BEST PRACTICES IN STEM EDUCATION

Innovative Approaches from Einstein Fellow Alumni, *Second Edition*

EDITED BY
Tim Spuck, Leigh Jenkins, Terrie Rust & Remy Dou

Science, technology, engineering, and mathematics (STEM) education are seen by leaders from across the globe as key to economic success and prosperity. The goal of *Best Practices in STEM Education: Innovative Approaches from Einstein Fellow Alumni, Second Edition* is to improve the state of STEM education, not only in the United States, but internationally as well—good education anywhere is good for education everywhere. As the body of STEM-learning research grows, this second volume provides the unique perspective of nationally recognized educators who have spent, collectively, more than 600,000 hours at the interface between teaching and learning. The 24 chapters included in this volume are the product of years of practice, mistakes, reflection, and refinement. They provide the experiential pragmatism backed by research so desired by practitioners. Each chapter communicates how its author has implemented a specific STEM practice in the classroom and how the practice might be modified for use in other classrooms, schools, and learning environments. These are stories of success, as well as stories of struggle. Readers of this second edition will gain powerful insight about what really works when it comes to teaching and learning STEM.

Best Practices in STEM Education: Innovative Approaches from Einstein Fellow Alumni, Second Edition will serve as an excellent resource for use in any science, technology, engineering, and mathematics teaching methods course, and no professional education library, K through college, should be without a copy.

Tim Spuck is Director of Education and Public Engagement at Associated Universities Inc. Major awards include the Albert Einstein Distinguished Educator Fellowship, American Institute of Aeronautics & Astronautics Educator Achievement Award, Pennsylvania Christa McAuliffe Fellowship, and the Tandy Technology Scholars Award. Tim earned his M.Ed. in Science Education from Clarion University of Pennsylvania, and his Ed.D. in Curriculum & Instruction from West Virginia University.

Leigh Jenkins is currently a doctoral candidate in Administrative Leadership at Shenandoah University in northwestern Virginia. Leigh taught biology and environmental science for 18 years in West Virginia. She holds a M.A. in Sociology and an M.A. in Science Curriculum and Instruction. Leigh was awarded the Albert Einstein Distinguished Educator Fellowship, Japan Fulbright Memorial Teachers Fund Scholarship, and was the 2016 West Virginia Conservation Teacher of the Year.

Terrie Rust is an ITEEA Distinguished Technology Educator. She has contributed globally on STEM education projects, most notably while working in India. Terrie holds M.A. and M.Ed. degrees in education fields, and an Education Specialist (Ed.S.) degree in Organizational Leadership. Terrie received numerous awards for her teaching programs from ITEEA and ACTEaz. She is currently serving as a STEM consultant in the DC area.

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Educational PSYCHOLOGY

PRAISE FOR THE FIRST EDITION

"Prior to Congress, I spent over 20 years as an educator; serving as a science teacher, school board member, principal, and education researcher. *Einstein Fellows: Best Practices in STEM Education* is an outstanding publication, featuring some of the best STEM educators in the nation, and insights and guidance on what really works to improve learning in and out of the classroom. Broad implementation of these best practices has the potential to improve STEM education both here in the United States and across the globe. I urge teachers, school administrators, my colleagues in Congress, and education leaders across the nation to give it [a] read; you won't be disappointed."

—U.S. Congressman Mike Honda, California's 17th District

"In a community where we struggle to define 'STEM,' this book provides a clear vision with tangible exemplars to help define the role of science, technology, engineering, and mathematics in our nation's education system. *Einstein Fellows* provides research paired with practical programming and resources in a groundbreaking way that speaks to practitioners, administrators, researchers, and policymakers. This book is STEM for the 21st century."

—Sarah Young, K–12 Science Specialist, Utah State Office of Education

"[The contributors to] *Einstein Fellows* represent a group of master STEM educators who are leaders and education innovators in the classroom and beyond. This collection of essays represents decades and decades of experience and expertise boiled down to best practices current STEM educators can use immediately. *Einstein Fellows: Best Practices in STEM Education* is highly recommended for any educator seeking proven practices from some of our nation's best STEM educators."

—DaNel Hogan, STEM Coordinator, Office of Pima County School Superintendent

"The Albert Einstein Distinguished Educator Fellowship provided this group of STEM educators the opportunity to deepen their knowledge of best practices in STEM education research on teaching and learning. Their insights, distinctive because of their experiences both in the classroom and at the federal-level shaping STEM education policy, provide a unique view into what engaging STEM learning can look like. This collection of essays shares relevant instructional practices and strategies that recognized educators have found to be successful in classrooms around the country. This book could not come at a more critical time, considering our country's dire STEM workforce needs."

—Cindy L. Hasselbring, Special Assistant to the State Superintendent,
Maryland State Department of Education

"I applaud the [contributors to] *Einstein Fellows*…for putting forward their best thinking about doing STEM. They offer a useful guide to educators who seek STEM clarity in the form of practices that can be readily adopted in their own classrooms or informal learning settings. Through their writing, the fellows give those of us who work in policy and advocacy roles greater insight into the multiple and subtle variations in meaning that can only be understood in context or inflection or when accompanied by gestures as STEM is spoken in schools."

—Tom Peters, Executive Director, South Carolina Coalition for Mathematics and Science

"This collection of essays provides concrete examples to bring STEM alive in classrooms, including informal learning experiences and the integration of engineering design, which is critical to implementing the Next Generation Science Standards. Since 1990, the Albert Einstein Distinguished Educator Fellowship program has brought accomplished STEM educators from across the nation to Washington, D.C., to inform policy and programs with their knowledge. In turn, they learn the intricacies of federal education policies and gain access to myriad educational resources. I encourage future fellows to continue this tradition and blaze new trails."

—Ioannis Miaoulis, President & Director, Museum of Science, Boston;
Founder, National Center for Technological Literacy

"This book captures the diverse, collective wisdom of over a dozen distinguished and experienced science teachers. If you are a STEM educator, you may want to save yourself time and buy two copies right away as you will surely want to give one of your copies to a younger colleague."

—Stephen Pompea, Education & Public Outreach Department Head,
National Optical Astronomy Observatory

"*Einstein Fellows: Best Practices in STEM Education* is a uniquely positioned book because it synthesizes solutions for many pressing issues in STEM education from some of the most influential teachers, and does so in a practical way. The breadth of topics is comprehensive—from girls in STEM, to gaming, to research experiences for teachers, to sustainability, among others—and each chapter delves deep to offer tried and true practices from expert teachers. This book will be useful for policymakers, teacher educators, STEM industry professionals, as well as teachers."

—Erin E. Peters-Burton, Associate Professor of Science Education
and Educational Psychology, George Mason University

"In *Einstein Fellows: Best Practices in STEM Education*, the topics covered are exceptionally important. Each chapter covers subject matters exceptionally well.... Overall, it is a timely arrival of a book that everyone including parents, students, politicians, and practicing professionals must read and understand their roles in improving the society at large and their authentic participation in educating the young minds early and maintain the discipline at later ages is critical to the society. I applaud the authors for putting forward an excellent book focusing on their ideas of best methods for improving STEM education more realistically."

—Dhadesugoor R. Vaman, Texas A&M Regents Professor, Prairie View A&M University, Texas;
Chief Technology Officer, Digital Compression Technology, Virginia

"This informative collection of essays provides overviews of research insights in the field of STEM education coupled with the wisdom of the teachers who apply it in their classrooms. Each essay—whether it focuses on problem-based learning, engaging girls, interdisciplinary learning, research experiences or informal learning—moves from the theoretical to the personal as the teacher authors provide practical examples for everybody engaged in the valuable work of educating the children of America."

—Arthur Eisenkraft, Distinguished Professor of Science Education, Professor of Physics, Director,
Center of Science and Math in Context (COSMIC), University of Massachusetts—Boston

MORE PRAISE FOR
BEST PRACTICES IN STEM EDUCATION

"This STEM publication with chapters prepared by young theoreticians and practitioners of STEM pedagogical knowledge is a seminal work. The diversity of topics for the effective involvement of all youth in the structure of science makes this publication a necessary resource in all schools. This is a very significant contribution to STEM education."

—H. Prentice Baptiste, Regents and Distinguished Professor, New Mexico State University;
President, National Association for Multicultural Education

"STEM teachers, this book is for you. You'll catch glimpses of your future self in these stories. They're not about rocket science—they're about deep commitment to students' thinking and learning."

—Colleen Megowan-Romanowicz, Senior Fellow,
American Modeling Teachers Association

Best Practices
in STEM Education

Educational
PSYCHOLOGY

Critical Pedagogical Perspectives

M. Cathrene Connery and
Greg S. Goodman, *General Editors*

Vol. 27

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Acknowledgments

The editors would like to express our deep gratitude to all the authors who took time from an already busy life to share their best practices with others. In addition, we would like to acknowledge educators who, on a daily basis, strive to enrich the lives of all children without bias, who uphold that responsibility with fervor, and who balance their role as parent, counselor, mentor, and friend each day in the classroom. Those educators go above and beyond the required workday to provide a whole child experience toward the goal of creating a productive populace of lifelong learners. Further, we recognize that it is through equality in education opportunity that we achieve a more fair and just society for all. Every child, regardless of economic status, gender, race, nationality, sexual orientation, religion, etc. comes to us with tremendous gifts and talents. We applaud those educators who seek constant innovation in teaching and learning: unlocking the process of discovery for all.

Foreword

The Teacher's Voice: Notes from the Frontline of Education Reform

"Education is the future." We hear that often because it is central to the knowledge economy and the success of a strong democracy in our ever-more-technical age. When finding ways to improve education, many leaders in the field draw on a plethora of books, studies, and on-line material. What we too seldom hear, however, is the teacher's voice.

Now a group of science, technology, engineering, and math (STEM) teachers have taken a big step forward: putting the teacher's voice on center stage. The essays in *Best Practices in STEM Education* are written by participants in the Albert Einstein Distinguished Educator Fellowship Program. Developed and supported by the Department of Energy, the Einstein Program brings outstanding K–12 STEM teachers from around the country to Washington, D.C., where they work for 1 and sometimes 2 years. The teachers serve in technical agencies including the Department of Energy, National Science Foundation, National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA). Some work in congressional offices or on congressional committees whose members can and have drawn on their experience to help draft legislation, and others have been placed at the U.S. Department of Education.

Over the past several years, the Program on America and the Global Economy of the Woodrow Wilson International Center for Scholars has held a number of events with the Einstein Fellows, who, in addition to being outstanding teachers, have all reflected on past efforts in order to help define new directions for school reform. In short, they are system thinkers about education as well as experienced educators themselves. In this book, Einstein Fellows have come together to share their thinking and insights on best practices in STEM teaching and on how to continue to hone the skills of teachers.

Several prominent themes run through the chapters. Many stress the importance of project-based learning. There is a parallel emphasis on increasing student engagement through the active solving of real-world problems. They preach the same philosophy when it comes to afterschool education opportunities: when classroom structures confine learning, afterschool programs can increase motivation and access. Some of the themes focus on honing a teacher's skills through summer sessions in a lab where science practices are applied, rekindling the spark that led the teacher into a particular STEM field to begin with.

Whether you are an administrator, teacher, or informal educator, there is something for you in *Best Practices in STEM Education*. This book offers tips on implementing project-based learning, enhancing teacher preparation and meaningful professional development, improving communication in the classroom, reaching the most challenging students, increasing female participation in STEM, using language arts to enhance learning, and using science, technology, engineering, and mathematics to improve learning for all students. You will read stories and case studies about students moving from Fs to As, growing food for their school cafeteria, and contributing to professional science through the discovery of asteroids and exploding stars.

The wealth of knowledge in this collection is seemingly endless and as diverse as the authors themselves. It is no surprise that they have received numerous local, state, national, and international awards recognizing them as outstanding STEM master teachers. The authors, too, are unique in that they maintain strong connections to their disciplines outside of education, many of them having explored different careers before coming to teaching. Such experience adds to their ability to think about education as a part of the greater picture of the American economy and American competitiveness.

In the next few years, Congress is expected to turn its attention to renewing the Elementary and Secondary Education Act, the latest version of what is commonly known as the No Child Left Behind Act. The House Science Committee is already thinking about renewing the America Competes Act. Earlier versions of the America Competes Act emphasized investments in physical science and STEM education from elementary to postgraduate levels. As Congress and the Obama administration consider renewing major legislation dealing with education, they will draw on a host of academic specialists, Washington-based think tanks, and leaders within teacher associations. Too often, however, individual teachers with recent classroom experience are absent from the witness lists. In our work on education, and STEM education in particular, we here at the Woodrow Wilson International Center for Scholars have learned a great deal from listening to and talking with the Einstein Fellows. I strongly encourage teachers, those who prepare teachers, school administrators, those who fund school reform, Congress, and the Obama administration to give this publication a thorough review as they work to prepare the next generation of STEM innovators. This collection of essays offers lessons for us all.

Kent H. Hughes, Director
Program on America and the Global Economy
Woodrow Wilson International Center for Scholars
1300 Pennsylvania Ave., NW
Washington, DC 20004–3027
June 2014

Introduction

Between the private sector and government, it is estimated that the United States spends over $400 billion annually on research and development—nearly twice that of its closest competitor, China. Investment in science, technology, engineering, and mathematics (STEM) has been identified as the critical piece necessary for the nation's economy to remain innovative and competitive, one that is crucial to improvements in the quality and longevity of human life. Throughout the 1960s and 1970s, the Space Race and other STEM initiatives brought many into STEM-related careers. Those individuals are nearing retirement age and will soon leave the field. Who will take their place? Who will be the innovators of tomorrow? Are the students we are preparing today ready to meet the current and future STEM challenges facing our planet?

There is immense concern that the United States is falling behind in its competitiveness and ability to meet the global challenges that lie ahead. Compared to students in other countries, U.S. 15-year-olds rank 20th in science, 27th in math, and 17th in reading, as measured by the 2012 Programme for International Student Assessment (PISA). When these same students arrive in our colleges, they struggle there as well. Fewer than 40% of students who enter college majoring in a STEM field complete a STEM degree. In addition, the general public seems to struggle in its understanding of STEM concepts. A recent Pew Research Poll showed that 85% of scientists view the public's lack of scientific knowledge as a major problem, and nearly 50% believe the public has unrealistic expectations of scientists. Even after years of media focus and attention, 35% of Americans do not know that carbon dioxide is a gas linked to rising global temperatures, nearly 50% do not know that stem cells can develop into many different types of cells, and more than 50% do not know that an electron is smaller than an atom. We are indeed a nation at risk.

The call for the creation of a STEM Master Teacher Corps, a team of experienced and highly vetted educators that will lead the charge to improve STEM education, has been sounded. President Barack Obama's FY2014 budget called for the creation of such a corps to be established through the U.S. Department of Education. The authors of *Best Practices in STEM Education: Innovative Approaches from Einstein Fellow Alumni* are part of an elite group of K–12 STEM educators recognized nationally as Albert Einstein Distinguished Educator Fellows. Not unlike the proposed STEM Master Teacher Corps, Einstein Fellows are recognized as some of America's most talented STEM teachers, whose expertise is leveraged by federal agencies to improve STEM education and raise the profile of the STEM teaching profession. Collectively, the authors have more than 600,000 hours of practice teaching STEM. Just as important, Einstein Fellows, while limited in number, have been offering their STEM expertise in Washington, D.C. for over 20 years!

The goal of this publication is to help improve the state of STEM education. As the body of STEM-learning research grows, this volume provides the unique perspective of nationally recognized education professionals who have spent years at the interface between teaching and learning. The chapters that follow are the product of years of practice, mistakes, reflection, and refinement. They provide the experiential pragmatism backed by research so desired by practitioners. Each chapter communicates how its author has implemented a specific STEM practice in the classroom and how the practice might be modified for use in other classrooms, schools, and learning environments. These are stories of success, as well as stories of struggle.

Although the chapter order has been given significant attention, this book may also serve as a reference guide to a variety of STEM education professionals. The chapters may be read in order, or readers may choose to skip around from one topic of interest to the next. From the benefits of interdisciplinary teaching to the role of informal education in the classroom, every topic contributes to building an effective STEM education system. More important, the methods proposed are not only supported by research, but have been tried and proven by educators in a variety of diverse STEM classrooms around the country.

In the event that you have questions about what an author has written, or if you want additional information, please do not hesitate to contact individual authors. In addition, if your school or district seeks professional development to implement practices outlined within this volume, please feel free to contact the editors or authors directly. The Einstein Fellows initiated this publication to serve as a resource for teachers and schools. This volume will be effective only if its pages become worn and tattered.

WHAT'S NEW IN THIS EDITION?

The increased interest in the topic of STEM best practices led to the request for this revised edition by the publisher, Peter Lang, who selected the first edition as their *2014 Book of the Year*. We're grateful to those who've not only praised Einstein Fellows: Best Practices in STEM Education, but who have used it in their teaching practice. We've been excited at the usage across a broad audience. We are especially pleased that the first edition has been translated into Spanish which will lead to an even broader impact.

- The book title has changed in the second edition from *Einstein Fellows: Best Practices in STEM Education* (first edition), to *Best Practices in STEM Education: Innovative Approaches from Einstein Fellow Alumni.*
- Eight new chapters have been added to the original 16 chapters. These additional chapters, representing 11 new authors, provide unique approaches to STEM learning, offering readers further ways to incorporate innovative STEM best practices into their teaching.
- All web links have been updated where necessary.
- Author bios have been updated. Many of the authors have had exceptional experiences since the last edition that are worthy of sharing.
- Nationally-recognized changes to educational terminology have been noted.

ABOUT THE EINSTEIN FELLOWSHIP

Founded in 1990, the Albert Einstein Distinguished Educator Fellowship Program is a paid fellowship for K–12 STEM educators who have demonstrated excellence in teaching and leadership in STEM. The Einstein Fellowship aims to increase understanding, communication, and cooperation between the legislative and executive branches of the government and the STEM education community. This goal is achieved by embedding experienced and highly vetted STEM educators into a variety of federal agencies, which have included the Department of Energy, the National Science Foundation, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Department of Education, as well as in the offices of congressional leaders on Capitol Hill.

The Albert Einstein Distinguished Educator Fellowship Act, authorized by Congress in 1994, gave the Department of Energy (DOE) federal responsibility for the program. Today, the Albert Einstein Distinguished Educator Fellowship Program is managed by the DOE Office of Science's Office of Workforce Development for Teachers and Scientists in collaboration with the sponsoring agencies and the Oak Ridge Institute for Science and Education (ORISE). ORISE is a world class DOE institute designed for a variety of research and scientific workforce endeavors. Teachers interested in applying for the Einstein Fellowship can apply online at http://science.energy.gov/wdts/einstein.

Neither the U.S. Department of Energy or the AEF Program endorse this publication or the ideas expressed in it.

About THE Authors

Dan Carpenter, PhD is an Assistant Professor in STEM Education at Texas Tech University in Lubbock, Texas. Dan earned a BS in Natural Science Education, an MA in Curriculum and Instruction and a PhD in Education, all from the University of Nebraska-Lincoln. He is currently the STEM Education Program Chair and co-chairs one of the largest blended delivery PhD programs in the world. His research interests include inquiry instructional models, school improvement processes, standards-based application in instructional settings, and the development of 21st century skills in K–16 settings. Prior to working at Texas Tech, Dan served as a high school science educator for about 20 years. Dan spent most of his career working in the Midwestern United States on school culture and professional learning community models. The models served both practice and policy on shared leadership structures that promote teacher job-embedded professional development and organizational improvement through teacher-driven data systems. Dan is passionate about providing all students with high quality STEM education. Dan served as an Albert Einstein Distinguished Educator Fellow at the National Science Foundation in the Division of Graduate Education (2005–2006), where he developed program evaluation policy for education programs. (Contact Dan at daniel.carpenter@ttu.edu)

Buffy Cushman-Patz is the founder and School Leader for the School for Examining Essential Questions of Sustainability (SEEQS), a public charter secondary school in Honolulu, Hawai'i. Buffy served her Einstein Fellowship from 2010–2011 as the inaugural fellow in the Office of Legislative and Public Affairs (OLPA) at the National Science Foundation. Following her fellowship year, Buffy completed her EdM in School Leadership at the Harvard Graduate School of Education (2012), with School Development as her concentration. During the program she simultaneously wrote and submitted the charter application for SEEQS and earned her principal's license while serving as a member of the leadership team of Neighborhood House Charter School in Dorchester, Massachusetts. Prior to the fellowship, she taught math and science in public, charter, and independent schools in Hawai'i. Buffy earned an MS in Geology and Geophysics from the University of Hawai'i at Mānoa and a BS in Geology from the University of Florida. In early 2010, Buffy returned to the Galapagos Spreading Center, her MS thesis study area, to serve as a Teacher at Sea, sharing geologic research conducted using the Alvin submersible with students in Hawai'i and around the world. She volunteered with Teachers Without Borders (2008 and 2010), leading math and science workshops for teachers in South Africa. Buffy's exploration of teaching and learning through the lenses of theory, policy, leadership, and through her firsthand experiences as a teacher in both conventional and unconventional settings, guides her work as a School Leader. (Contact Buffy at bjc231@mail.harvard.edu)

Remy Dou, PhD grew up and taught in a richly diverse metropolis. From 2011 to 2013, as an Albert Einstein Distinguished Educator Fellow, Dou worked at the National Science Foundation on projects related to both engagement and diversity in STEM education, including the development of a design and evaluation framework for federal STEM intervention programs. This framework was used by the White House's Committee on STEM Education in the development of a five-year Federal STEM education strategic plan. Currently, he works in academia performing research investigating the affective outcomes of active-learning strategies in STEM education. His focus lies in career decision-making constructs, including self-efficacy, interest and recognition. He has presented on these topics at various organizations, including the National Science Foundation, the American Association for the Advancement of Science, and the National Association for Research in Science Teaching. In addition, he invests some of his time in curriculum development and pre-service STEM teacher training. Prior to becoming an Einstein Fellow, Dou taught high school biology, AP biology, chemistry, and physics. He also led teacher technology workshops and pre-service teacher training. As a former K–12 Science Department Director, he helped transform his school's science "culture" across all grade levels. He has received various awards, grants, and accolades for his work in K–12 education, as well as for his academic research. Remy's many hobbies include writing, both nonfiction and fiction. He is a member of the Society of Children's Book Writers and Illustrators. He also serves as a department editor for *The American Biology Teacher*. (Contact Remy at douremy@gmail.com)

Brenda Gardunia taught high school mathematics in Boise, Idaho, for 22 years, working with at-risk students. She was selected for the NASA Educator Workshop in 2003 and the Fulbright Memorial Fund program in 2006, where she spent three weeks as a guest of the Japanese government, learning about education and culture in Japan. Brenda served as an Albert Einstein Distinguished Educator Fellow at the National Science Foundation, 2010–2012, working on programs that provide research experiences to K–12 teachers and undergraduates. Brenda serves on the Council of Teachers of Mathematics Classroom Resource Committee and is a board member of Idaho Council of Teachers of Mathematics. She is currently on staff at the College of Western Idaho Mathematics Department. Her professional interests are finding ways to increase authentic learning experiences for high school mathematics students and improving teacher preparation programs to include stronger content knowledge for K–12 teachers, especially those who will be teaching elementary and middle school mathematics. Brenda has a Bachelor's degree in Secondary Mathematics Education and a Master's Degree in Curriculum and Instruction with an Endorsement in English Language Learners. (Contact Brenda at brendagardunia@gmail.com)

Melissa George, PhD is CalTeach Internship Coordinator at the University of California, Santa Cruz. As a practicing K–16 teacher-researcher in science education for nearly two decades, she uses empirically validated teaching practices, advocates discovery-based research courses, and sustains partnerships among stakeholders. Her MS (1998) and PhD (2005) in Curriculum and Instruction, Science Education, from Purdue University (IN), were earned under the advisement of the late Sandra K. Abell while teaching middle school in the Lafayette (IN) School Corporation. Following a two-year Einstein Fellowship (2011–2013) at the National Science Foundation (NSF) in the Division of Environmental Biology (DEB), she taught a stewardship-focused zoology course at Lafayette Jefferson High School, an ethnically and socio-economically diverse city school in Lafayette, Indiana. Her work focused on creating sustainable ways to situate, fund, and enhance the learning experiences of her students to best reflect the vision of the *Next Generation Science Standards*. She has several recent publications base on her work with partnerships. The first, in *Bioscience*, evaluates the grant proposals to the NSF's DEB from submission to reporting to analyze the implementation of broader impacts. One contribution to this project was her preparation of the supplemental table entitled "Annotated History of NSF's Broader Impacts Criterion." Melissa also co-authored two chapters in *The Power of Partnerships: A Guide from the NSF GK–12 Program*. (Contact Melissa at mgeorge.efemeritus@gmail.com)

Eduardo Guevara, PhD is a citizen of the United States and Colombia. His focus on improving the academic performance and educational attainment of at-risk students and English language learners led him to design the project- and inquiry-based Student-Centered Sheltered Instructional Approach and Growth (SSIAG) Model, and its accompanying SSIAG Teacher Training Modules, both successfully implemented in a number of public school districts in Texas. Eduardo received his BS in biology from Universidad del Valle in Cali, Colombia, an MS in Fisheries and Allied Cultures from Auburn University (AL), and a PhD from the University of South Carolina. He is certified in Science Composite and Spanish in Texas. His career includes leadership, applied research, and teaching in the British West Indies, Colombia, Mexico, and the United States. Guevara served his Albert Einstein Distinguished Educator Fellowship from 2009 to 2011 in offices on Capitol Hill. His awards and accolades include the Excellence in Science Teaching–Mentoring Award: Trainer of Trainers and Role Model in the Teaching Profession (2010), Outstanding Science Teacher Award from the Houston Independent School District's ASPIRE Program (2007–2008, 2008–2009), a Distinguished Teaching Award for Recognition of Exemplary Performance in Science Teaching by the Cynthia & George Mitchell Foundation (2007), the Excellence in Science Teaching Award and Science Teacher Mentor (2004), and the National Award on Applied Research by the Colombian National Science Foundation (1983). He is an active member of AAAS, NSTA, the Texas Science Teachers Association and the Texas Classroom Teachers Association. (Contact Eduardo at eguesansta08@gmail.com)

Joseph Isaac is a ten-year veteran of science education in the District of Columbia, spending the last eight of those years as Teacher and Department Chair of Biotechnology at McKinley Technology High School, the public school system's STEM-focused school. During his teaching career, Joe has taught Biotechnology, Molecular Biotechnology, Plant Biotechnology, Forensic Science and Advanced Placement Biology, among others. He also served as adjunct faculty at Fortis College in Maryland, where he taught General and

Protein Biotechnology. Joe served as an Albert Einstein Distinguished Educator Fellow from 2012 to 2014 at the National Science Foundation's Division of Molecular and Cellular Biosciences and the Division of Education and Human Resources, during which time he was able to present at several domestic and international conferences on the topics of STEM education in urban school settings and international collaboration in STEM subjects. One of the many highlights of Joe's fellowship experience was participating in NASA's Microgravity Flight experiences with "The Flying Einsteins" in the summer of 2013, during which time they conducted research on "Coacervate Formation in Variable Gravity Conditions." Issac completed his BS in Biology from Howard University (DC), his Master's in Teaching in Secondary Science from Trinity University (TX), and is now pursuing a PhD in Curriculum and Instruction from Texas Tech University's Global PRiSE (Pragmatic Research in Science Education) program. Joe is also currently a science curriculum writer for Planet3, which is developing an interactive learning platform for middle school Earth and Life Science. (Contact Joe at bootneylee2000@gmail.com)

Arundhati Jayarao, PhD is currently Chief Education and Operations Officer with BLUECUBE Aerospace, a start-up established by educators. As a 2009–2011 Albert Einstein Distinguished Educator Fellow, Arundhati was the legislative lead staffer on P-20 STEM and higher education issues at the office of Senator Kirsten E. Gillibrand (D-NY). Jayarao started her career as a theoretical physicist at the Bhabha Atomic Research Center (BARC), a premier national lab in Mumbai, India. She entered the field of education in 2002, teaching physics, AP chemistry, and chemistry to grades 10–12 at Oakcrest, an independent school for girls in Virginia. As a female physicist passionate about motivating girls to pursue STEM careers, she brought into Oakcrest a culture of science learning based on a rich curriculum supplemented by project-based learning and research methods. Within two years, Arundhati was leading the science department as department chair, serving as a role model and teacher to Oakcrest students, as well as a mentor to her departmental colleagues. Arundhati's enthusiasm for teaching is reflected in her many awards, including the Virginia Governor's 2008 Outstanding Educator Award, and the 2007 Coach for Regional Winners of NSTA-Toshiba's Exploravision Competition, and teacher appreciation awards from the American Chemical Society, the American Physical Society, and the American Institute of Aeronautics and Astronautics. Arundhati earned a doctorate in theoretical physics and mathematics from Bhabha Atomic Research Center and University of Mumbai, an

MS in Physics from Hyderabad Central University, India, and a BS in Math, Physics, and Chemistry from Nizam College, India. (Contact Arundhati at arundhati.jayarao@gmail.com)

Leigh Jenkins taught science for 18 years in rural Morgan County, West Virginia. Prior to receiving her teaching certification in biology and general science, she worked as an environmental specialist for a cement corporation in Texas. She taught biology and environmental science for 14 years at Berkeley Springs High School. In 2001, she was chosen as the Eastern Panhandle Conservation Teacher of the Year for bringing environmental awareness into her curriculum. In 2007, Leigh was a scholarship recipient through the Japan Fulbright Memorial Teachers Fund, where she studied Japanese culture and education. In 2009, Leigh and her Advanced Placement Environmental Science students received a $41,000 grant from the State Farm Youth Advisory Board to add solar upgrades to an existing campus greenhouse. In 2010–2011, she served as an Albert Einstein Distinguished Educator Fellow in the Office of Vocational and Adult Education at the U.S. Department of Education, where she assisted with the Sustainability Education Summit: Citizenship and Pathways for a Green Economy. Upon returning to her teaching position, Leigh initiated a sustainability team at her high school which, in 2016, was recognized as a U.S. Green Ribbon School for efforts to reduce environmental impacts, improve health and wellness, and provide environmental education that incorporates STEM learning, civic engagement, and promotes green career pathways. Leigh earned her Master's degree in Curriculum and Instruction from Shepherd University (WVA) and is currently a doctoral candidate at Shenandoah University (VA) in the Administrative Leadership Program. (Contact Leigh at jenkileigh@gmail.com)

April Lanotte is a Senior Instructor/Master Teacher for the University of Colorado at Colorado Springs' UCCSTeach secondary math, science, and engineering education program, and a former secondary science and English teacher with over twenty years of education experience. Her primary university responsibilities include the design and teaching of *Reading in the Content Area*, pre-teacher field supervision, and instruction of other teaching pedagogy courses. April earned a BA in English Literature from La Roche College (PA) and a MA in Curriculum and Instruction in Science Education with a Space Studies emphasis from the University of Colorado at Colorado Springs. In addition to her university duties, April is also an Instructional Designer and provides education support for NASA's Aeronautics Research Mission Directorate. Having grown up in a small, rural community, her education research and specialization has primarily focused on attrition rates of rural students in higher education, literacy and STEM, and bridging the gap between traditionally underserved populations and success in STEM. April served as an Albert Einstein Distinguished Educator Fellow for NASA's Aeronautics Research Mission Directorate from 2011 to 2013, where she helped shape education policy, created lesson materials to support NASA's *Dressing for Altitude* book about the history of pressure suits, oversaw rewrites for NASA's *Museum in a Box* education series, and provided education support for NASA's Space Shuttle requirements. (Contact April at april.lanotte@gmail.com)

Jenay Sharp Leach, PhD is a National Board Certified science teacher who loves to spark her students' curiosity about the natural world. Jenay earned a BS in Physics and General Science/Secondary Education from Grove City College (PA), a Master's degree in Educational Leadership and Administration from the George Washington University (DC), and a PhD in Education from the University of Virginia, where she also worked as a research assistant and supervisor of student teachers. Her research interests include inquiry, teacher professional development, and science for English Learners (ELs). Jenay has spent most of her career in Fairfax County Public Schools (VA), one of the nation's largest and most diverse districts, serving as a physics teacher, elementary science resource teacher, curriculum writer, and K–12 Science Coordinator. She now oversees science for the district as the K–12 Science Coordinator and is passionate about providing all students with equal access to a high quality science education. She served as an Albert Einstein Distinguished Educator Fellow at NASA in the Aeronautics Research Mission Directorate (ARMD) from 2010 to 2011, where she developed science curriculum and education policy. She received the 2011 ARMD Associate Administrator Award for Program and Mission Support. (Contact Jenay at jenaysharpleach@gmail.com)

Carmelina O. Livingston is an elementary educator with expertise in STEM education and pedagogy for K–12 education. In her career, she has focused on interdisciplinary, standards-based, and real-world instruction within formal and informal education settings in Charleston, SC. Some of her typical projects include research-based professional development opportunities for teachers and partnerships with the scientific and business communities for student programs, particularly in the ocean sciences. Livingston contributed to the creation of the Ocean Literacy Scope and Sequence Framework and the *Next Generation Science Standards* as a Critical Stakeholder. Her greatest inspiration was serving as NOAA Educator at Sea and riding in the submersible

2,000 feet under the ocean. She is a strong advocate for experiencing science and technology education early in life. She collaborates with community stakeholders to support STEM literacy and workforce development through events such as STEM festivals, symposiums and media resources. Livingston has a Masters of Education in Special Education/Learning Disabilities from The Citadel (SC) and Master Plus 30 in Science and Technology Education from the College of Charleston (SC). She served her Albert Einstein Distinguished Educator Fellowship at the National Science Foundation in the Directorate of Geosciences in 2011–2012. She's also served on the board of the National Marine Educators Association. Livingston is the recipient of the South Carolina Marine Educator President's Choice and Marine Educator of the Year awards and the Mickelson ExxonMobil Science Teacher recognition. Livingston's joys in life include her family and friends, her love for the ocean, and her disposition to have fun in life! (Contact Carmelina at carmlivingston@gmail.com)

John D. Moore was an Albert Einstein Distinguished Educator Fellow at the National Science Foundation's Directorate for Geosciences from 2009 to 2011. John is a past president of the Satellite Educators Association and chaired the American Meteorological Society's Board of Outreach and Precollege Education (2013–2015). He was the first author and draft committee chair for the AMS Policy Statement on Earth System STEM Education. John is the New Jersey State Coordinator for the Presidential Awards for Excellence in Mathematics and Science Teaching (PAEMST) and is the founder, Executive Director and Chairman of the Board for the American Council of STEM Educators. Formerly, he was the developer and instructor of Career and Technical Education (CTE) programs, which included Environmental Science, Geoscience and Remote Sensing, and Geospatial Technologies, at the Burlington County Institute of Technology, a CTE High School in New Jersey. Currently, John is the Director of Earth Observations and the NJ GLOBE and Environmental Discovery Center in New Jersey. (Contact John at mr.moore.john@gmail.com)

Dave Oberbillig teaches general biology and International Baccalaureate Biology at Hellgate High School in Missoula, Montana. Dave earned his BS in Biology from Metropolitan State College in Denver, Colorado. It was here that Dave first experienced science research, earning a first-place research award in the American Chemical Society Colorado Undergraduate Research competition for work on enzyme kinetics. Dave earned a Master's degree in Secondary Education at the University of Montana, which led to his serving as co-principal investigator on a National Science Foundation GK–12 grant at the University of Montana. He has served as a panelist and presenter at the NSF, GK–12 annual meeting and worked on the national planning team for that event. As the first high school educator to serve on the Ecological Society of America Education and Human Resources Committee, Dave helped develop strategies to recruit the next generation of ecologists. Dave served his Albert Einstein Distinguished Educator Fellowship from 2010 to 2012 at the Department of Energy's Office of Science–Workforce Development for Teachers and Scientists. Partnerships serve as an important part of Dave's pedagogy. His work with forest service ecologists and local community naturalists inspired his students to better understand and appreciate the local environment. Dave promotes the benefits of teacher-scientist partnerships at educator conferences. Currently, Dave also works with Garden City Harvest in Missoula to introduce his students to the biology of food production and organic farming. When not in the classroom, Dave can be found in the wilds of Montana and the West. (Contact Dave at daves.soccerstop@gmail.com)

Paulo A. Oemig, PhD has taught science in the Las Cruces Public School District in New Mexico for the past ten years. He studied chemistry in Argentina at the National School of Technical Education No. 1. His research thesis involved optimization processes in the production of lactic cultures. At the University of Utah in Salt Lake City (SLC), he completed studies in physical anthropology. While in SLC, Paulo worked for five years at an environmental laboratory. He also studied behavior ecology at Cambridge University in England. Looking to bridge physical and cultural anthropology brought Paulo to New Mexico State University (NMSU) in Las Cruces where he completed his Master's degree in Cultural Anthropology. Paulo is interested in the anthropology of science education with an emphasis in bilingual education and social justice. As an Albert Einstein Distinguished Educator Fellow (2012–2013) at NASA Goddard Space Flight Center and NASA Headquarters, Oemig became involved in several projects while reviewing and researching NASA's Education Portfolio and its New Lines of Business. In this fellowship role, he focused on designing professional development for pre-service and in-service teachers that is both comprehensive in its specificity and self-sustaining. He has presented numerous papers across the country and abroad. In 2012, Paulo was recognized with the Las Cruces Public Schools Teacher of the Year and the New Mexico Golden Apple Excellence in Teaching awards. In December, 2016, Paulo earned his PhD in Curriculum and Instruction with an emphasis in Science and Bilingual Education from NMSU. (Contact Paulo at poemig@gmail.com)

Bernadine Okoro taught science in Washington, DC public schools for twelve years. A trained chemical engineer, Bernadine has worked for Bethlehem Steel, Perfecseal, the U.S. Patent & Trademark Office, and BioCore Medical Technologies. Bernadine obtained both her Master's in Communications, Producing Film & Video, and her Master's in Teaching from American University (DC). In 2008, Bernadine worked with the National Institutes of Health, National Library of Medicine, where she collaborated with a team of teachers, college freshmen, and high school seniors to produce a YouTube video promoting the agency's "MedLine Plus" medical database to middle and high school audiences. In 2009, as a National Endowment for the Humanities (NEH) Scholar, she joined other teachers from across the United States in traveling to coastal New England in search of the inspiration and origins of Winslow Homer's paintings for a unique discovery about maritime history in the nineteenth- and early twentieth-centuries. In 2010–2011, she served as an Albert Einstein Distinguished Educator Fellow at the National Science Foundation in the Directorate of Engineering. Bernadine was one of the writers for the *Next Generation Science Standards* (NGSS) in engineering and physical science. Bernadine is passionate about finding ways to merge engineering, science, and the arts. Her 2009 novel, *Peculiar Treasures*, set in Washington, D.C., spins a dramatic tale about relationships. As a 2012 D.C. Humanities Council Community Heritage grant recipient, she produced *Preserving Trinidad*, a documentary about the history of the Trinidad neighborhood. Bernadine currently serves as a STEM Learning Consultant, creating professional development videos for science educators. (Contact Bernadine at Bernadine.okoro75@gmail.com)

Jean Pennycook served her multi-cultural, multi-lingual urban school district in Fresno, California, for over 20 years as a secondary science teacher providing quality classroom experiences in the sciences. Jean passionately encouraged her students to pursue careers in the STEM fields as well as promoted the next generation as life-long learners and scientifically literate adults. In 1992, Jean took her teaching overseas to the American International School of Florence, Italy, where she was challenged to provide science education across all the disciplines to students speaking several different languages. This experience provided a lifelong sensitivity to students with limited English proficiency. Jean's enthusiasm for teaching is reflected in her many awards and accomplishments as an educator, including: NASA teacher grants, Sierra Club Environmental

Educator of the Year, NSF Teachers Experiencing Antarctica grant, and district- and state-level committees and boards. Jean has been nationally recognized as she translates and repackages the science research of Antarctica for classrooms around the world. She makes the excitement of discovery available to all through an interactive website as she provides a virtual field trip to that extraordinary continent and the Adélie penguin breeding colony on Ross Island. In 2010–2012, Jean brought her dedication to quality education to the National Science Foundation as an Albert Einstein Distinguished Educator Fellow, working to make a difference in our education system. Jean holds a BS degree in Wildlife Fisheries Biology from the University of California, Davis, and a MS in Education and Curriculum from California State University, Fresno. (Contact Jean at jean.pennycook@gmail.com)

Erin Peters-Burton, PhD is a National Board Certified science and mathematics teacher who helps students who feel excluded in science become more aware of the scientific enterprise and the ways scientific knowledge is generated. Erin has a BS in Physics from the University of Illinois, a MEd in Educational Psychology and Social Foundations of Education from the University of Virginia, and a PhD from George Mason University (VA) in Educational Psychology and Education Research Methods. Her research focuses on interventions that explicitly teach science as a way of knowing, using metacognitive prompts set in a self-regulatory delivery system and teacher implementation of such methods, as well as explorations of the decisions students make when engaged in scientific inquiry and open-ended questioning and how these decisions compare to decisions that scientists make in their work. Erin served as an Einstein Fellow in the NASA Exploration Systems Mission Directorate from 2006–2007. During this time, she developed national engineering education strategic plans and reviewed engineering education policy. Her experience as a professional engineer, prior to her teaching career, helped frame contributions she made while serving on the K–12 National Engineering Education Standards Committee. Erin's experience as an Einstein Fellow has helped inform her work as an education researcher at George Mason University, where she is the Donna R. and David E. Sterling Endowed Professor in Science Education. She is currently pursuing research projects in the nexus of the nature of science, student learning, science teacher pedagogical content knowledge, and educational psychology. (Contact Erin at erin.peters1@gmail.com)

Terrie Rust, Distinguished Technology Educator (DTE) taught technology education, engineering education, and career exploration to middle school students for 18 years in Peoria, Arizona. Terrie built a program at her school that received Program Excellence and Teacher Excellence Awards from the International Technology and Engineering Educators Association (ITEEA). She developed a passion for integrative STEM education. Her concern for gender equity in STEM fields led to the creation of a Girls Exploring Technology (GET) club at her school. She was recognized with the Visible Difference Award from the Association of Career and Technical Education of Arizona (ACTEaz) for her efforts. Terrie received BA and MA degrees from San Jose State University (CA), a MEd degree from Northern Arizona University, and an EdS degree from Northcentral University (CA). Terrie served as a 2010–2011 Albert Einstein Distinguished Educator Fellow at the National Science Foundation, in the Directorate for Education and Human Resources, Lifelong Learning Cluster, during which time she created a database of the education outreach offerings of the 101 NSF National Research Centers and eighteen NSF Large Facilities, allowing the data to be shared by all NSF Directorates. In 2010, Terrie was awarded the Distinguished Technology Educator citation from ITEEA in recognition of her contributions to the field of technology education. After her fellowship, Terrie served for two years as the Director of Academics for Creya Learning in Hyderabad, India and has since worked directly with educators in China, Malaysia, The Netherlands and Saudi Arabia. (Contact Terrie at terrierust@gmail.com)

John F. Trey Smith began teaching middle school science and social studies in Philadelphia in 2007. He later taught biology and chemistry and chaired the science department at an all-boys high school where he established U.S. FIRST and SeaPerch robotics teams, monthly speaker and field trip programs, and a junior chapter of the National Society of Black Engineers (NSBE). With the NSBE junior chapter and educators from The Math Forum, Trey co-founded the Philadelphia Engineering and Math Challenge. He also taught graduate courses as an adjunct instructor in the University of Pennsylvania's Graduate School of Education. A teacher-consultant with the Philadelphia Writing Project, Trey partnered on a grant with the Academy of Natural Sciences at Drexel University to create an afterschool program for middle school youth to create science-themed games. In 2012, the Philadelphia Chapter of the Pennsylvania Society of Professional Engineers named him Philadelphia's Outstanding Science Teacher. He is a past Philadelphia Social Innovations Lab Fellow and a 2014 National Liberty Museum Teacher as Hero award recipient. Trey served as an Albert Einstein Distinguished Educator Fellow in the office of Senator Kirsten Gillibrand (D-NY) in 2014–2015. He helped secure bipartisan co-sponsors for Senator

Gillibrand's computer science, engineering, and career and technical education amendments included in the *Every Student Succeeds Act of 2015*. The following year, Trey was the Science Teacher-in-Residence at the Library of Congress and explored the use of historical primary sources in science classrooms. Trey is now a Learning Sciences PhD student at Northwestern University (IL). (Contact Trey at jftreysmith@gmail.com)

Nancy Spillane, EdD feels privileged to have spent most of her life helping others become excited about STEM. She taught chemistry in high school, life and physical sciences in middle school, physics labs and science methods courses at the university level, and has been a volunteer science teacher for elementary school. She also served as a science teacher and science department chair at the Williams School, a 7th–12th grade independent day school in New London, Connecticut. Her passion for education led her to a 2-year position (2009–2011) as the voice of the classroom teacher as an Albert Einstein Distinguished Educator Fellow at the National Science Foundation. Facilitated by this experience, Spillane earned her doctorate in Curriculum and Instruction as a George Washington University (DC) Presidential Merit Fellow. Her research focused on STEM teachers at highly-successful STEM-focused high schools. She worked tirelessly to communicate across university silos to engage in interdisciplinary research and collaboration. Nancy is now an Associate Clinical Professor in the WVUTeach Program at West Virginia University where she helps students majoring in STEM fields explore teaching as a possible career path. In addition to her EdD from George Washington University, Spillane earned a Bachelor's degree in Chemistry and a MEd in Teacher Education from the University of Vermont. She was recognized for teacher excellence through The Brian J. Carey Award and was awarded grants and scholarships from the Ford Foundation, Pfizer Inc., and the Siemens Foundation. (Contact Nancy at nks1300@gmail.com)

Florentia Spires is currently a STEM Instructional Leader in Prince George's County School System (MD), where she attended high school. Previously, she worked in Washington, DC at Howard University Middle School of Math and Science, where she developed a STEM curriculum, and at Edmund Burke College Preparatory School as a science teacher. Her teaching career began as a US Peace Corps Volunteer serving in Southern Africa. This global experience catapulted her love for science teaching. For two years, Florentia also served as a Peace Corps trainer for incoming new volunteers. Her teaching spans more than two decades. Florentia earned a BA and BS in Biology at Bennett College for Women (NC) and a MEd in Curriculum and Instruction at Loyola University (MD). She earned a NASA Endeavor Program STEM Certificate with Columbia University (NY). Florentia is currently pursuing her PhD at Texas Tech University in Lubbock, Texas. She served as an Albert Einstein Distinguished Educator Fellow in 2013–2014 at the National Science Foundation expanding computing in education. Florentia has been recognized with numerous prestigious awards. President Barack Obama honored her at the White House where she received the Presidential Award for Excellence in Mathematics and Science Teaching (2013–2014). She was also named a NASA Endeavor Fellow in 2011–2012 and a Helen DeVitt Fellow in 2013–2014. Florentia was selected in 2013–2014 as a NASA Master Teacher and most recently was selected to serve on the National Physics Master Teacher Leader Taskforce (2016). (Contact Florentia at florentia.spires@gmail.com)

Tim Spuck, EdD currently serves as the Director of Education and Public Engagement at Associated Universities Inc. (AUI) and has been a leader in STEM education for more than 20 years. He has developed and led a range of programs focusing on astronomy and STEM education. He currently serves as Principal Investigator (PI) on four NSF-supported projects including: the Chile-US Astronomy Education Outreach Summit, Astronomy in Chile Educator Ambassadors Program (ACEAP), Innovators Developing Accessible Tools for Astronomy (IDATA), and the 2018 National Society of Black Physicists National Meeting award. Prior to his role with AUI, Tim served as an Albert Einstein Distinguished Educator Fellow at the National Science Foundation in the Division of Graduate Education (2010–2012), taught astronomy and earth sciences at the high school and college levels for more than 20 years, and served as K–12 Science Coordinator for Oil City Schools in Pennsylvania. He has led numerous professional development programs throughout the United States and abroad, and has developed a variety of astronomy experiences for learners of all ages. While teaching, his students regularly engaged in authentic astronomy research, and have been recognized throughout the scientific community for their discoveries. Tim's own contributions have been recognized through the American Institute of Aeronautics & Astronautics Educator Achievement Award, Tandy Technology Scholars Award, the Pennsylvania Christa McAuliffe Fellowship, PolarTREC, NITARP, TLRBSE, and numerous other STEM education awards and programs. He earned his Master's degree in Science Education from Clarion University (PA) and an EdD in Curriculum and Instruction from West Virginia University. (Contact Tim at timspuck@gmail.com)

June Teisan, PhD is a National Board Certified teacher who brought science to life for her 7th graders in Harper Woods Schools on Detroit's northeast border for 27 years, and now designs and delivers vibrant learning experiences for students and fellow teachers across the country. June served as Michigan Teacher of the Year (2007–2008) and was one of four finalists for 2008 National Teacher of the Year. She received the Presidential Award for Excellence in Mathematics and Science Teaching in 2005 and was one of five inductees into the National Teacher Hall of Fame in 2016. She holds a BA in Biological Sciences, a MA in Teaching Biological Sciences, an EdS in Educational Leadership, and a PhD in Educational Leadership. She was an Albert Einstein Distinguished Educator Fellow in 2014–2015, placed in the Office of Education at the National Oceanic and Atmospheric Administration, where she continued to work as an Education Outreach and Program Specialist after her Einstein Fellowship. June is passionately committed to widening opportunities for under-represented and under-served students in the STEM fields, and is committed to supporting urban and early-career educators with rich, innovative professional development. (Contact June at jLteisan@gmail.com)

Rebecca Vieyra is the K–12 Program Manager at the American Association of Physics Teachers outside of Washington, DC. She taught high school physics, physical science, and engineering at public schools in both central and northern Illinois for seven years. Rebecca earned a BS in Physics Education from Illinois State University in 2007 and a MAS in Science Education from the Illinois Institute of Technology in 2010. In 2011, she became National Board Certified (AYA/Science-Physics), and in 2013 she was honored by President Obama with the Presidential Award for Excellence in Mathematics and Science Teaching. Rebecca served as an Albert Einstein Distinguished Educator Fellow in the Aeronautics Research Mission Directorate at NASA Headquarters during 2014–2015. During her fellowship, she co-authored, along with her father, a three-volume book, *Teaching High School Physics* with an emphasis on physics teacher preparation and professional development. Rebecca also started an educational technology company with her husband, Vieyra Software, to develop free mobile sensor apps for STEM Education. Vieyra Software is the producer of Physics Toolbox apps, used by over half a million students, teachers, and researchers in every country where Google Play is available. Her work in physics education, research-based teaching practices, and educational technology has led to her being invited as a guest speaker in Mexico, Italy and Indonesia. Rebecca currently resides with her family near Washington, DC. (Contact Rebecca at rebecca.elizabeth.vieyra@gmail.com)

Sue Whitsett knew in third grade that she wanted to be a teacher, and she followed her dream. Sue began her career teaching grades 7–8 in a Catholic school in Oshkosh, Wisconsin, for 5 years with a BS degree in Secondary Education (major in biology and minor in chemistry). She continued her own education and obtained her MS in Curriculum and Supervision with a science emphasis. Sue returned to the high school classroom to teach all levels of biology for 25 years, the last 24 in Fond du Lac, Wisconsin. While in Fond du Lac, Sue received awards for Teacher of the Year, was a state finalist for the Presidential Award for Excellence in Mathematics and Science Teaching three times, and became a National Board Certified Teacher. Sue was awarded a NSTA Toyota TAPESTRY grant, which allowed her students to "do science" by researching pond ecology on newly formed retention ponds. Sue's love of research led her to participate for six summers in Research Experiences for Teachers programs at the University of Rochester (NY) and the University of Wisconsin-Madison, which allowed her to bring authentic scientific research into her classroom. Sue was selected as an Einstein Fellow in 2009 and served her fellowship for two years at the National Science Foundation in the Directorate for Biological Sciences, Division of Molecular and Cellular Biosciences. Sue continues to promote science education through her work at the National Science Teachers Association as the NSTA Director of Army Educational Outreach Programs. (Contact Sue at whitsetts54935@gmail.com)

CHAPTER ONE

The Search FOR Interdisciplinarity

Moving from Biology, Chemistry, and Physics to STEM and Beyond

NANCY SPILLANE

INTRODUCTION

Since the Industrial Revolution, worldwide development and use of technology has been advancing at an exponential rate. The human capital required to adequately meet the needs of this changing infrastructure involve greater understanding and capacity in STEM (science, technology, engineering, and mathematics). In a recent address, President Barack Obama stated, "We must educate our children to compete in an age where knowledge is capital, and the marketplace is global" (President's Council of Advisors [PCAST], 2012b, p. v). To meet increasing needs for a population that is literate in STEM, capable of informed decision making, and adequately prepared for the workforce, our educational system must change. Global problems such as climate change, food security, healthcare, and energy are going to require interdisciplinary solutions. In order for our students to be prepared to participate in these solutions, we must help them to see the connections between the subject matter they learn in school and the broader applications in society.

There are movements at all levels of education that address ideas of interdisciplinary learning and application of knowledge (National Research Council, 2012; Sanders, 2012). National initiatives support interdisciplinary research (*Introduction to interdisciplinary research*, 2013). Attention is given to the need for twenty-first-century skills that focus on "the 4Cs," including critical thinking and problem solving, communication, collaboration, and creativity and innovation (*Framework for 21st century learning*, 2013). On the state and local levels, funding has enabled the design and implementation of STEM-focused schools (T-STEM Network, 2004–2010; NC STEM Learning Network, n.d.) and project-based learning models (New Tech Network, 2013). Within schools, administrative support for collaboration among interdisciplinary teams of educators has provided space and time for cooperation at the most local levels.

Change of this kind, however, is not occurring in every school and in every district. In some schools, the disciplinary boundaries are seemingly impermeable and impenetrable. There is resistance at the administrative level, and an interdisciplinary philosophy is not supported. Even in cases such as these, however, a single teacher can make a difference. Working from inside the classroom and reaching out to the department and beyond, interdisciplinary inroads can be made and can be effective. As classroom teachers, connecting across disciplinary lines allows each one of us to think more broadly about our subject's place within the universe of knowledge in exciting and transformative ways while also advantaging our students, helping them to scaffold their learning across separate classrooms, and situating content knowledge into the larger world.

Who Am I?

I entered the teaching profession as a science content area major in college and was very much embedded in the world of science. I started teaching in my classroom the way I was taught, primarily through lecture and lab. I improved as a teacher through trial and error, a little bit of informal coaching, some professional development, and regular response to student evaluations, concerns, and recommendations. My undergraduate science learning experiences were primarily theoretical—a consequence of the post-Sputnik-era philosophies of teaching—and my own coursework did not emphasize practical applications of the science content. However, through continuing education and select professional development after I started teaching, I slowly came to understand how all of the sciences interrelated. I learned how having this knowledge, as well as an even broader understanding of how science connected to subjects beyond the sciences, enabled me to expand my learning in ways I had never attempted. It only made sense that if this interdisciplinary understanding helped me, it would also help to contextualize science for my students. What could I do within my own chemistry classroom to help give this scientific content knowledge a solid place in my students' academic lives and their experiences beyond the classroom?

What Is STEM?

In the mid-1990s, under the acronym "SMET" (science, mathematics, engineering, and technology), seeds for connections among these four disciplines were sown through funding initiatives from the National Science Foundation. Later, in the 2000s, the acronym changed to the more familiar "STEM" that is used today. Since the beginning, there has been increasing research and education focused on how learning and knowledge in one of these disciplines supports gains in each of the others. Beyond just an acronym representing four independent subject areas, STEM has been defined as

> an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy. (Tsupros, Kohler, & Hallinen, 2009, slide #10)

In this definition, we see a focus not only on the acronym's four content areas, but also on the ideas that tie them to each other and how their interrelationship results in valuable new knowledge, the grand hope being that through learning, integrating, and applying the STEM disciplines to the problems of the world, we can find solutions.

What Is Meant by "Interdisciplinary"?

Many terms have been used to describe learning that spans more than one subject area. Interdisciplinary, multi-disciplinary, cross-disciplinary, integrated or fused curriculum, and core content are among them. These are used to talk about crossing the borders between academic subject areas and allowing or enabling content to infuse, merge, blend, or support. Although some research literature intends specific meaning through the use of one or more of the terms listed, they have all been used interchangeably.

What Are the Conversations in Science Education?

In September 2010, the President's Council of Advisors on Science and Technology (PCAST), in its report to the president, *Prepare and Inspire: K–12 Education in Science, Technology, Engineering and Mathematics (STEM) for America's Future*, concluded:

> To meet our needs for a STEM-capable citizenry, a STEM-proficient workforce, and future STEM experts, the Nation must focus on two complementary goals: We must prepare all students, including girls and minorities who are underrepresented in these fields. And we must inspire all students to learn STEM and, in the process, motivate many of them to pursue STEM careers. (PCAST, 2012b, p. 11)

In February 2012, PCAST's report on higher education, *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics* (2012a), included the statistic that "fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree" (p. 1) and cited the following as reasons: uninspiring introductory-level classes, difficulty in math with little assistance available, and, in particular, "members of groups underrepresented in STEM fields, cite[d] an unwelcoming atmosphere from faculty in STEM courses" (PCAST, 2012a, p. 1). Research data show that "evidence-based teaching methods are more effective in reaching all students—especially the 'underrepresented majority'—the women and members of minority groups" who, while representing 70% of all college students, only make up approximately 45% of all STEM graduates (PCAST 2012a, p. 1). Clearly, the STEM education field needs to do a better job of educating all members of society—particularly those populations formerly neglected by the STEM world—if we are going to be adequately prepared to meet future global workforce and intellectual needs.

BACKGROUND

What Is Already Happening in K–12 Science Education?

There is research evidence to support the connecting of student learning across subject areas to students' prior knowledge and to their lives beyond the classroom. Bransford, Brown, and Cocking's *How People Learn* (2000) describes learning requiring a "network of connections" (p. 129) among the objectives in a lesson, in addition to the relevant uses of new knowledge to be gained. In *The Liberal Art of Science: Agenda for Action, a 1990 report by the American Association for the Advancement of Science*, the importance of integrating science into the human experience was highlighted with recommendations to incorporate "philosophy, values and methods of science into instruction in the natural sciences" (p. viii). These recommendations were further reinforced by A. Truman Schwartz in a speech where he lamented the vast divide between the sciences and the humanities and suggested that concerns of scientific illiteracy could be better addressed by working to actively embed science within "the liberal arts tradition" (Schwartz, 2007). More recently, the National Research Council (NRC) released two documents that pay particular attention to interdisciplinary connections. *A Framework for K–12 Science Education* (hereafter referred to as the *Framework*) introduces the ideas of "cross-cutting concepts" (NRC, 2012, p. 83) and "practices of science" (p. 41) that represent knowledge and understanding permeating and connecting all sciences with technology, engineering, and mathematics as important areas of focus in writing new K–12 science standards. And moving beyond the integration across STEM fields alone, the NRC's *Facilitating Interdisciplinary Research* (2005) suggests that "interdisciplinary studies could help to increase the coherence of students' learning experience across disciplines … and could facilitate an understanding of how to promote the transfer of knowledge from one setting to another" (p. 169).

We are hearing the calls for a STEM-literate citizenry and are made aware that specific populations are glaringly absent from our current STEM workforce. STEM literacy requires interdisciplinary learning. Integrating STEM into the broader array of high school subjects and applying this knowledge to problems beyond the classroom makes STEM knowledge more accessible to all students. It is sensible that we, as STEM classroom teachers, do our part to make these connections explicit for our students.

Current Ideas on Interdisciplinary Learning

The *Framework* represents the dedicated work of the Committee on a Conceptual Framework for New K–12 Science Education Standards on which the *Next Generation Science Standards* (2013) have been constructed. The *Framework* focuses on three key aspects of science education: (1) core ideas, (2) science and engineering practices, and (3) crosscutting concepts.

Historically, core ideas have been the primary focus of any secondary science discipline generally representing the science content. Increasingly, we have seen the *process* or *practice of science* articulated as intentional and foundational to all sciences, including but not limited to concepts such as the scientific method, inquiry method, nature of science, hands-on science, and active learning. In the *Framework*, these ideas are expanded and more clearly articulated under the umbrella of science and engineering practices, but it is in the crosscutting concepts that targeted attention and emphasis are given to those ideas that span the breadth of the disciplinary subject areas. In particular, there is an effort to focus on common themes and vocabulary that can be reinforced throughout science learning in the K–12 continuum.

On Crosscutting Concepts

In the *Framework,* crosscutting concepts are identified as those that "transcend disciplinary boundaries and prove fruitful in explanation in theory, in observation and in design" (2013, p. 83). They are foundational ideas that take root in kindergarten (or before), extend beyond high school, and permeate knowledge and understanding in science, engineering, and technology. The use of common language and reinforcement of the seven crosscutting concepts (i.e., patterns, cause and effect, scale proportion and quantity, system and system models, energy and matter, structure and function, and stability and change) provide a link to all areas of science: life sciences, physical sciences, earth and space sciences, and the fields of engineering and technology. The *Framework* highlights how these concepts flow through and among the STEM disciplines to provide coherence of thought and language in the establishment of scientific understanding throughout the K–12 continuum. Of significant importance is the concern that these crosscutting concepts are not stand-alone ideas, but rather provide common themes that connect all STEM content areas. They should not be taught in isolation from the applicable core content in each subject specific area.

A Brief History of Interdisciplinary Learning

Thoughts about the importance of interconnectedness are not new in science education or in education in general. Even in their earliest efforts to define the American curriculum, educators sought to divide learning content into manageable chunks, and then find ways to link the chunks together (Kliebard, 2004). These chunks have most often been the subject areas we are accustomed to (e.g., science, history, language arts, etc.). The links between these subject areas have taken a variety of forms, including projects, activities, themes, integrated content, and cross-disciplinary learning. This connectedness is supported by education research literature as a way to provide *scaffolding* for future learning, to aid *transfer* of knowledge and skills, and to demonstrate to students the *applicability* of their learning in the real world.

Scaffolding

Learning that has been provided a structure that supports its acquisition is considered to be "scaffolded." In the early development of the language arts curriculum, there were efforts to have English serve as a foundation for learning in social studies, science, and the arts with the idea that commonalities among these subjects could provide a support structure for student learning (Kliebard, 2004). Other approaches, termed *core*, *broad fields*, and *needs-based* curricula, searched for common ground or common themes among diverse subjects to enable structural support. The more recent curriculum theorists Wiggins and McTighe, authors of *Understanding by Design* (2005), which focuses on utilizing the desired educational outcomes and working backward to design curriculum, highlight a continuing search for connections within and among subject matter. Through their *big ideas*, they describe the "umbrella concepts" or "conceptual velcro—that help the facts and skills stick together" (2005, pp. 66, 67), and in ferreting out the big ideas, *essential questions* are formulated that "often jump curricular boundaries" (2005,

p. 281). Education theorists point to the value of making connections between content in one subject and content in another, with the idea that the commonalities among them will provide an easier, quicker, or more sustained level of learning (Figure 1.1).

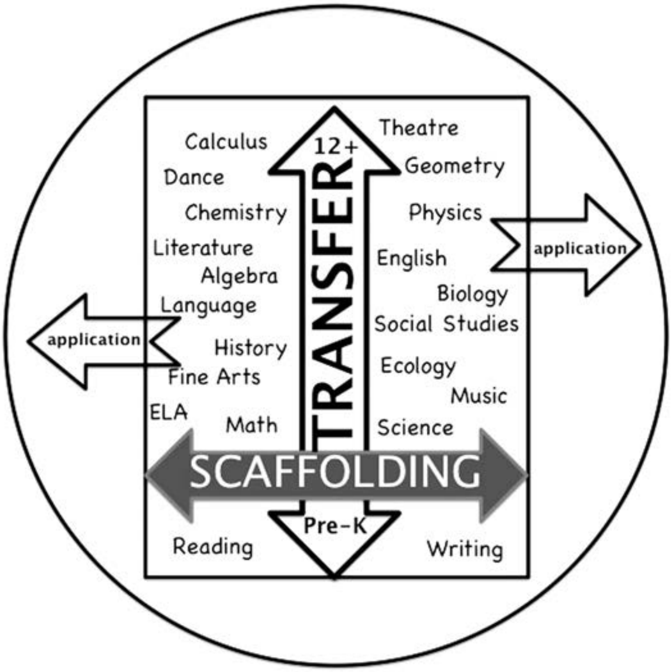

Figure 1.1. Scaffolding, Transfer, and Application.
(Source: Author.)

Transfer

Loosely speaking, transfer relates to the facilitation of new learning by previous learning. The early *mental disciplinarians*, those who believed that training the "faculties" would enable future learning by developing the "powers of the mind" (Kliebard, 2004, p. 4), felt that a curriculum of very specific coursework would lead to the mental development necessary to facilitate the acquisition of new knowledge. In the mid-twentieth century, Ralph Tyler, an American educator and author of research on developing and evaluating curriculum, highlighted "evidence that learnings which are consistent with each other, which are in that sense integrated and coherent, reinforce each other" (Tyler, 1950, p. 41) and are advantageous in student learning. Jerome Bruner, an American cognitive psychologist, suggested that the "structure of a subject" (Bruner, 1960, p. 7) provided students with interrelationships among content that could increase a student's intuitive thinking.

He proposed a spiral curriculum that clearly articulated the advantages of providing a young child with foundational conceptual knowledge early and reinforcing it through subsequent years of education. Transfer, according to Wiggins and McTighe (2005) is the ultimate evidence of understanding, representing application of previously learned knowledge, skills, and ideas to novel experiences and problems, whether they are classroom situations or something in the child's life outside of school.

Each theorist articulates the idea of transfer in a different way, but fundamental is the thought that there is learning that lays a foundation for the construction of subsequent learning. Theorists might argue about what exactly that foundational learning looks like, the best way to orchestrate its study in the school, or the absolute outcome and its measure, but they all appear to agree that aspects of prior learning enable learning that follows.

Applicability

Real world applications have been used either to directly teach subject area content, to reinforce classroom teaching, or to represent the ultimate goal of an American education. John Dewey, a leader in educational reform in the early to mid-1900s, advocated the use of *social occupations* to tie activities in school to those in everyday life in order to provide children with a context into which to fit learning (Kliebard, 2004). Both Dewey and William Heard Kilpatrick, an education philosopher who followed in Dewey's footsteps, thought learning could be made more interesting and applicable through *project organization*, also known as *activity curriculum* or *experience curriculum*. This type of education was inspired by Rufus W. Stimson, who conceived the "home project," an activity designed to help vocational education students in "applying the teachings of the school in their home farm work" (Stimson; cited in Kliebard, 2004, p. 131). During the early 1900s, when much of the motivation for a public education was directed toward efficiency, the applicability of an education was pushed almost to an extreme. At this time, the primary outcome of curriculum was social utility, and classrooms focused almost exclusively on training students for specific jobs in mills and industry. Later, in the mid-1900s, Tyler (1950) suggested that curriculum design should facilitate students' practice of what they learn in school.

All of these examples are broad-brush connections to applicability, but each theorist makes the case that curricular connections between classroom learning and the world at large are important. Students learn from their environments and can build on that knowledge in the classroom; in turn, they can take knowledge from the classroom and apply it to their real lives.

Since the beginnings of the struggle to determine the content of the American curriculum, there have been efforts to divide content and efforts to synthesize it.

While it is likely that no perfect segregation of concepts and no ideal organizational route through them exists, the easy way is the one that has dominated: subject-area content taught in isolation from other courses. This approach requires a teacher to be prepared in only one discipline, allows a classroom full of children to be treated as a single unit, and requires only minimal communication between these components. Since theorists have been recording their ideas about curriculum, the advantages and processes of teaching across, between, and among subject lines have been studied, espoused, championed, and supported by research. Connections can be made from year to year (transfer), from course to course within a single year of study (scaffolding), and from the course out into the student's world at large (application). These three facets of learning are not isolated from each other; they intermingle and constructively interfere in the grand search for understanding.

Wiggins and McTighe speak of *understanding* as the ability to "perform effectively with knowledge" (2005, p. 82), and they identify six facets that make up this understanding: (1) can explain, (2) can interpret, (3) can apply, (4) have perspective, (5) can empathize, and (6) have self-knowledge (2005, p. 84). The crosscutting concepts outlined in the *Framework* assist in enabling the first three facets of Wiggins and McTighe's *understanding*: can explain, can interpret, and can apply.

Vertical alignment (i.e., the flow of specific learning throughout the K–12 continuum) and curriculum spiraling (i.e., revisiting concepts at increasingly higher levels of learning) provide structure and enable transfer, assisting the student in *explaining* through the generalization and articulation of recurring principles. Conscious, intentional, horizontal alignment (i.e., connections across concurrently learned content) scaffolds learning between different subjects, providing new scientific ideas with a context in history, literature, or art. This helps the student *interpret* the new data to establish its significance and relevance. Correlations of course content to students' experiences beyond the classroom walls help students *apply* and use the theory in practice, and to identify and clarify the relevance of learning. Through all of these connections, the crosscutting concepts are what link and reinforce. In Jerome Bruner's words, when speaking of student learning, "the more fundamental or basic is the idea he has learned, almost by definition, the greater will be its breadth of applicability to new problems" (1960, p. 18). We see crosscutting concepts again in Wiggins and McTighe's (2005) *essential questions*. They are the glue that holds subject area knowledge together and the understanding that enables transfer to subsequent learning and to the problems our students will be responsible for solving in the world they encounter when they leave the classroom.

John Dewey and Interdisciplinary Learning

John Dewey formulated many ideas about science teaching and learning that still resonate in today's climate of STEM integration. He spoke to the need for connections between student learning, both in and out of school, and between subject area learning and its application to students' lives and experiences. Dewey felt that students must be actively engaged in their learning, proposing that "methods of instruction and administration be modified to allow and to secure direct and continuous occupations with things" (1916, p. 38) if the learning is to be significant. He suggested "that education is not an affair of 'telling' and being told, but an active and constructive process" (Dewey, 1916, p. 38). Dewey also raised concerns about dividing the world into in-school and out-of-school learning, suggesting that "when the schools depart from the educational conditions effective in the out-of-school environment, they necessarily substitute a bookish, and pseudo-intellectual spirit for a social spirit" (1916, p. 46). Making these connections is of utmost importance in enabling students to learn in ways that will help them to be informed, productive citizens in a constantly changing world.

Dewey recognized that there are different ways of thinking in each of the disciplines. To become an expert necessarily requires a narrowing of one's field of study in the pursuit of depth of knowledge in a single discipline. The languages spoken in the unique disciplines become refined in ways that are no longer universal, and it becomes easy to lose track of related fields and how they are interconnected. Dewey spoke to the need for each of us, within our own disciplines, to remember this when we find conflicts in our thinking with other disciplines. We must "discover some more comprehensive point of view from which the divergencies may be brought together, and consistency or continuity of experience recovered" (1916, p. 326).

As educators, we must look for the connections between and among subjects that students take in a single year to better scaffold student learning, to help our students see the ties that bind these subject areas rather than allowing students to assume they are unrelated because terminology is unique. As Dewey says, we must help our students see the "essential unity of method and subject matter; [and] the intrinsic continuity of ends and means" (1916, p. 323). In addition, even though the majority of our students (based on current statistics) will not go on to become scientists, scientific understanding is important. Even in the 1900s, Dewey cited this significance when he stated:

> Since the mass of pupils are never going to become scientific specialists, it is much more important that they should get some insight into what scientific method means than that they should copy at long range and second hand the results which scientific men [sic] have reached. Students will not go so far, perhaps, in the "ground covered," but they will be sure and intelligent as far as they do go. (1916, p. 221)

Given that the majority of students who enter our science classrooms may not go on to study a science, what can we, as science teachers within our own science disciplines, offer them that will increase both their scientific literacy and the likelihood that the scientific knowledge will be both useful and perceived to be of value in their lives?

AUTHOR'S BEST PRACTICES: WHAT DO I DO?

With the above ideas solidly in mind, I would like to describe my own journey in teaching science at the secondary level and consider what I have done to facilitate my own and my students' understanding of the place of chemistry within the full science spectrum. No doubt, my ideas are not unique and others have found their way to a similar end through a different pathway, but my student gains are marked, and the process is worthy of note.

There are two experiences that significantly impacted my teaching. The first was the result of a series of nominally unrelated summer experiences that exposed me to content areas beyond my field of chemistry, and the second was my effort to incorporate a theatrical play into learning in my classroom.

Through the first experience, I found that every time I learned something that was not specifically related to chemistry, I became a better chemistry teacher. Through the second experience, I learned that taking a very different approach to teaching resulted in different effects on different students, sometimes the greatest impacts being on the very students who seemed to be making the least connection with the content in my classroom. I will address these in two separate sections below, even though their respective impacts resulted in similar conclusions and effects on my teaching.

Non-Chemistry Professional Development Experience

After the first few years of my teaching career, I started searching for summer professional development opportunities that would come at no cost to me. There were a multitude of offerings, provided that I was willing to expand my vision of what a summer experience for a chemistry teacher might look like. I stopped seeking out experiences that were targeted specifically for chemistry and discovered others in material science, paleontology, microbiology, summer internships with pharmaceutical companies, experiences that introduced me to the whole of scientific and engineering research and discovery, fuel cell research and design, and countless others. Each time I learned something that did not seem to be targeted specifically to chemistry, my understanding of chemistry's place within the sciences—and more broadly within learning and discovery—expanded in ways I never anticipated. I was better able to help my students understand these connections and better able to help them think about how my course might fit into their future studies and careers. In addition, each of these experiences brought together teachers, scientists, and engineers in learning environments that enabled productive, interdisciplinary conversations about student learning.

Communicating across boundaries

During these multi-disciplinary professional development experiences, educators from a variety of backgrounds engaged in discussions about the different uses of terms in our respective subject areas, as well as the different ways we introduced students to similar ideas and concepts. We found that while we were teaching our students the same concepts, we were not using consistent language to describe similar ideas. Minimally, this enabled me to go back into my classroom and tell students, "When you learn this in biology, it's called ___, and in physics you'll speak of it as ___." I have found that when I do this and make *explicit* these differences, the students can make the connections more easily, and the content is no longer separate and unique from course to course. When I do not, there are often no connections made. The students simply think these concepts and ideas are different and unrelated to each other.

These experiences caused me to constantly search for overlapping ideas and concepts in my students' learning that I could reinforce, troubleshoot, or presage. My students usually come to me having spent a year in biology. When they leave me, they usually go on to physics. I have actively sought to highlight the connections and conflicts between these subject areas to help students see these as part of a larger whole—a continuum of learning—rather than independent and unique ways of viewing the world.

Some Examples

Physical change/chemical change

When I first start talking about physical change, I reference the water cycle. Instead of starting directly with typical chemistry examples, I start with diagrams from biology books, using similar terms, and talking very specifically on the molecular level about how they are related to our lab experiments. When we first learn of chemical change, we use examples from the nitrogen and carbon cycles, as well as photosynthesis and respiration. These are already familiar concepts, and it makes sense to build on this previous knowledge.

Chemical reactions

When introducing chemical reactions, one of my favorite discussions is helping the students "discover" the products and reactants involved in simple respiration. I start by noting that to stay alive we breathe in and we breathe out. I then ask students to name what is going in and out of the lungs when we breathe. This seems like a simple and silly question, but it is surprising how little thought students have actually given to the overall process. Most students will say that we inhale oxygen and exhale carbon dioxide. But when I ask how this can happen, it gets them thinking, and they have to remember what they learned in biology. Students usually remember that air is composed of oxygen and nitrogen, and some will remember that the percentage composition is approximately 22% oxygen and 78% nitrogen. They usually know that our bodies use the oxygen and extract it from the air, but they really have not given much thought to what happens with the nitrogen that is taken into the lungs. If they think about what they know from the nitrogen cycle, they may remember that while our bodies need nitrogen to build proteins and other macromolecules, we cannot directly extract nitrogen from the air. They may remember that we need to consume proteins (which are nitrogen-containing molecules) from other sources in order to build our own proteins. What this tells them is that humans cannot take nitrogen directly from the air and use it. (Neither can plants, for that matter.) When we breathe, the nitrogen is inert; we breathe it in, and breathe it back out unchanged.

The students have learned that oxygen dissolves in the blood by passing across the lungs' surface and is carried by the hemoglobin in red blood cells from the lungs to the body cells. (This same circumstance can later be used to discuss diffusion, solutions, equilibria, and so forth.) Once the oxygen is in the body's cells, the mitochondria facilitate the reaction between oxygen and glucose in cellular respiration. At this point, I ask students: "Where does the glucose come from, and how does it get to the cells?" We do not get too involved with these reactions, but rather try to stay focused on the cellular respiration reaction. They usually remember that one of the products of cellular respiration is carbon dioxide, that it is transported in the blood back to the lungs and expelled when we breathe out. For some reason, they often forget that a second product of cellular respiration is water. To prompt them (since I have usually taught in the northeast and it gets cold in the winter), I ask what they see when they breathe out in the winter (i.e., condensing water vapor), and where that comes from. Of course, this water vapor comes in part from the moist linings of the lungs, but it is also a product of cellular respiration. It is interesting that they do not necessarily think of this process as sets of chemical reactions when they learn them in biology class. There is so much chemistry in this "simple" process that when students connect these new descriptions to material they learned the year before, it does two things: (1) it reminds them of what they already know and allows them to revisit that knowledge, and (2) it provides scaffolding for new knowledge. Even this kind of interdisciplinary learning helps students to realize that these concepts are not isolated within a single discipline—that biology and chemistry are different ways to look at similar problems and represent interconnected and interwoven material that can reinforce and support each other in the greater understanding of the world.

More connections

Math is an easy common denominator when teaching chemistry, and something that is integrated by its very nature across all science disciplines, but I have found that students learn much more readily if I have taken the time to talk with their math teachers to find out what they already know and how they have been instructed. I do not have to use the same processes or even the same words, but it certainly helps if I can make ties between how I am teaching something and how they learned it, or will be learning it, in their math classes.

After a fairly lengthy discussion between the math and science departments several years ago at our school, we found that we were not using even simple terms such as *proportion*, *ratio*, or *significant figures* in the same ways. The similarities and differences in the ways we use language in different classes is important to know, even if we continue to use terms in ways unique to our subjects. It can be confusing to students to hear different terms used to identify the same thing, or similar terms used differently in the different subjects. It gives the impression that the content in one subject is simply different from the content in another. Being explicit, and making these differences very clear to our students—and, when possible, explaining *why* we use these words differently—helps students compartmentalize and clarify ideas. Even better outcomes result when we work across departments to arrive at a common language. When students can see the similarities among the content in these classes, when teachers can actively highlight these similarities, it connects rather than separates the learning.

Another example comes from physics. When talking about frequency, I found that the physics teacher in our school always used the variable f, and yet, in chemistry, we almost always used the Greek character $\boldsymbol{\nu}$. Telling students to expect this difference, that both f and $\boldsymbol{\nu}$ can be used to mean the same thing (not a different kind of frequency, in this case), helps bring these ideas to a common foundation. Even though this seems like it might be obvious and simple, it does make a difference in students' understanding.

I have found over the years that there are times when I am talking with other teachers about concepts that are familiar to math, physics, biology, earth and space sciences, and chemistry, and realize that we use different language, different terms, and different approaches to teaching these subjects. Using different language to talk about the same thing often leads students to think that the material is different and unrelated. As teachers, we need to make sure we are aware of the different conceptualizations and make sure we explicitly clarify connections; students will not easily make them on their own.

A Story About a Play

This is a story about a classroom lesson—an evolutionary tale, but not about Darwin—a story of change over time, but not about climate change. It all started in Manhattan.

Spring 2001; The TKTS office (vendor of day-of-performance tickets) in Times Square, New York City

Scanning the list of available plays and musicals, I noticed a play called *Copenhagen*, with a science theme—a definite rarity in my performance-going experience. What could be better than a theater performance that is also an academic experience? A science teacher's dream! Three tickets: one for me and one for each of my school-age daughters. Stage seats facing the rest of the audience. It was as if the play were being performed just for us. The cast: three performers. The set: an empty ellipsoid floor with one simple chair. The performance: spectacular. I was in heaven.

I had been teaching science at a small school in Connecticut for a few years, a school that prided itself on its arts curriculum as well as its academics, but rarely did the boundaries blur. Theater, dance, music—the performances were often classical or contemporary presentations, sometimes based on history or biography or literary beauty alone, but never science, and here was a play with science at its very core!

The play finished and I had laughed, cried, and pondered moral questions with the characters. My elder daughter, a physics student, was similarly enthralled; my younger one, in eighth grade physical science, was less so. The language in the play was scientifically sophisticated, and an understanding of nuclear science, as well as a basic familiarity with the history of the time period, made it easier to understand, and to laugh with. I *needed* to figure out a way to share this play, this experience, with the students in my chemistry classes.

Spring 2002; The touring company

A weekday evening performance of the same play was being presented in my hometown, a mile from our school. I wangled department funds to pay for 15 tickets, which I offered to the first 15 students who were interested in going. I had talked up the play in class, and there was definite enthusiasm, but a weeknight performance beginning at 8:00 P.M. can be a tough sell to a commuter crowd with a long trip home at the end of the day. Nevertheless, 15 tickets were gone in record time. Again, a fabulous performance. I was thrilled. My students with stronger science backgrounds and those with an interest in theater found the greatest enjoyment, but no one was quite as excited as I.

Spring 2003; The local repertory company

A local college theater company was putting on weekday, daytime performances specifically for school groups. My school granted us permission to take all of our chemistry students on a field trip, and I could not wait to share this play with them. We prepared by learning about nuclear chemistry and the historical background of the play. All students had taken some American History, another plus. The repertory company did a fantastic job of staging the production to make it more student-friendly by adding furniture and props to describe time and place, and visual descriptions to support the science being addressed. But even this time, there were not many students who loved it the way I did – just the same ones: the stronger science students and some of the theater students. The rest could find a few good things to say about the experience, but not many. There had to be a way to make this experience as significant for my students as for me. How could I help them appreciate it—enjoy it—as much as I did?

A caveat

One student, Sophie, was unable to join us on the field trip, so I gave her my copy of the play to read and asked her to meet with me one week later to talk about it. Two days later, well before our scheduled meeting time, we passed in the hallway. With an excitement I did not often see in her, Sophie said, "Ms. Spillane, this is incredible! I loved this play!" I was dumbfounded. Why did she, an athlete, a fairly disinterested science student, and someone not involved in theater, love this play? What was it that spoke to her in ways that my other students did not hear? Her comments: "This play made me see scientists who were human, who had families: spouses and children. They worked together and argued with each other; they played jokes and hiked and skied with friends; they struggled with moral dilemmas and had to make decisions about their work based on far more than just the science they researched. They were real." I was astounded. This is what I loved about the play, and what she experienced by reading, that my other students did not when they watched a live performance. What could I do to help the rest of my students have the experience that Sophie did?

The Play: *Copenhagen* (Frayn, 1998) is a challenging play. It is both hilarious and profound, and much of its entertainment value requires a sophisticated scientific vocabulary and working knowledge of the scientific concepts, scientists, geographical locations, and historical references. It is about Niels Bohr and Werner Heisenberg—colleagues, collaborators, and family friends throughout most of their academic lives. They met in 1941. The content of the meeting is not known, but the two scientists never spoke again: a friendship lost. This play explores three possibilities of what might have happened during that fateful encounter, and in the process covers vast historical and scientific territory.