling school system. San Francisco, for example, has announced $113 million in cuts for fall, 2010. Some school districts are talking about four-day school weeks. In the midst of such a crisis, Dr. Chen says, we need science centers and museums, universities and non-profits like the YMCA to step up and fill the void.

"So, it's a sad story, but I think our only hope for saving our school systems is for us to think about a new learning day and other organizations picking up the slack," Dr. Chen says.

**Curb-cuts have turned out to be of great value . . . The same thing is happening with digital curb cuts, that the same devices and tools being created for students and adults with special needs are being used by all of us.**

## "Digital Curb Cuts"

What about the children with disabilities and special needs?

Dr. Chen says we should take a hint from curb-cuts, originally put in place to help people in wheelchairs, or on crutches.

"Curb-cuts have turned out to be of great value to skateboarders, parents with strollers, and lot of folks who may have more limited mobility," he says. "The same thing is happening with digital curb cuts, that the same devices and tools being created for students and adults with special needs are being used by all of us."

These include technologies like speech-to-text readers, speech recognition and synthesis software that were originally designed for people with special needs that are turning out to be a boon for everyone.

"We all have special needs," Dr. Chen says. "I was the first kid in my fourth grade class to have glasses. We're very fortunate because our society does not label us as disabled because we wear glasses, somehow we've solved that kind of cultural issue which we're talking about; that the wearing of glasses, even though we are visually disabled, is not considered a severe disability. So, we've got to do that for some of these other issues because the more we understand that we all have special needs, the more we will understand that technology can support us in better learning across the board."

# CHAPTER EIGHT

## Innovations In Engineering Education Curriculum: Secondary School through College

*Rafael Bras (Facilitator)*
*Theodore W. Ducas, Wellesley College*
*Ari Epstein, Massachusetts Institute of Technology*
*Rafael Bras, University of California, Irvine*
*J. Michael McCarthy, University of California, Irvine*

The many obvious rewards of an engineering career are simply insufficient to lure the needed numbers of American students into that field. One reason, of course, is that engineering by its very nature requires intense focus and discipline to master.

The rigor of engineering does not necessarily mean that it has to lack a sense of fun. Is there some way to make engineering more attractive and relevant, without watering down standards? Can we teach engineering in a way that is more "real world" and useful?

A growing body of programs—from U.S. high schools to colleges—suggests that when students are asked to learn engineering by constructing objects that people need and appreciate, passion enters the equation.

### Liberal Arts: Making STEM Connections

Theodore W. Ducas brings a unique perspective to the question of inspiring undergraduates to consider an engineering career—Dr. Ducas teaches at Wellesley.

Students come to Wellesley with an interest in engineering, Dr. Ducas says, many wanting to take advantage of Wellesley's links to the Massachusetts Institute of Technology and the Franklin W. Olin College of Engineering. But few have a lot of actual knowledge about engineering.

"So the goal is to create an impedance match between these schools," Dr. Ducas says, employing an electrical engineering term describing the equalizing of inputs and outputs of an electrical load. That match is an introductory, hands-on course designed at Wellesley College to expose liberal arts students to engineering.

"What do we mean by an introduction to engineering?" Dr. Ducas asks. "One way is to learn by doing—getting engaged on these projects, working in teams, doing real-life things connected to the world. That's what motivates, and it's one of the hooks for learning. But it is also a core reality of engineering.

"The second way was learning about the wide range of engineering fields," he says. "What are the possibilities, from civil and environmental engineering to biomedical engineering?"

Wellesley's introductory engineering class, taught by Wellesley and Olin professors, gives students experience working in teams on project-based assignments. Students are also offered a career seminar series in which visiting engineers talk about their work in engineering.

The Wellesley program offers "coordinated advising," in which the student's interests are worked out with Wellesley, Olin or MIT faculties. "We help her chart a path through different possibilities," Dr. Ducas says.

Why go to all this trouble to encourage liberal arts students to go into engineering?

"If engineering in some crude sense is science that services society, it's important for people to know not only the technical knowledge, but to have a core understanding of the world around them," Dr. Ducas says. "That includes cultural sensitivity, language skills, communication skills—the very skills that a liberal arts college provides."

**Learning by doing—getting engaged on projects, working in teams, doing real-life work connected to the world—that's not just the best way to learn. That's also a core reality of engineering.**

**Students need more than the technical knowledge. They need to have a core understanding of the world around them. That includes cultural sensitivity, language skills, communication skills—the very skills that a liberal arts college provides.**

## Teaching Opportunities in Physical Sciences

A prime destination for a student strong in both engineering and liberal arts might be teaching. The need is great. After all, about two-thirds of the students studying chemistry and physics in U.S. high schools are taught by teachers with no major or certificate in the subject.

Dr. Ducas points to a six-week summer program, the MIT-Harvard Teaching Opportunities in Physical Sciences (TOPS), in which undergraduate physics majors in teams of four work with experienced lead teachers to develop curricula and hands-on experience to teach a course to middle-school students at the Boston Museum of Science, and to high school students at MIT.

"Our objective is to inspire physics majors to enter teaching, pre-college teaching careers, and to create an expanding network of those teachers, and to serve as a model program for others," Dr. Ducas says. "If you want to encourage people to do research, one of the things that's very successful and necessary is to get them into the lab. The analog for teaching is to get them in direct contact with young learners."

## Helping Students Find Their Voice

In addition to learning by doing, students can also learn by reporting. Student radio productions on science and the environment can be a very powerful medium for STEM projects and learning.

Why radio?

Students, says Ari Epstein of the Massachusetts Institute of Technology, think they know what an essay or a project is supposed to look like. But most don't listen to a great deal of radio, and thus lack preconceptions about what they should be producing for radio.

"And that lack of preconceptions is extremely valuable to us," Dr. Epstein says, freeing up students to experiment. "Radio is also a very difficult medium to do well in the sense that it's linear. You can't skip ahead a few pages if you're bored, you can't go back to something you missed. So if you're going to produce effective radio, you have to have your audience in mind all the time. What does your audience need, what are they interested in, what do they care about? Are you boring them?"

"It is very important for me to develop communications skills in people who are already interested in STEM topics," Dr. Epstein says. "And one of the important communications skills is to have a sense of who your audience is and what they want. There's also a low barrier to entry in radio. You don't need cameras, lenses, lighting. The microphone, a recorder, a set of headphones and a computer to do some audio editing, are all it takes. On the other hand, it's very hard to do radio well.

"Most of all, radio is a very powerful medium for story telling."

Radio production out of MIT is being used to enhance STEM learning at both the high school and college levels. For example, MIT freshmen can sign up for a semester-long, project-based, team-oriented class called Terrascope Radio.

Students not only learn all about radio, Dr. Epstein says. They learn how to listen.

"In the very first class, we blindfold them and lead them around campus, and ask them to really experience the acoustic environment," he says. "For many of them, the walk down that first hallway is remarkable. They had no idea that there's this huge acoustically different setting from one end of the hallway to the other . . . They learn how to tell stories using just sounds, and for this we spend a lot of class time just listening to previously produced radio pieces of all kinds, produced in all different periods of audio production, because they need to build up a vocabulary of what kinds of work can be done, what's important."

What do the students get out of the class?

"For one thing, they improve their communication skills, but not just in radio, because writing for radio is really difficult," Dr. Epstein says. "You have to be concise, you to have a sense of where you're headed. Those skills carry on into their other writing work. They're able to see not just the science and technology of the problem, they're able to see the social, political, human elements of the work they will be doing as scientists and engineers."

A related program is Terrascope Youth Radio, in collaboration with Cambridge Youth Programs, funded by the National Science Foundation, in which MIT students serve as mentors for a diverse group of teens, ages 14 to 18.

"We have kids at all levels of educational achievement, and representing all races, ethnicities, and national origins, first-generation immigrants and people whose families have been around for a while," Dr. Epstein says.

## Promoting Creativity: The Terrascope Program

Rafael Bras of UC Irvine helped found and run MIT's Terrascope program with Ari Epstein. Terrascope, which encompasses much more than the radio course, is a "learning community" of students and faculty that involves problem-solving centered on an annual theme in environmental and Earth sciences. Bras describes his Terrascope work as "the best times of my life."

**Developing problem-solving skills is the number one goal of Terrascope. The promotion of creativity and self-confidence, that's also right at the top.**

"As you can imagine, politics plays a major issue in such projects," Bras says. "Students are asked to develop a new preservation strategy for the Galapagos Islands, or a tsunami prediction system right after the tsunami in Southeast Asia, or to develop a plan for the future of New Orleans right after the disaster of Katrina, or a plan to make global fishing practices sustainable."

Bras adds that developing "problem-solving skills is the number one goal of Terrascope. The promotion of creativity and self-confidence, that's also right at the top. Really we do not care very much what we are teaching them to do technically or scientifically, that is a secondary great benefit, but developing the problem skills and creating that self-confidence is crucial . . .

"The students needed to know that what they were doing was relevant, and they were willing to expose themselves against the experts," Bras says. "When we examined the Alaskan Wildlife Refuge, we flew native people from Alaska and the Vice President of Exxon in for a panel to question them. And so students were facing the real people who had a stake."

## Engineering Project Education

J. Michael McCarthy started thinking about real world applications of engineering learning ten years ago when one of his students asked him to join a start-up company in trouble.

Turning around this start-up got Dr. McCarthy to thinking about retooling how engineers are taught. Projects by teams of senior engineering majors often suffered from poor time and cost management. Could undergraduates benefit in preparing for these real-world projects by getting engineering into their bones through project work as freshmen?

So when he returned to campus, Dr. McCarthy had an epiphany.

"I look at all our students," Dr. McCarthy says. "And what do I see? I see heads down working on homework problems, struggling to do tests. And I'm thinking, 'Well, I know we're teaching you the right stuff, but where is the excitement that comes from when you have accomplished something that other people appreciate?'"

Dr. McCarthy's epiphany is now a project class, one that involves the give-and-take of real engineering at University of California at Irvine. Dr. McCarthy quotes George Hazelrigg of the National Science Foundation, "Design is all about decision making, not problem solving."

What kinds of problems do engineers face? Engineering involves budgeting. It involves assigning the right task to the right people. It involves creating an initial design matched to an exact need.

Thinking about these decisions is what Dr. McCarthy brings to his project courses in which he must deal with highly motivated students.

**To learn engineering, students need to learn budgeting, management and creating an initial design matched to an exact need.**

## The 'A' Team

"First of all, our admission policies select for the overachiever," Dr. McCarthy says. "They select for the person, if there is a group project, who did the project by themselves. They will not allow anyone to detract from their potential for an 'A'."

At the university level, when a team of three or four such people is suddenly put together on a quick-burn project (like building robotic cars), negotiations and trade-offs between students become intense.

"I have to deal with the emotional breakdown of students who thought they were going to do it all and realize they simply cannot," he says. "It is an emotionally difficult challenge for the students to release that control. It's a kind of headache—it's a kind of a pain—it's difficult."

And it's also real world.

No one can learn on their own how to adapt mathematics, as well as science and engineering fundamentals, to the differing circumstances presented by real design problems.

Project skills training and experiences are thus needed to ensure students learn mathematics, science and engineering fundamentals.

# CHAPTER NINE

## Gender Differences in Science Faculty: A Conversation: Dr. Nancy Hopkins and Dr. Robert Birgeneau

Nancy Hopkins is a Professor of Biology at MIT, a renowned scientist working on the early development of vertebrates, and a member of the National Academy of Sciences, the Institute of Medicine, and the Academy of Arts and Sciences. And yet when she joined the MIT faculty thirty-five years ago, Dr. Hopkins gradually became aware that something was working against her.

"What I discovered was that if a man and a woman made a discovery of equal scientific importance, the woman was not valued in the same way as the man," she says. "And the discovery was not valued in the same way and often was not even attributed to that woman. This was impossible for me to comprehend because I believed that science was a merit-based occupation."

Dr. Hopkins was not having a difficult time scientifically, or in winning tenure and promotions. It was the administrative details that made her life, she says, "unbelievably difficult." It all crystallized for her when Dr. Hopkins wrangled with administrators to get 200 square feet of space in a department in which senior faculty members had 3,000 square-feet.

She was told that her work was not that important. Around that time, Dr. Hopkins happened to read the biography of Rosalind Franklin, a scientist many believe had not received proper recognition for her role in helping James Watson and Francis Crick discover DNA.

**It was possible for a woman to make Nobel Prize-winning discoveries and still be ignored.**

After reading this book, Dr. Hopkins says, "the penny dropped. I saw that it was possible for a woman to do Nobel Prize-winning discoveries and still be ignored and not have that work credited equally to the accomplishment." She eventually learned that there were only 15 female faculty members in her department, while there were 197 men.

Dr. Hopkins and other female faculty members drafted a letter in a secret, off-campus location. "We didn't want to be called feminists," she says. "We were scientists."

That letter arrived in the summer of 1994 in the inbox of the Dean of Science, Robert Birgeneau, a physicist who is now the Chancellor of UC Berkeley. Dr. Birgeneau had just returned from a research sabbatical to find that the first thing on his calendar was a meeting with Dr. Hopkins—and almost all the women faculty members.

"In the School of Science at MIT, 29 percent [of the faculty] ultimately become members of the National Academy," Dr. Birgeneau says. "And 70 percent of the women are members of the National Academy. So there was no issue about who were the best scientists at MIT. It was this very small number of women faculty.

"So Nancy arranged for each of them to go around and tell their story," Dr. Birgeneau says. "I just sat there and had, I would say, a religious experience where I just suddenly understood that this wasn't that

Nancy needed more than two hundred more square feet of space. This was really a deep, systemic problem and that there was really something fundamentally wrong with the culture we had had at MIT."

So how did MIT react to the initial overture?

"We're all scientists, so studied this issue quantitatively," he says. "But there's also a lot of soft science . . . a whole series of issues which are not so readily quantifiable and are just as important."

After several committees had studied the problem, a consensus for change had emerged. In a short amount of time, Dr. Birgeneau says, MIT increased the number of women faculty in the sciences by 50 percent. With the hiring of more women came a new, fresh approach to a more equitable culture at MIT.

Until his first meeting with Nancy Hopkins, Dr. Birgeneau says, "I simply hadn't understood that, even though one of my daughters was working in the lab at MIT."

Dr. Birgeneau's daughter subsequently went on to a career in a renowned medical school. He says: "It's really because of Nancy that this kind of full career for women has become possible."

# CHAPTER TEN

## Breaking Down the Silos And Building Bridges Across Pre-K Through Higher STEM Education

*Michael Feuer (Facilitator), Executive Director of the Division of Behavioral and Social Sciences and Education in the National Research Council (NRC) of the National Academies*
*Sybilla Beckman, University of Georgia, Committee Member of National Research Council, "Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity" Report*
*Phillip Bell, University of Washington, National Research Council, Co-Chair, "Learning Science In Informal Learning Environments: People, Places and Pursuits" Report*
*Linda Katehi, Chancellor, University of California, Davis, National Research Council, Chair, " Engineering in K-12 Education: Understanding the Status and Improving the Prospects" Report*

The resources exist for tremendous engagement between higher and lower levels of education, between formal and informal means of learning, between early childhood instructors and sources of instruction that makes math come alive for children.

Yet education, like any business, can be unnecessarily divided into silos, barriers that keep us from drawing from the whole gamut of what we know. As a result, we often suffer from an inability to share knowledge and strengths across these boundaries.

What can we do to breach these silos and strengthen STEM learning across the board?

This somewhat abstract but important question is a matter of interest not just to STEM specialists, but also to anyone who cares about an educated citizenry. Michael Feuer of the National Research Council of the National Academies points out that several studies bear out the same truth—that many more people can make contributions in science and engineering, "not just the domain of the intellectual elite."

Greg Pearson, a program officer at the National Academy of Engineering, acknowledges another reason for STEM education, beyond supplying a "pipeline" of future engineers. All adults should be technologically literate, he says, and "have an understanding of where our world comes from—why sometimes it doesn't work, and who is involved in creating it."

In thinking about such a technologically literate adult, of course, we have to begin with the education of the child.

**All adults should be technologically literate, with an understanding of where our world comes from—why sometimes it doesn't work, and who is involved in creating it.**

## Engaging Children: Beyond Flashcards

Sybilla Beckmann of the University of Georgia echoes the widespread agreement that educators should defy the expectation that mathematics is not developmentally appropriate for young children.

To raise the bar for young children, teachers need to know how to bring the "engagement, exploration and playfulness" that is too often lacking in math instruction.

**Teachers need to know how to bring the "engagement, exploration and playfulness" that is too often lacking in math instruction.**

This wide and growing body of dissent includes a National Academies Report of the Committee on Early Childhood Mathematics that holds that, "when given the appropriate learning opportunities, young children can become competent in mathematics." That report recommends, "A coordinated, national early childhood mathematics initiative should be put in place to improve mathematics teaching and learning for all children ages 3 to 6." It calls for high-quality mathematics curricula and instruction.

What would such curricula look like?

"They should be planned and sequenced," Dr. Beckman says. "They should use a variety of instructional approaches. Sometimes when people hear about early childhood math, they think we're talking about kids sitting in rigid rows and working with flash cards. That's not what we're talking about. It's active, engaged, interesting, child-oriented, but also intentional and focused on real analytical ideas."

It is not enough, however, to engage children on mathematics if one first hasn't engaged their instructors.

## Engaging the Early Childhood Workforce

The National Academies Report comes down unequivocally on the need for better prepared early childhood workforce: "These individuals are central to supporting the intellectual/academic, social, emotional, and physical development of young children." And yet, there is significant variation in the educational background and training of these professionals so important to the development of children. The report also notes that those in the early childhood workforce "are generally less supportive of mathematics in the classroom than literacy or social-emotional development."

"In early childhood education, it seems clear that teachers need to be more knowledgeable," Dr. Beckman says. Thus, the National Academies Report calls for "changes to be made and enforced by early childhood organizations that oversee credentialing, accreditation and recognition of teacher professional development programs." There is also a need to improve in-service education for teachers already out in the field.

## Engaging Children in Informal, Elective Environments

Phillip Bell of the University of Washington is a faculty lead on an NSF-funded Science of Learning Center called Life Center, which examines learning in informal and formal environments.

A case study from Dr. Bell's work takes us to a Saturday morning in a three-year-old's bedroom in which she encounters a daddy long-legs spider—and "freaks out." Her screams bring her parents running to her bedroom.

"Within an hour or two," Dr. Bell says, "the father's looking through the paper and sees that the local science and culture museum on campus is holding an 'Insectapalooza Day' the very next day. Off they go to see if they can moderate this fear reaction."

**The father takes his daughter to a museum, and leads her up to a table with a tarantula. She backs away—and then goes right back to it.**

The father takes his daughter to a museum, and leads her up to a table with a tarantula. She backs away—and then goes back up. At the table is an expert spider wrangler to help children hold the spider.

“It is a completely stunning moment for her—this situational interest with insects gets stabilized in that moment in a very powerful way,” Dr. Bell says.

Before long, the girl who was afraid of spiders is posting movies on YouTube about her pet snail.

When it comes to STEM education, Dr. Bell says, “we need to think about the broader landscape, the ecology in which this learning agenda gets mobilized and brought into deep competencies.”

What kinds of settings and activities might foster this STEM learning outside of the school? A broad set of informal education activities take place in zoos and aquariums, botanical gardens, after-school programs, summer programs, elder hostel programs, citizen science programs, educationally designed media, popular media and interactive media—as well as the broad world of science journalism and communication.

An example: One program in Montana within Native American communities relates culture and science by sending children out to do field ecology work. The children are encouraged to use the conceptual resources of Native American languages to arrive at a deep understanding of the specimens they studied.

If we can engage very young children with exploration and playful ways of learning math—and engage children with informal learning environments like museums and touch pools—how might universities engage students all across the K through 12 spectrum?

## Engaging the Universities in K-12 STEM Education

Linda Katehi, Chancellor of University of California Davis, says that when deans of engineering are asked about their challenges in attracting good students from a diverse population, they will always point to deficiencies in K-12 education. But can the universities reach down and do more to fill the “pipeline” of K-12 students ready to learning STEM subjects?

To go deeper into this issue of the “pipeline,” the National Academy of Engineering sponsored the Engineering in K-12 Education Report.

The specific goal of the study was primarily to provide guidance to key stakeholders regarding the creation or implementation of K-12 curricula. What kind of connections could be made between engineering and science technology or math? How could those connections be used to leverage learning?
It took this committee two-and-a-half years to develop its report. What did it find?

First, the committee discovered a heartening fact—K-12 engineering education is small, but growing. Since the early 1990s, about 6 million children have experienced some form of K through 12 engineering curriculum. About 18,000 teachers had received professional development while they were in service.

“So we found that the problem with teaching engineering in K through 12 is not just that there’s not enough material available,” Dr. Katehi says. “It is that we do not have enough teachers who understand it well enough to do it.”

**The problem with teaching engineering in K through 12 is not only a lack of available material; the problem is that there are not enough teachers who understand engineering well enough to cover it.**

What kinds of impacts can such K-12 engineering learning have on young minds?

“We found a correlation between the participation of children in some form of K through 12 engineering education and their comprehension of math and science,” Dr. Katehi says. “It made sense to us later to see that engineering is not just a separate discipline that has to be taught, but that it can provide the platform on which to build the understanding of math and science.”

The committee found many other positive effects of engineering in K-12 education.

“There were gains specifically with girls and underrepresented students,” Dr. Katehi says. “What really made that type of education exciting to kids was their participation in design and their ability to connect math and science to a particular problem of interest to them.”

## Not an Isolated Discipline

Dr. Katehi also speaks of "integration" or "interconnectness," in learning about engineering. In fact, the National Academy of Engineering report concluded that current STEM education does "not reflect the natural, real-world interconnectedness of the four STEM components." Science, technology, engineering and mathematics intimately relate to the operation of the natural and man-made worlds around us.

**Engineering is not just an isolated discipline. It improves our quality of life . . . the glue that makes math and science learning stick.**

"What we found important is that engineering is not just an isolated discipline," Dr. Katehi says. "It is an attempt to create something that will improve our quality of life . . . using engineering as the glue on which to base math and science learning."

# CHAPTER ELEVEN

## University Leaders on STEM Excellence

*Deborah Vandell and Rafael Bras (Facilitators)*
*Maria Klawe, President, Harvey Mudd College*
*Robert Birgeneau, Chancellor, University of California, Berkeley*
*Linda Katehi, Chancellor, University of California, Davis*
*Michael Drake, Chancellor, University of California, Irvine*

What can the university do to improve STEM education, to make STEM knowledge central to the 21st Century well-educated, well-rounded person? How can the university help improve STEM education at all levels? Do we need a new hybrid of liberal arts and science? And what might STEM education look like twenty years from now?

The leaders of four institutions of higher learning delve into these questions in describing their approach to STEM education.

### Maria Klawe, President, Harvey Mudd College

Dr. Klawe speaks about the role Harvey Mudd College plays in STEM education K–12, beginning with the importance of clear communication.

"We care about writing and speaking," Dr. Klawe says. "We noticed that even though our students take so many classes in humanities, social sciences and the arts, and do a massive amount of writing in those classes, it doesn't really transfer into their ability to write extremely well in technical disciplines."

To teach students about writing in science and engineering classes, however, required the faculty itself to be able to teach writing. As a result, about 40 percent of Harvey Mudd's math, science and engineering faculty were sent to a writing workshop, so that every single incoming student will now take a class on writing in their first semester—taught by a technical faculty member.

This is typical of Harvey Mudd, where interdisciplinary studies—even to the co-teaching courses across the humanities and sciences—are common.

Harvey Mudd is also active in K-12 education.

"Every single one of our first-year students does something called the Lead Lab as part of their chemistry course," Dr. Klawe says. "Our students go out into a grade five or grade six classroom. They teach about the effects of lead on children's growth. They explain to them about the history of leaded gasoline and how there can be lead in the soil. They take the students out to gather soil and teach them how to analyze for lead contamination."

## Robert Birgeneau, Chancellor, UC Berkeley

When he was in high school, Robert Birgeneau's physics teacher was the football coach. Birgeneau was quite young for the eleventh grade, age 14.

"The teacher realized that I and one other person in the class understood physics better than he did," Birgeneau recalls. "He essentially handed the course over to us. We graded the final exam."

A thirst for learning and teaching was born in that class. Both Birgeneau and that other student became physics professors.

Troubled by the continuing assignment of STEM-related classes to teachers who are not fluent in their subjects, Dr. Birgeneau, now Chancellor of the University of California, Berkeley, oversaw the creation of Cal Teach, where students can major in STEM subjects while taking courses in the School of Education.

At the end of their studies, students receive a teaching certificate, and retain the option of going on to teach high school physics.

"We now have well over 100 of our new graduates, hyper-smart undergraduates who are in this program, and so we are going to increase by a factor of twenty approximately," he says. Funding is a challenge in these tough economic times, but Birgeneau is optimistic that foundations will come through with support.

What would it take to support master teachers in STEM subjects?

About $2 billion a year to significantly supplement the salaries of master teachers, the top 20 percent in science and math.

"As I've been pointing out to people, in the context of the California budget situation, the federal government for better or worse chose to invest something like $200 billion to save AIG," Dr. Birgeneau says. "I hope AIG survives. But for an amount that is on the order of $100 billion, you could basically save the top public research universities in the country permanently."

**For what we spent on AIG, America could save the top public research universities permanently.**

## Linda Katehi, Chancellor, UC Davis

Although the ten campuses of the UC system have excellent humanities departments across the board, they are primarily science campuses.

"I would argue that we educate our students in STEM extremely well," says Linda Katehi. "Even our critics will say that we do a pretty good job . . . What we have not done very well, I believe, in UC and other places that I've been, is that we have not asked the question: What is happening to those other students we do not see."

"There are many students who have the capacity to learn science or engineering and practice it very successfully who never make it to a science or engineering school, or never learn science or engineering," she says. "And so the question, really, that we are facing right now is what are the issues in K through 12, and how should research universities play a visible role in changing these conditions.

Dr. Katehi grew up in Greece, and was educated in that country's schools. In the European system, Dr. Katehi notes, there was a decision made decades ago to invest more in teachers and their ability to teach specialty courses, even if the shift in resources resulted in larger classrooms. The United States went in the opposite direction, focusing on class size at the expense of teacher support and specialization.

**What is happening to those other students we don't see?**

"We thought that fewer kids in the classroom was the way to go," she says. "But eventually because of the size of the population and the numbers of teachers, we ended up having more, while still paying less. And that has lead to many other social problems. So it was a decision made in the Fifties with all good intention that has led us to where we are today."

About 90 percent of everything around us is man-made, she says. Speaking as an engineer, Dr. Katehi notes that "we give our kids many opportunities to learn about nature, and that's wonderful, that's how you learn science, but we do not teach much about everything else that is manmade."

The result is a population of young people who come to college with limited curiosity about technology. They use it, they want to replace it if it's not good enough for them, but they don't know how it's working.

"We use high-tech to do things, but our ability to interact with these tools creatively and to change the tools in a way that will improve our art, is very minimal," she says.

**We use high-tech to do things, but our ability to interact with these tools creatively and to change the tools in a way that will improve our art, is very minimal.**

Although a lot of artists use software, they know very little about the software they are using and its capacity.

"They have very little capacity to even think on how to improve it, how to change it in creative ways that will impact their art," she says.

## Michael Drake, Chancellor of UC Irvine

"You know, one of my least favorite terms is 'hard science,'" Dr. Drake says. "I think that's the wrong thing to say to people whom you want to get to try something. It's the meaning for the soft ones, but it's also a barrier for people to try to learn how exciting and fascinating these worlds can be."

In a prior role as Vice President for Health Affairs for the UC system, Dr. Drake performed a lot of work with admissions to health sciences schools.

Dr. Drake points to three areas in which a professor must excel to be promoted—research, teaching and service. Which area is most important for promotion?

"It's 95 percent research, and then some mixture of 5 percent teaching and service each," he says. "I think that's being kind. We talk about those things, but the systems that we have in place don't really reward teaching and the success of other people who come to our classes as much as they reward our own success and ability to make contributions to the field.

"So I think there's a broad culture change that we need to make to make these more attractive and exciting fields," Dr. Drake says. "And then another culture change we need to make, those of us who have been successful enough to be in positions to make decisions, is to look at new ways of approaching the way we do science and math teaching to make it more interesting to students."

# CONCLUSION

## Catalyst for Conversation

*Deborah Vandell, University of California, Irvine*
*Rafael Bras, University of California, Irvine*
*Gerald Solomon, Executive Director, Samueli Foundation*

The Summit concludes with participants reflecting on their expectations for the two-day conversation—and how they were surprised by what they learned when experts in child learning, university engineering instruction, hands-on educators and business leaders were brought together to share their STEM knowledge across institutional boundaries.

"In a Summit centered around STEM education, I wanted to say to this diverse group how important it is that early childhood learning have a place at the table," says Deborah Vandell, who was pleased that it did.

The presentations on project-based learning and engineering were a revelation, she says. "The little light bulb that went off for me," she says, "were that from project-based learning to after-school, these programs involve the same general principles of effective learning seen in high-quality, early childhood programs."

As important as teamwork is, she says, it is important to have "a mentor or a teacher or an adult who is there to help scaffold hands-on, active learning so that it is substantive, incorporates motivation and a sense of utility."

Rafael Bras points out that the incentives in higher degrees in engineering might not be as clear as some discussants think they are.

"Students and parents are very sensitive to the perception of the long-term rewards and the immediate rewards," he says, adding that a personal cost-benefit analysis may not show that a Ph.D. in engineering compares well to a law degree. "In terms of return on investment, it just doesn't add up—and that's the plain truth. You have to do it because you want to do it, because you like it, and have hope" for a great career as an engineer.

Dr. Bras also spoke in favor of project/problem-driven education.

"It just has to be fun," he says. "Make it fun and it will work—and that is true at any age."

Gerald Solomon says that he is often asked what the Samueli Foundation hoped to achieve from this STEM Summit.

"My candid and realistic answer—I had no expectation," he says. "Philanthropy is one of the last frontiers where it is okay to take a risk and fail. And one of the things we can do in philanthropy by taking these risks is to become a catalyst for conversation.

"I think we succeeded."

That conversation continues in an online venue, on the Summit blog at www.stemsummit2010.org.