NEUROSCIENCE AND EDUCATION SYMPOSIUM REPORT

A ONE-DAY SYMPOSIUM
May 14, 2014

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The video recording of the event and the panelist' Powerpoint presentations are available on the Potomac Institute website at: The full agenda, presentations, and recorded videos of the event are available at:

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Event EMCEE: *Heather Dean*

EXECUTIVE SUMMARY

The Potomac Institute for Policy Studies and the American Association for the Advancement of Science held a symposium on the topic of education neuroscience on May 14, 2014. This symposium tackled the issues of how to apply neuroscience research to the classroom and how to reshape the future of education through neuroscience. The panelists discussed their concerns with the mismatch between education practices and neuroscience knowledge. Many schools are pushing students to perform tasks outside of their brain development stage, ignoring the multiple benefits of early bilingualism, and neglecting to differentiate between developing students and those with disabilities. Neuroscience research often provides support for enriched learning environments that incorporate the arts, foreign languages, and motivational systems, but these findings are not reflected in school curricula.

The symposium featured a keynote presentation from Mariale M. Hardiman, EdD. who described the development of a brain-targeted teaching model. Effective teaching that incorporates neuroscience will have a great beneficial impact on the education system. The brain-targeted teaching model includes lessons on the emotional climate and physical environment for students, objectives for teaching concepts and the "big picture", and methods for improving students' creativity and problem-solving abilities. The symposium did not just focus on early stage learners; a discussion of higher education made the point that learning is a process that develops well into adulthood. Colleges are decoupling learning from the traditional classroom and developing new environments to foster student development and competency. Across all age groups, it is important to assess talent, intelligence, and creativity as parallel processes with a neuroscientific basis. There is a great opportunity to perform applied neuroscience research within the classroom and to provide disruptive solutions that enable progress in students' academic performance.

Neuroscience enhances these education models and programs because it provides empirical evidence for the efficacy of a teaching tool that is not observable from "outside" behavior. Neuroscience can be successfully incorporated into the education system as long as teachers, parents, and students are able to access research findings and navigate their impacts on learning as a whole. This symposium provided a platform for insightful discussion regarding an education system that works hand in hand with neuroscience.

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

THEME #1: THE EDUCATION SYSTEM IS NOT INFORMED BY NEUROSCIENCE

FINDINGS

- **Learning multiple languages improves overall language proficiency.**

  The fundamental neural changes that occur when a child is exposed to multiple languages at an early age are different from those that are seen after exposure to a single language. This early multilingual exposure is a powerful predictor of reading success. However, our educational system teaches English at an early age and then second languages much later in school. There is an ingrained notion that exposure to multiple languages causes delay in learning and confusion, but the research information concretely demonstrates the opposite result.

- **Students are tasked beyond their developmental readiness.**

  While the education system on one hand avoids early exposure to second languages, it completely disregards this notion when it comes to other learning material. Many students are asked to learn handwriting before their motor skills are developed and coordinated enough to complete this task. Institutional reading programs try to teach reading skills and concepts before students have developmental readiness. Executive function development is very slow, but students in middle school are asked to manage their time, interact with different teachers, navigate hallways, and complete other executive cognitive skills. The idea of a standardized, rigorous education system that pushes for earlier and earlier benchmarks is completely opposed to research findings on individual neurodevelopmental differences.

- **Brain plasticity and developmental differences affect the efficacy of interventions.**

  Behavioral interventions are more successful the earlier they are implemented, but there is more difficulty in helping later learners who continue to struggle with reading or math. These individuals have typically seen minimal responsiveness to instructional interventions and may have diminished plasticity as a result. Prescribed interventions' dosages and timescales are not tailored to individual students' needs. There is no identification process or marker for students who might be minimally responsive to traditional interventions.

CONCLUSIONS

- **Education is improved by a focus on developmental time points.**

  Our education system does not take into account that children fall within a range of development in all biological domains, from motor skills to cognition. Each student has individual differences. Taking steps to focus on this disparity will allow for learning improvements in students at all stages of readiness and development. Students will be more willing and able to adjust to school tasks if curriculums draw from current and past research. In addition, research gives us indicators of risk for disabilities, as well as a base of knowledge about heritability and environmental factors that modulate their development. The earlier an intervention occurs, the greater the chance of success.

- **Education practices are best served by incorporating research findings.**

  Incorporating system-level and classroom-level changes to develop functional education-neuroscience partnerships can only help education practices. The more collaboration there is, the more we can avoid unintended consequences. This is a two-way street; it is not neuroscience informing education, but also education informing neuroscience. These reciprocal relationships need to continue. They are built through collaboration and understanding of our respective fields, and we need to bring them together.

RECOMMENDATIONS

- **Apply directed neuroeducation and directed lessons at various developmental time points.**

  Identify the brain processes and systems that are involved in the problems facing students in contemporary education. This research gives educators more information about peak sensitivities to information, appropriate ages of exposure to learning material, the plasticity of neurological systems, and areas where the brain is resilient enough to compensate for missed developmental periods. This knowledge plays a role in determining best educational practices. There is a great deal of promise in neuroscientific indices that provide more salient information than behavioral data. For example, there are not currently any strong behavioral markers for predicting future reading in students with dyslexia. Brain imaging might allow researchers to predict an outcome prior to an intervention and help in the determination of the most applicable course of action. If we could clearly define the boundaries of developmental disorders, we could provide more accurate diagnoses and stronger treatments.

- **Use neuroscience research to help define educational practices.**

  The education system needs to be structured to allow for more frequent implementation of recommendations and changes. Through the National Science Foundation, the Department of Education, and other federal agencies, education research has received significant funding. This funding has enabled scientists to develop better diagnostics learning and reading; however, their influence on classroom practices is small. The conceit of the education system is that we can help students learn better than they could on their own. When neuroscience provides us with concrete examples of education best practices, there is no excuse to avoid their implementation.

THEME #2: TEACHERS ARE INTERESTED IN NEUROSCIENCE AND EDUCATION

FINDINGS

- **Teachers are paying more attention to, if not actively seeking out, neuroscientific information.**

  The way that the brain works, especially in developing children, is an intriguing topic. Teachers are always interested in information that will improve their practices, especially findings from neuroeducation research. However, teachers do not always filter out psuedoscience, neuromyths, and unsubstantiated educational practice claims. The trends show that teachers are increasingly enrolling in neuroscience graduate programs. Universities like Vanderbilt and Johns Hopkins are expanding their graduate programs that relate neuroscience and educate to meet this increased interest.

CONCLUSIONS

- **Teachers and students will benefit from resources and lessons in neuroscience.**

  Scientists can provide teachers and students with an incredible array of information about neuroscience research findings. Neuroscience research findings allow teachers to create more effective lesson plans for their students. Teachers can also begin to give their students lessons in neuroscience and the processes of the brain. If students can also become interested in the science of learning, they will become more involved in their own education. They can better sculpt their own learning goals and interact with their teachers and mentors.

- **Dialogue between scientists and teachers works bi-directionally.**

  The utility of a system where scientists share neuroscience research with teachers is augmented by the fact that teachers will be able to discuss their perspective and issues and help to develop new research questions. Science should establish basic principles for education and then researchers should work hand in hand with teachers to formulate pragmatic and applicable solutions.

RECOMMENDATIONS

- **Provide teachers the opportunity to learn about neuroscience and education.**

  There should be a true partnership between neuroscience and education, one that involves common understanding. Teachers want information on educational neuroscience, but if scientists do not provide this information, that knowledge gap will be filled by programs and approaches that are not research-based. We can enhance teachers' professional development through training in bridging education and neuroscience. They need a framework to see neuroscience in context of behavior, they need to have the knowledge to make informed decisions about interventions and methodologies, and they need to be comfortable navigating the different options and marketing schemes.

We can enhance their professional development with basic knowledge about the relationship between neuroscience and education. To achieve this, professional development and graduate training programs need to apply scientific principles into their curriculums as well as a framework for implementation. Teachers cannot be expected to inject neuroscience research findings into their teaching after one-off training sessions on a topic. A more concerted effort is needed to build this understanding. Education is an integrated service-delivery system. Science can interact with both system-level and classroom-level changes and there is a need for functional partnerships at both levels. Teachers, and the broader administrative staff at schools, are the ones tasked with formulating the broader structural changes that they want to implement. Teachers do not need to become neuroscientists but they do need a functional knowledge of the science. They are going to need to make decisions about the nature and timing of an intervention, and to do this successfully requires a framework to see behavior in the context of neuroscience.

- **Integrate neuroscience imaging technologies into the classroom.**

  Neuroimaging technology is becoming cheaper and more widespread, as evidenced by the number of companies that sell EEG hardware for video games and other applications. There is a short learning curve for these technologies and they would be instrumental in giving teachers and students a more concrete representation of how the brain functions. These insights into the processes of learning, memory, and motor control can excite and motivate students. Additionally, these headsets (they could be called Thinking Caps) could be used in targeted applications like test-taking and cognitive exercises to provide neuroscience researchers with a broad cohort of data. Massive longitudinal and cross-sectional studies on the developing brain should become a reality.

THEME #3: EFFECTIVE EDUCATION ADVANCES SOCIETY

FINDINGS

- **An educated populace leads to a better democratic society and global economic performance.**

  We educate our population so that they can contribute to society, in terms of both civic duty and economic participation. Closing the achievement gaps between our highest and lowest performing students has a direct impact on our country's productivity. We want to encourage students to become integrated citizens of our culture and society, and education is the best driver of this process.

- **Teachers do not have the time and capacity to provide their students with personalized education.**

  Teachers create lesson plans with the intent to teach to a classroom as a whole. Teaching content in a lecture-style, rote-memorization presentation can be an effective method. However, each student has individual interests, attention capacity, and aptitudes. Teachers try their best to keep all of their students on task and on track, but this is an incredibly difficult juggling act. They are not collecting any data on their students. There is no collection of physiological data and metrics to address student disengagement, confusion, or frustration. There is no collection of neuroscientific data to assess developmental readiness, cognitive ability, or aptitude.

CONCLUSIONS

- **Technology and innovations in the classroom will improve teaching efficacy.**

  Neuroscience and technology that help to improve the personalization of a class, lesson, or task will play a beneficial role in students' education. This includes anything that helps a teacher coordinate and organize their time so that they have the ability to cater to the needs of their students. Teachers would benefit from technology that analyzes students' performance and tailors lessons to their needs or streamlines lesson planning, as it would provide them with more useful information to incorporate into their daily teaching and more time to mentor their students. Building neuroscience and neurotechnology into our education system revolutionizes the way every student learns as an individual. Students and teachers can work together to ensure that these tools are truly forming a personalized, unique education.

- **Personalized education will lead to dramatic shifts in society.**

  Historically, technological revolutions have enabled changes in the spread of information and educational practices. Where apprenticeship and one-on-one tutoring was once the only way to acquire skills and knowledge, the advent of the printing press, books, and libraries provided many people with the opportunity to learn a trade or field of expertise. The development of the Internet further empowered teaching and learning by providing access to immense sources of knowledge and instantaneous global communication. A neurotechnology-driven, personalized education implements all of these previous advances and allows more students to achieve mastery of a larger range of skills. Just as the Age of Enlightenment and the Renaissance employed education and knowledge to foster societal revolutions, an education system that exponentially enhances learning will create new ways of thinking, develop cultures, and change society.

RECOMMENDATIONS

- **Increase neuroeducation research towards the development of personalized instructional interventions that are applicable for various stages of learning.**

  The current state of education ignores the individual differences of biologically developing human brains. Personalized education should be structured similarly to personalized medicine. It should incorporate as much biological and behavioral data as possible. Research should focus on technology that can recognize when a student becomes disengaged, whether through metrics like heart rate, blood flow, eye saccades, or neural activity. Understanding the nature of learning and behavior in a variety of environments provides targeted interventions for every student. When teachers and computers are armed with sufficient data about a student, they can administer the right balance of concept-based learning for deeper engagement, rote memorization for solidifying knowledge, real-world examples for synthesizing lessons, and breaks for minimizing cognitive overload and attention deficits. If students are no longer classified into separate levels of intellectual achievement or ability, but are instead classified based on their individual needs, then the production line mentality of the education system will become diminished.

- **Demonstrate the societal importance of our children's education by supporting a complete neuroeducation system.**

  Many people, inside and outside of the education system, are unhappy with our students' educational outcomes. This disapproval should be matched with support for ideas, research, and technologies that improve education. We have the tools that let us bring neuroscience research into the classroom and collect data from our students. Whether we are using this information to develop brain-based teaching programs or to tailor personalized lessons for each student, neuroscience directly engages and improves our education system. By supporting a complete neuroeducation system we will be ensuring a brighter future for our children.

EVENT TRANSCRIPT

Neuroscience research into how the brain learns has significant ramifications for education policy. We can elucidate the cellular processes and neural systems that inform us about the biological basis of learning and then apply this information to develop best educational practices. Although education neuroscience has been studied for many years, a lot of the work has yet to translate into the classroom setting. A deeper understanding of the state and relationship of the two fields requires open conversation to determine the areas where neuroscience can improve the education system of today and for the future.

The symposium featured two panels and a keynote presentation from some of most respected leaders at the forefront of neuroscience, psychology, and education. The discussion focused on two aspects: i) emerging findings in neuroscience and how they relate to education and ii) potential applications of these findings. The panelists drew from their areas of expertise in order to address how neuroscience has informed education thus far and discuss questions that future studies may raise. The overall findings, conclusions, and recommendations of the symposium stemmed from their knowledge, expertise, and opinion on this hotly debated topic.

The policy recommendations discussed at this symposium will help to bring about important change into how education professionals develop school curriculum and enable teachers to better interact with their students. Overall, the objectives of the symposium are to continue the dialogue between neuroscientists, educators, and policy makers on the emerging field of educational neuroscience.

ALAN LESHNER

Welcome

I have a charge for you. The topic that we are here to talk about today is multi-factorial and it is tremendously important. Neuroscience is gaining an incredible amount of interest in this country. In addition, the frustration with what is going on in education, and where American education has been, is also growing tremendously. The intersection of these two trends seems to be an obvious one. There should be insights from neuroscience that are in fact concretely applicable to education.

I am myself a neuroscientist, and I spent many years at the National Science Foundation (NSF), the National Institute of Mental Health (NIMH), and the National Institute on Drug Abuse (NIDA). When I was at the NSF, I was one of the staff directors of the first National Science Board Commission on Precollege Education in Mathematics, Science and Technology. It was in 1983, and it was a commission of luminaries. At the end of it, Erich Bloch (then the director of NSF) was visited by a delegation of very famous cognitive scientists. The purpose of the delegation was to ask for money. They said, “We, and the cognitive science community, are poised to ask the right questions. Send money.” Erich Bloch said, “Where have you been for thirty years?” I thought that was a very telling question. “We’ve been supporting you for thirty years, what have you produced that in fact would change the way we do education?”

It is now thirty-one years later. I challenge you to have an interesting and provocative conversation today and to be as concrete as you possibly can about what those literal insights are that are applicable to education. We do not want to have the conversation with the director of NSF thirty years from now, where he or she says, "Where have you been for sixty years?"

With that challenge, know that this set of panelists is terrific. The speakers are among the very best and the topic is as important as any in current science. In terms of the intersections between science and the rest of society, science and policy, or science and education, you cannot ask for something more important. So, do not mess it up.

PHILIP RUBIN

Opening Remarks

As part of my role at the White House, I lead something called the White House Neuroscience Initiative. It is a very broad initiative, whose coverage includes issues of mental health, Alzheimer's, neurodegenerative disease, the BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies) and a host of other things. One of the initiative's key activities is the National Science and Technology Council (NSTC) Interagency Working Group on Neuroscience. The working group is composed of over twenty entities that meet regularly to consider opportunities for neuroscience in the federal government. According to its mission statement, this working group will "enhance federal efforts related to: improving our fundamental understanding of the nervous system, including brain structure, function, development, and plasticity; improving our understanding of learning and cognition and applying that to improvements in education and other areas." Education is an area that we are focusing on in the second year of this group. We are therefore delighted that this symposium and other such activities are starting to happen, and we will to try to be as supportive as possible. In general, such federal groups mostly work behind the scenes.

At the end of the day we expect to have Tom Kalil here. He is our Deputy Director for Technology and Innovation. He will be talking to you about the BRAIN Initiative and the President's "all hands on deck" effort to try and get further commitments for that program.

In closing, the President's Bioethics Commission is, at this moment, releasing a report called "Gray Matters: Integrative Approaches for Neuroscience, Ethics, and Society." Integrating ethics explicitly and systematically into the relatively new field of neuroscience allows us to incorporate ethical insights into the scientific process and to consider societal implications of neuroscience research from the start. This report is one of eventually two, so we are very excited to have that happening. We have worked with the President's commission to make sure that in the BRAIN Initiative and other areas of neuroscience and ethics were integrated right from the beginning. With that, I hope you have a great meeting, and thank you for inviting me.

PANEL 1: EFFECTIVE CLASSROOM APPLICATIONS FOR NEUROSCIENCE RESEARCH

The speakers discussed their experiences in education neuroscience research and their observations of our school system. Researchers have produced large amounts of data, findings, tests, and interventions, but there is no mechanism for translation of these findings into the classroom. It is important to take pressing educational issues and to identify the relevant brain processes and systems that allow students to successfully overcome these issues. Whether the problem is developmental readiness, language learning in deaf students, or reading ability in dyslexic students, neuroscience can provide answers. These solutions also inform our knowledge and understanding across the broad spectrum of individual differences in students, regardless of their development or ability. Neuroscience research can play a role at the student level, classroom level, and system level, but we need to build functional partnerships within each domain.

JAY GIEDD

Moderator

Good morning! I am very honored to be here. I am passionate about the topic of neuroscience in education, which I come to through several convergent pathways. The first, and most important, is as a parent of four teenagers. Seeing their educational experiences, with different strengths, weaknesses, learning styles, I have been frustrated with the lack of progress in bringing neuroscience into the classroom.

Another path is from my day job, where I look at how the brain develops and what influences this development for good or ill. As doctors, we started out by asking what is wrong with the teenage brain. Why do all these illnesses occur? In actuality, we are coming away with a notion of all that is right with the child and teenage brain. It has enormous plasticity. It is extremely exciting to think about what can be achieved by harnessing just a fraction of this potential.

However, in terms of imaging – and I would say the same for genetics – the results have been largely disappointing. We have generated a lot more papers than we have helped people, whether by using imaging for diagnosis or for clinical care. In this regard, I have failed at that initial effort to change clinical practice, but I am much more optimistic about education. This is because we do not have to cure education, we just need a one or two percent increase in leverage across two billion K-12 students across the planet – by far neuroscience's biggest bang for its buck. This is why I am so passionate about this area!

My third path, which is a bit more convoluted, is from John Bruer's book, *Education and the Brain: A Bridge Too Far*. Bruer makes the claim that we have accomplished nothing – just like the challenge that Dr. Leshner pointed out. Other than waving our arms, what have we actually changed about teaching or parenting through neuroscience? I thought answering this question would be easy, but it is not as easy as it seems. I am on the advisory board of the Learning and Brain Conference; I have been to dozens of international conferences and hundreds of domestic ones on these topics. The prefix "neuro" is used in so many of the top titles: "neuro-marketing," "neuro-education," or "neuro-gaming." Sitting in the audience of conferences, I hear these words used as marketing tools rather than as scientific terms. Like "nano" or "molecular," they are buzzwords that immediately add credibility to a statement, whether or not they are actually related. How do we get past the hyperbole and the false claims and get to honest science and progress?

One of the speakers for this afternoon, Mariale Hardiman, wrote a book on brain-targeted education, which really revitalized my interest in the field. She relied on real, solid science, which made her work a breakthrough step in the right direction. I am therefore delighted she is part of this conference.

The idea of bridging the gap between neuroscience and education will begin with Martha Bridge Denckla, who is an inspiration to all of us in this field and an ideal person to kick off this panel.

MARTHA BRIDGE DENCKLA

Panelist

I am an MD, a neurologist, and I have been involved in this topic since 1970 when I was thrust in my first job into working with children who cannot talk and children who cannot read. I do confess that I am not a child neurologist. I am a neurologist with a cognitive-behavioral training, and I was simply thrown into a clinic at Columbia Presbyterian Neurological Institute, and told, "You will see every child whose chief complaint is 'cannot talk' or 'cannot read.'" My first publication addressing, "Why can't Johnny read?" was in 1972, with something called the Rapid Automatized Naming Test, which I worked on in conjunction with Rita Rudel and later with Maryanne Wolf and then Laurie Cutting.

This test was developed in order to find out whether children were ready to read on a very mechanistic, neurological basis. To the best of my knowledge, it is not applied anywhere. I would like to quote my friend Frank Vellutino, Professor Emeritus at SUNY-Albany, with whom I have done research in the past. He said that educationally targeted research has been beautifully funded (he has built a career on it) but he sees almost no impact. Findings that have been published since the 1970s, and have been circulated among professionals, have not influenced education at all.

Rapid Automatized Naming came out of neurology. I was first attracted to neurology after hearing Norman Geschwind talk about pure alexia without agraphia. Following that concept further to alexia with agraphia, I learned about the pathway in the left side of the brain, which goes from the back to the front, and takes audio-visual information up essentially to the mouth (the "see-it-say-it" circuit). I wanted to do something that involved speed – I knew children would never show glaring absence of the ability to do the task, but on an age-dependent basis they would get faster and faster in a way that would support the activity. The whole idea was to get an index by increased speed of the myelination (the insulation around the long neural pathway that allows it to operate as an "express train" rather than a stuttering "local train").

In the last 25 years, I have had the privilege to perform a lot of imaging. Imaging data supports the inference that myelination would be a good marker for dysfunction. We have a small study comparing children with dyslexia to typically developing controls in which the superior longitudinal fasciculus in the dyslexic children contains an inordinate number of fibers that get off the express highway and go into the parietal lobe. It is as though their brains just want to go to the underlying meaning and do not wish to stay on the superficial level of "see it, say it."

Thanks to pressure from my junior colleagues, Random Automatized Naming has become commercially available. People in diagnostic centers use it, but has this marker for readiness of reading been implemented on a wider educational scale? No. Nothing has happened.

The second piece of research in which I participated in the 1970s was developing the Physical and Neurological Examination of Subtle Signs (PANESS). This hitched a ride on work of psychiatrists who had worked on before, trying to find neurodevelopmental markers. At first, because I'm a neurologist, I was trying to study hyperactive children. Hyperactivity was folded into a category called Minimal Brain Dysfunction (MBD), which was a really global meaningless grouping that just meant the brain was involved. We developed a motor examination with a timed component to determine whether the brain was involved in these hyperactivity disorders. We found that certain aspects of the PANESS, particularly the ones involving "inhibitory insufficiency," or overflow/ extraneous movements, were highly diagnostic of children who were then called hyperactive. We also found that, on timed motor tasks, the children were slower. This gave rise to the apparent oxymoron that hyperactive children are slow at accomplishing directed tasks.

Within this battery of tests, there was a finger sequencing element, and we found that among five-year-old boys, five percent had "mitten hands," they could not move each of their five fingers individually in sequence. Virginia Berninger applied this work broadly to the development of handwriting, creating a robust readiness measure based on finger sequencing speed.

Thus, in the service of doing work on disorders, the research has produced large bodies of normative data, one of which has to do with a brain basis for readiness for reading, and another of which has to do with readiness for handwriting. Have these made any impression on public education? Quite to the contrary. I am alarmed that within the past ten years, and now institutionalized by the Common Core, that we do not apply readiness concepts to when we begin instruction. We have children who are not wired up yet to successfully read being asked to start reading. We have children who are not wired up yet to do successfully write being asked to start handwriting – and so they do it with the hand or the arm rather than with the fingers.

I see a tremendous crisis. We have decided, arbitrarily, that kindergarten is first grade. We have decided, arbitrarily, that everyone is going perform academic tasks a year earlier. Even leaving aside the fact that the curves for boys and girls at age five are very different – in fact, the motor coordination curve for girls who are five fits over that of boys who are six – there is intra-gender variability. If a boy has a birthday in the summer, he is four times as likely as other boys to be diagnosed with ADHD, because for each grade in school, he is too young. In addition, if a child is given preschool, we may make premature demands on them in the form of academic programs, when their brains are not ready.

The third area I have been performing research on is executive function development, or the ability of the control systems (headed up by the frontal lobes) to cope. We have undergone systematic prematurization by pushing middle school earlier – as early as fifth grade, when it used to start in seventh grade. We are asking students to manage time, deal with different teachers, navigate hallways, and other sorts of executive skills. These skills, however, are far beyond the earlier grade levels.

I see a real crisis, which is getting worse, not better. This is because we have completely ignored forty years of publications on this topic. We have decided that children are not biologically-developing human beings with brains that have individual differences, and we are just pushing them forward. We will get a lot of pushback from children, in terms of hating school and being maladjusted to school. We will not achieve the results we desire by ignoring what we already know. We will certainly learn more, but I think we possess a good deal of knowledge, and it is frustrating – both as a mother, a grandmother, and a professional – to see that this knowledge is not used.

LAURA-ANN PETITTO

Panelist

I will begin by thanking you so much for inviting me. I am very much looking forward to speaking today. I, too, will begin with a personal journey. I was sitting in my office at the Montreal Neurological Institute in the year 2000. I was a researcher in the department of neurology and neurosurgery, working with Brenda Milner, Michael Petrides, and Robert Zatorre. We had received a McDonnell Pew Foundation grant for the Center for Cognitive Neuroscience, and were about ten years into the studies and very excited about them. But we were also frustrated: discoveries were being made – about the bilingual brain, about when children should be exposed to bilingual education, about bilingualism's impact on reading and academic performance – but they were having very little effect on the educational system around us. The Quebec Ministry of Education, for example, had a law against exposing children in French-language schools to English until grade four, which flew in the face of biology. By the time they were twenty, these children would have slower, more effortful processing and greater accents in English, and this in turn would have radical implications for their integration into a multicultural society.

In that context, I received a phone call from a dean at Dartmouth College. He said, "We need you. Come down; you have to fix something." Dartmouth had a psychology department that had previously been wed to an education department and had been pulled apart, as the education component was dying. Rather than closing the department, Dartmouth wished to revolutionize it. So in 2000, I moved to Dartmouth College and created a program that I named "Education Neuroscience."

In that context, I received a phone call from a dean at Dartmouth College in Hanover, New Hampshire (U.S.A.). He said, "We need you. Come down; you have to fix something." Dartmouth had a psychology department that had previously been wed to an education department and had been pulled apart, and the education component was dying. Rather than closing the department, Dartmouth wished to revolutionize it. So in 2000, I moved to Dartmouth College and created a new department that I named "Educational Neuroscience and Human Development."

I therefore argue that the marriage of these two fields has already been completed. We have a solid body of knowledge, additionally aided by the advent of the National Science Foundation's Science of Learning Centers. At Dartmouth, we were awarded a NSF Science of Learning Center grant and created the Center for Cognitive and Educational Neuroscience, where we built an undergraduate program and trained teachers to be educational neuroscientists. The discipline is not education and neuroscience; it is instead a married couple. It is a joint study of how humans learn, particularly core learning at the heart of early child development, and early schooling. It has five domains: how children learn language and bilingualism; reading and literacy; science and biological concepts; math and numeracy; and social, emotional, and moral growth. The discipline is powerfully committed to cognitive neuroscience methods, and to principled translations of research findings in meaningful ways that reach and aim to solve core problems in contemporary education, as well as to a two-way discourse between the educational community and neuroscientists. The field is alive and well. It is rich and poised to communicate with policymakers.

We are trying to take real educational issues that are real problems to students in contemporary education, and to identify the brain processes and systems in real-world educational contexts, in order to understand the brain mechanisms and systems involved. This can give us information about when the child has peak sensitivity to certain types of information over others, at what age they need to be exposed, how plastic neurological systems are, and how forgiving the brain is if key developmental periods are somehow missed by the child.

I will outline a few examples of dramatic findings that have implications for education. The human brain is extraordinarily responsive to its environment; it undergoes dramatic, adaptive changes in brain structure and brain function. However, the brain is not only plastic, but also resilient. Not everything is neurally plastic, and components that are not plastic are equally informative to us.

We see fundamental brain changes when a child learns to read, and when a child is exposed to two languages rather than one language. The change is very different when a child is exposed to two languages later in the educational system as opposed to earlier. In fact, one of the most powerful predictors of reading success is a child's age of exposure to two languages. The earlier the child is exposed to a second language, the better reader he or she is in each of their two languages. Yet we have an educational system that pulls the languages apart, and exposes the child to them in a stage-like manner. There is a notion that exposure to the second language might contaminate the child and cause language delay or confusion, despite concrete information to the contrary.

One of the most extraordinary findings of my career was the discovery that deaf children who are exposed to sign language begin to babble on the identical timetable as hearing children. This is remarkable: we viewed the onset of early vocal babbling as being determined by the maturation of the oral-facial cavity and by the connections between the motor cortex and oral-facial control. We also saw it as being dovetailed with the perception of sound. In that view, a child who is stripped of hearing and exposed only to sign language should not babble. But we found that they do – like hearing children they produce meaningless phonetic-syllabic linguistic babbling – though not on the tongue but instead on their hands. This suggests that whatever controls the onset of the milestone in spoken language is also controlling that in sign language.

We then examined the radical hypothesis that both vocal and sign language babbling involve mediation by the same brain tissue. When we showed deaf people meaningless movement units-which have significance to deaf signers as the phonetic movements that make up their language – they accessed the identical brain tissue that a hearing person accesses when he or she listens to phonetic-syllabic units like “ba,” “da,” and “pa.” This means that the brain tissue that mediates sound also mediates signs. The implication here is that maybe particular science beliefs were wrong. We made a mistake: here, the new conclusion would be that this brain tissue is not set for sound, but rather for aspects of the patterning that make up human language.

In another study, with Robert Zatorre and Virginia Penhume, we performed volumetric analyses (voxel by voxel) of grey and white matter in the brain’s primary (A1) and secondary (A2) auditory tissue. We found that in deaf and hearing brains, the grey and white matter were identical in volume. This results showed that the brain tissue classically thought to be the exclusive bastion for the processing of sound was instead alive and well in the brains of signing deaf people, even though it did not get sound. Here, again, the implication was that particular beliefs in science were wrong. Rather than being unimodal sound processing tissue, aspects of the tissue are set to the patterning of human language.

What is the educational implication of this? We were able to use new technology to study the children’s neural processing. This is the first time in history that we have been able to look at neuroanatomical and temporal dynamics across the brain’s hemispheres, using a functional near infrared spectroscopy (fNIRS) brain imaging system that is very user friendly. We can therefore follow tracts of brain tissue and complex connections between brain systems over time, which has shown us that aspects of the planum temporale and the superior temporal gyrus are highly sensitive to rhythmic undulating patterns at the core of human language structure. This allows a child to attend to, find, and extract out the critical phonological units (those at the core of their particular native language) from the complex stream of sensory stimulation around them. The brain can then tacitly do a distribution and frequency statistical analysis over these phonological units, allowing the child to find the language’s phonetic inventory from which all the words and sentences of their native language will be built over life, and to find the word from in the input stream, so as to discover the meanings of words. The human sensitivity to rhythmic patterns allows the deaf baby to crack the code of the visual stream around it in the same way that it allows the hearing baby to crack the code of the auditory stream. If a baby is exposed to sign language early in life, he or she actually segments the visual stream into those small meaningless phonetic-syllabic units at the heart all world language, and does so on the same maturational timetable that hearing babies phonologically segment the sound stream. In this way, children who are profoundly deaf and learning to read are not profoundly lost: they, too, can see the letter on the page, access aspects of their brain’s “Visual Sign Phonology,” or the phonetic-syllabic phonological unit from their natural sign languages, and then they use this segmental information as a means to decode print en route to meaning. However, children who were not exposed to sign language early in life, and exposed only to extensive speech training, bypass the ability to set up these visual phonological units that would have let them crack into reading.

Across the eyes and across the tongue, then, the brain imposes and finds a phonological organization, which has an educational impact if we want to promote optimal reading in all young children. For one, concerning the debate in education about phonics versus the whole word: there is no option. Children need exposure to phonological segmentation information during their very earliest entry into the reading process. These types of evidence, however, are not being embraced in educational policy. Early language experience is vital for all children. We know well the devastating impact that minimal language input can have on children (witness, Hart and Risley's renowned "30 million word gap" in low SES children). The brain devastation can be even worse for many deaf babies whereupon they may receive no language input in early life. Thus, it is vital that young deaf children have exposure to a natural signed language early in life and this is so even if they are receiving speech training, and even if they have a cochlear implant. Visual language exposure provides these babies with the vital visual phonological information that they need to achieve healthy language and reading success – and does so at the right developmental period. Thus, early visual language exposure avoids the deleterious impact during the wait for speech training, or the wait for their cochlear implant to be useful. Moreover, dual language exposure (here, signed and spoken language) does not hurt the brain's language and cognitive processing power. (Our neuroimaging research has shown that the brain's auditory tissue is not "colonized" by exposure to a signed language). Instead, decades of research from my lab on the young bilingual brain have demonstrated that early dual language exposure is optimal for all children. We see extraordinary advantages in the early-exposed bilingual child's phonological and reading ability, lexical access, and higher cognitive and Executive Functions over the monolingual child – advantages that persist across the lifespan. I therefore hope that through this discussion, findings of this sort, which have been in laboratories for decades, can really begin to be heard by the educational policy community. See and download Petitto publications at http://petitto.gallaudet.edu.

GUINEVERE EDEN

Panelist

It is a real pleasure to be here. I would like to thank the organizers; I would like to thank AAAS and the Potomac Institute for having this meeting and for including me in the panel. The work that we do is highly collaborative. I am at Georgetown University but I collaborate with Gallaudet University, Wake Forest University, and others to try and understand the brain basis of reading. Our work is supported by the National Institute of Child Health and Development and the National Science Foundation.

One area that has received a lot of interest is how research in brain mapping and neuroscience can inform educational practices, and I think the areas of reading and literacy, and numeracy and math education have been of primary interest. These seem to be the obvious examples of where we should be able to bring education and neuroscience together, the way Laura-Ann just described. I will focus on the area of reading, and outline for you where the neuroscience research has made an impact, where we have learnt from educational practices when we design our studies in neuroscience, and how we hope that what we learn will also impact educational practices. This is a two-way street: it is not neuroscience informing education, but also education informing neuroscience. These reciprocal relationships need to continue. They are built through collaboration and understanding of our respective fields, and we need to bring them together.

One of the things that is so interesting about studying the neural basis for reading is that reading is a very special skill. It is uniquely human, it is a cultural invention, and it is a skill that we have not been using for that long compared to spoken language, which we have had for hundreds of thousands of years. There are no brain systems dedicated to reading. We essentially hijack the brain to make it do something that is important for our culture, for our learning situation, and for our schooling requirements. We have to use brain areas that were dedicated for something else – primarily areas in language, particularly those involved in phonological processing and in the object-visual processing stream – to recognize the complex symbols that we use. We do this in different ways in different cultures, as indicated by early examples of differences between logographic writing systems and the alphabetic writing system.

We know a lot about reading from many years of research in education and psychology. We know that it involves mapping, bringing together visual information (the word form through orthography) with the sound representation (its phonology) in order to access the meaning of the word and the meaning of the sentence that we are reading. We know that children who have certain skills, such as understanding the alphabetic principle, having phonological awareness, and having strong oral language skills, are more likely to succeed in acquiring reading skills. We also know that how children learn to read is modulated by several factors. One of these is the language the children speak, another is the writing system in which they learn to read, and other factors like sex, IQ, and social class affect how successful children are at learning to read. We therefore have a very rich literature by which to begin to understand the neural basis for reading or for the kinds of skills that we know are related to reading.

I will outline a few examples of these kinds of neurological studies. We have some information on the brain basis for reading and how it changes across development. We can also integrate it with behavioral measures that are used in classrooms or clinical settings, in order to evaluate progress in reading and reading-related skills. In addition, we understand that the organization of the brain for reading skills depends somewhat on the writing system. Information from these studies can be used to influence theories about reading.

Our lab performed a functional magnetic resonance imaging study that showed a developmental trajectory of the brain from beginning readers to more skilled readers, and the areas that change as we become more advanced and more skilled at reading. We can then take brain function and relate it to behavior measured outside of the scanner, in this case through neuropsychological tests that are often used in a school or clinical setting, to begin to identify the relationship between how good a child is at rapid automatized naming (which Dr. Denckla spoke about) and the amount of brain activity that we see when those children are reading in the scanner. This begins to build a relationship between what we see in the brain and what we measure in a neuropsychological evaluation.

People have done studies on reading around the globe, and have identified similarities, but also differences depending on the writing system that you are born into. The demands that are made on the brain by a symbolic representation, which has a highly complex visual form and does not follow an alphabetic principle, are somewhat different than those made by an alphabetic system. This information, in addition to behavioral work predating it, has been used to provide more informative models of reading. For example, the wonderful work of Stanislas Dehaene recognizes the complexity of the reading system but also points out that when we learn to read, we not only utilize language systems that are already in place, but also recruit areas such as regions in the visual system (like the visual word form area) that become interconnected with the language system. This allows us to map the visual information to language and produce what we are reading.

One very important aspect of this research involves children who have difficulties learning to read. Reading disability, or dyslexia, is very common, and it is a significant problem because if you cannot read, you cannot access much of the information that you are trying to learn in school. Again, the brain research here has been somewhat helpful in informing models of reading, as well as in understanding the neural basis for reading disability. Researchers have not only mapped differences between dyslexic and non-dyslexic participants, but also looked at what happens when we apply an intervention and observe the neural correlate to a successful gain in reading. This has helped us to understand models of reading and reading disability, and is now being used to understand what reading outcomes may look like in students with and without dyslexia.

There are many studies around the world showing that there is less activity in areas such as the inferior parietal cortex in dyslexic readers, even when they can accomplish the given task. We can, however, provide an intervention and bring about gains in reading. In this case, it is important that the interventions not only train one particular skill, but also train a skill that generalizes to reading. You do not just want to get better at phonemic awareness; you also want to get better at single-word reading and deriving meaning from print.

Another example involves changes in adult brains. Even though we focus on young dyslexic readers, there is hope for dyslexic readers in their forties and fifties; the brain does change and reading does improve later in life. We have shown that brain areas contributing to these changes involve not just the left hemisphere, but also the right hemisphere, which appears to be compensating somewhat. This information came about through a reading intervention that was developed by clinicians, which we then applied in a school setting and studied. We as neuroscientists did not devise the intervention, though there are such studies. Studies also happen in real classroom situations, with neuroscientists coming in, collaborating with educators, devising interventions based on educational neuroscience research, and evaluating the results.

Another area of knowledge concerns anatomical changes following interventions. Experience-dependent plasticity has been a great focus in the field of neuroscience; it first gained interest when scientists observed the brains of college students when they juggle balls and noticed changes in visual systems. I think a more meaningful place to ask such questions is in regard to the neural changes – not just in function but also in grey matter – observed when children with dyslexia make gains in reading. Studies on these topics also have the benefit of pointing us to areas to which we may not have paid much attention. When we see changes in anatomy, they do not necessarily map onto the same areas where we see changes in brain function. This reminds us that the issue is very complex, and that we need to pay attention to more areas of the brain. This in turn refocuses our designs of new studies.

As a further example, a study by Fumiko Hoeft shows how functional MRI data is predictive of reading in children with dyslexia two years down the road. This begins to show you the transition from how education may inform and influence the design of neuroscience studies to the other way round. We are now looking at neuroscience perhaps playing a role, together with education, in understanding which brain areas can tell us something about which children may be more or less likely to succeed. Another way to think about this gets back to Dr. Denckla's comments on brain readiness. I think there is great potential in understanding when a child is ready to learn to read by looking at anatomical or functional data. We can then proceed appropriately in terms of the educational setting.

One of the interesting things about reading is that reading itself changes the brain. A study published in Nature a few years ago by Cathy Price's group shows that when you teach reading skills to adults who have never had the opportunity to learn to read (in this case, because they were involved in guerilla warfare in Colombia) and then compare them to their peers, you see changes in brain function and brain anatomy. Learning to read changes the brain. This is interesting, and becomes important when we consider disorders like dyslexia and identify differences in the brain between dyslexic children and their peers. Now we are beginning to ask why these differences are there. Are the anatomical differences in dyslexic brains the cause of the reading problem or are they the consequence of children with dyslexia not learning to read at the same level as their peers? There is a sort of circle: we know that the brain in has some kind of readiness, and that some brains are more likely than others to succeed in acquiring reading skills, but we also know that the act of learning to read itself changes the brain. This is an important concept that we should keep in mind.

Finally, another area where we can make advances in bridging the gap between education and neuroscience is by using study designs that are more valid. We should try to compare individuals with dyslexia to their age-matched controls as well as to children who are younger and reading at the same level.

I will give an example of where we have recently applied these principles of study design. Dyslexia is controversial in some regards; there are many alternative theories about what causes dyslexia. One area I have been interested in is the role of the visual system, particularly an area of the brain that is involved in visual motion perception, where there has been evidence for some time of differences between dyslexic and non-dyslexic students. We illustrated these differences by comparing dyslexics and non-dyslexics and showing that V5/MT, an area in the dorsal visual stream, is different in dyslexic and non-dyslexic students. We recently found that that difference disappears once you match the dyslexic students to younger, typical readers. This perhaps suggests that the difference is not so much a cause of dyslexia but rather an outcome of not learning to read. We are learning more and more about what reading does to the brain, not just in terms of reading but also in terms of visual processing (which has also been found in other studies). We can then apply a very common type of intervention approach, where we have students improve reading skills by learning phonological awareness, and we find that students who complete this intervention not only make gains in reading, but also increase the signal in area V5/MT, which is involved in visual motion perception. This suggests that the stronger signal is a consequence of improving reading, and we do not see it when students are involved in a math intervention that is happening at the same time, showing that it is very specific to the process of learning to read.

I aimed to show what we have learned from this field, and how we are beginning to integrate it into true educational neuroscience. We do not just understand the brain basis for things that students are learning in the classroom, but this knowledge informs our theories, provides support for theories and clarification on competing theories, and has a potential role in determining the best educational practices. We are really looking forward to more research into neural indices that may be more useful than behavioral data. For example, it has been somewhat disappointing that there are not very good behavioral markers for predicting future reading in students with dyslexia who are undergoing intervention. It may be the case that brain imaging will play an important role in predicting the outcome in dyslexic readers prior to an intervention and in telling us something about how they will fare in an intervention.

I want to emphasize again that there is a transfer of information in both directions between neuroscience and educational practices. Like Laura-Ann mentioned, there should be a true marriage, partnership, and common understanding between the two. Importantly, this marriage has to happen in order to bridge a gap that is still too large. Teachers want information on educational neuroscience; they are very excited about the concept. But if we as scientists do not provide the information for the teachers, that gap will be filled by others – and the rise of programs and approaches that have not had the benefit of proper studies is concerning. It is important that the information that is put into the schools has a research-based foundation. Thank you again for including me in the panel.

BRETT MILLER

Panelist

I have the benefit of being last, and I know some of the speakers ahead of me had similar content. Some of it will be a rather quick description of those points. One thing that will be useful for context for those of you who do not know me is that I hold a research portfolio at NIH. It gives me a different and potentially broader view of the research that is coming out. I benefit from a prospective as well as a retrospective view and it gives me the liberty to go a little broader than I might have done if I was still working in a lab.

What I want to hit on are a few examples of impact or potential impact. I am modestly more optimistic than Martha Denckla was on the lead end. It is worth keeping in mind that a lot of what we are talking about is at the micro level. For instance, we might be talking about reading instruction occurring within a classroom. All of these activities are embedded within the educational system, and we need to be thoughtful and keep in mind the potential ramifications to the entire system when we are making recommendations. We also need to focus on the structure of the system to make sure that the recommendations are actionable.

Today, we are conceptualizing and defining learning disability as a brain-based learning disability, and we are also going to touch a bit on plasticity. We have not necessarily seen the breadth of change in practice that we want yet. But we have certainly set the groundwork to move forward with some of the positive changes we have seen, and we are succeeding in empowering educators.

I am going to use reading disability as an example because it is in many ways the best-studied learning disability. There are some early differences based in how different people process sounds including early indicators of risk for reading disability. There was some work done in the early 2000s using EEG in infants, looking at responses to speech and non-speech cues and successfully distinguishing between at-risk and non-risk children. They discovered differences in how infants were processing these speech and non-speech cues predictive of their later risk for developing learning disabilities.

As a result, we have information about early indicators of risk. Some of them are behavioral markers, while others are neural markers. We can potentially think about how we can advantage ourselves and allocate resources in a world with limited resources to best help the people who are at the most risk for developing reading problems. We also have a good sense for the issue of heritability. There have been a host of behavioral genetic studies on its significance for reading disabilities. Heritability is often misinterpreted, but the key point is that reading and reading disabilities are highly heritable. The correlation varies depending on the metrics that you are looking at, but there is a strong genetic component. However, there is also a strong environmental component and gene-environmental interaction component as well. Note, we are primarily focused on identifying the risk factors rather than a mandated outcome.

I also want to discuss some finding from neuroimaging. We have used a host of neuroimaging technologies to give us a better sense of how the brain learns to read. Reading is a relatively new invention, so we are taking advantage of these biological systems that were already in place, primarily for language development, and using them for reading development. It is worth noting that the data in these slides is English-centric - note there are some differences in localization with other languages, but the general pattern is pretty consistent. I am also presenting high-level characterizations of the brain regions involved, so this is admittedly a simplified view of the developmental changes that occur.

At a high level, what you are seeing is some activation of various regions of the brain, particularly in the anterior and tempororoparietal regions of the left hemisphere. I am not suggesting a lack of involvement of the right hemisphere or the cortical region, but I will be focusing on the left hemisphere. As readers become more skilled, we see increased involvement of this left occipitotemporal region, which encompasses the visual word form area that Guinevere Eden mentioned earlier. As development occurs, you see more movement toward activation in the occipitotemporal region as well as more focal activation in anterior and temporoparietal regions. For our discussion, what is interesting is the brain changes in response to successful behavioral instruction - an example of brain plasticity. In response to a successful intervention, you can see movement towards normalization of system in response to instruction. After a successful intervention, a reader does not necessarily have a system that looks identical to a prototypical system. But there is a migration toward more focal activation and a movement toward that left occipitotemporal region.

Another important finding in the development of reading is that plasticity extends well beyond early childhood into adulthood, as Guinevere Eden mentioned. The study that I intended to list here discusses the use of repetition and the variation between high-repetition and low-repetition words to demonstrate that brain systems of individuals with reading disability still has a certain inherent amount of plasticity. This is important when we consider development of new or enhancing existing behavioral interventions for these learners. Currently, we have a greater success when intervening with individuals early. The current state of the science is finding it challenging to help later readers who continue to struggle. These individuals have frequently had a host of instructional interventions over a period of years and may have been minimally responsive to strong, efficacious instruction. As a result, we are likely looking at a more truncated set of individuals here rather than a broader set of readers. Some of these individuals also have not received what would have been the best solution for them and we are now left with students even further behind. . As such, we need to think about dosage and the length of time that we are giving intervention and the types of intervention when we are treating individuals who have had an ongoing long-term struggle to gain a skill, in this case reading.

One of the key insights we can derive comes from understanding what we mean by minimal response. We need to better identify characteristics of learners who are likely to be minimal responders to interventions and to do so early on so that we can identify these individuals early on and thus treat them more effectively.

To enhance learning we can also think about other biological factors that influence cognition - one of the key factors that we look at closely at NIH is the role of sleep. For example, you can think about sleep role in learning in terms of consolidation of memory and in terms of recovery from cognitive fatigue. You want people alert and ready to learn when they roll into school. There are some recommendations that are relatively straightforward, such as adjusting school start times later to allow for more time for sleep. Some studies show an increase in overall length of sleep and in alertness while at school when this step is taken. Harkening back to my early comment about thinking of schools as systems, there are potential impacts of making this change to the system, with the understanding that making such changes can have some unintended consequences.

Another often-discussed issue is teacher training. We can enhance their professional development with basic knowledge about the relationship between neuroscience and education. These individuals, and the broader administrative staff at school, are the ones tasked with formulating the broader structural changes implemented at schools. Note this should be a reciprocal relationship – science informing practice informing science - to take their issues into account while conveying the state of science at a level that is actionable for them. My recommendation is not to have everyone be neuroscientists but to make sure everyone has functional knowledge. In this case, they are going to need to make decisions about the nature and timing of an intervention. Basic knowledge of the neuroscience of learning will give them a better sense for how to evaluate packages being marketed and described as brain-based, and give them a better context to understand what is truly brain-based and what will work best in their particular context. We need to give them a framework to see neuroscience in the context of behavior.

Another key point is that we need to apply principles from cognitive science and cognitive neuroscience into training. The onus is on us to apply these principles systematically in training. We cannot hold one-off training sessions on a topic and then expect someone to go into a school setting and implement it. We need a long-term, more concerted effort to build this understanding. We need to remember that we are working with an integrated service-delivery system. Science can interact with both system-level and classroom-level changes and we need to create functional partnerships at both levels.

Lastly, we have to remember that our actions can have unintended consequences. For example, delaying the start of school can sometimes force after-school activities to be held before school for scheduling reasons. You can have the system working with you or against you, and that is why we need to work as a team on both the neuroscience end and the education end and to find out what our partners' needs are. This will also give us the ability to self-reflect on whether we have the data to meet their needs.

PANEL 1 QUESTION & ANSWER

The panel combined the individual expertise of the speakers to discuss how neuroscience research can be effectively translated into the classroom. Currently, our education system does not rely on the science of brain development. Individualizing the curriculum to each student's needs and standardizing it to peak periods of readiness will greatly improve the education system.

Changing the education system can start from a bottom-up approach beginning with teachers and parents. Currently, teachers are receiving inadequate training in education neuroscience and have difficulty carrying information back into the classroom. Parents are hungry for information and are willing to use any available resources to improve their child's performance. The gap in communication between research, educators, and parents is an entry point for those more interested in profits than education, which creates practices that are not based in science. Working with teachers and parents to provide reliable techniques and tools could be the first step in changing education policy.

Neuroeducation research does not currently influence the timing and content of lessons, but doing so can improve performance. For example, neuroscience data shows that students exposed earlier to multiple languages demonstrate improved linguistic abilities, yet secondary languages are not commonly taught until middle and high school. Furthermore, funding is often cut from the arts and physical education. These fields encourage computational processes, cognitive analyses, and spatial awareness, all of which are vital to math and science. Understanding the applications of neuroscience research to education is key to its successful implementation. These implementations will develop a more effective school curriculum with a focus on early language acquisition, the arts, and physical education, etc. Additional research should be conducted in classroom settings and with input from students and parents.

Jay Giedd
Dr. Denckla, one of your most powerful statements was that your grandchildren's education was worse than your children's education. That is a bold statement, given that we now have the Khan Academy, TED talks, and other similar innovations. What obstacles prevent us from using these modern technologies to improve?

Martha Denckla
These technologies do not address the main problem: the development of the human brain. No matter what technology you have at hand, you cannot get blood from a stone. You cannot force students to exceed their developmental readiness. My middle son, who is mildly dyslexic, went to school in a very good public school in New Jersey. It had multi-age classrooms and used a very individualized curriculum. He came out of the first grade saying, "I can read a lot of words but I don't get that phonics stuff," so we worked on that. In those first years, he had no homework. He learned at his own pace and he was passed along from year to year in his multi-age classrooms. He was never classified as dyslexic and went on to Columbia and Fordham Law and did fine. His daughter inherited his dyslexia and went to school in a similar area in New York at a similarly strong institution. She was asked to complete a first grade curriculum in kindergarten and became extremely frustrated. She developed school refusal and had to be transferred to a private school. She developed a hatred of school that has only been resolved now in the 7th grade, when we convinced the science teacher that answers that were misspelled but clearly correct should be counted as correct. The lesson from this example is that if you put pressure on people too early, it will backfire. Premature demands have very severe consequences. In my profession, we say, "First of all, do no harm," but I fear that is what is happening.

Jay Giedd
Dr. Petitto, my question for you has a similar theme. The timing of brain development and a highly individualized approach at the right age is a crucial one. How much can we individualize education with neuroscience?

Laura-Ann Petitto
I do strongly advocate for individualized education, but I also want to reinforce what Dr. Denckla said. There seems to be a mismatch between brain development, namely maturation over time, and education policy. They are sometimes at strong odds. What does knowing about brain development tell you? It helps you understand what types of information a child has peak sensitivity to at different stages of development. If we knew how to make that information available during each stage of sensitivity, it would be a tremendous advance. It is not the case that a child is wildly plastic. There are different stages that reach peak readiness at different times. In my own field, linguists were able to identify the different stages of language organization. Each component of language is mediated by its own dedicated brain area. The child has peak sensitivity to these language components, and the brain is more forgiving to some of those parts than others. A child is born with the ability to distinguish between any speech sign or hand sign. A remarkable brain change in the first year is that this open capacity attenuates over the first year of life. One of the jokes in child language research is that children get worse instead of better as they grow up. This is half-true: children lose the universal capacity to discriminate speech sounds but gain an increased ability to discriminate fine-grained sounds in their native language.

If you are learning two languages simultaneously, you literally wedge open that attenuation. The child's ability to differentiate those sounds stays open longer, which is related to gains in language competence and reading. We have this critical information about timing but look at our schools and educational programs. They are structured in a way that flies in the face of this biological information. There is a fear of early exposure to language and of introducing two different reading systems at the same time. Ironically, the brain sets up stronger reading systems when two are introduced at the same time. In contrast, when they are introduced sequentially, we do see transference and interference. We have research that teaches us about specific parts of language sensitivity and when the child has peak sensitivity, but we have a significant gap between that and education policy.

I think there are many ways we can bridge that gap. The brain is forgiving, and there are other routes we can take. The child can catapult over certain obstacles and there are compensatory processes. However, we do have the information necessary to facilitate optimal growth, and we can better utilize it if we can use neuroscience to marry educational policy, training for teachers, and expectations for society.

Jay Giedd

The educational system is sometimes called the largest uncontrolled experiment in the world, in terms of how much data should be available for these cognitive sequences. When you look at international education, it is striking how many approaches there are for when to teach reading. Finland starts teaching reading at 7 and they perform best on the age 11 tests. Maybe we should not learn reading until later. Some countries teach geometry first and others teach algebra first, but there is no compelling evidence as to which is best. There is a two-way street between neuroscientists learning from educators and educators learning from neuroscientists about the correct time to teach reading.

Guinevere, this is probably unfair because it is only peripherally related to the content of your talk. In terms of interventions, there is a burgeoning industry with things like Lumosity, computer-based, and online-based interventions. Could you share your thoughts on the current state and the future of these interventions, whether there is a path for parents to consider?

Guinevere Eden

This is something that I alluded to at the end of my talk, and it is important for several reasons. Parents who learn that their child has a reading problem go online and try to identify methods to assist their child. There is a lot of information out there and not all of it is based on solid research. As a parent, you do not necessarily know about the need for randomized controlled studies, in order to evaluate the efficacies of that kind of research. Parents are trying every available program; essentially, running in-house trials on their children to see if they benefit from one program or another. This is a problematic for several reasons. It is terrible for parents to fall prey to a less than ideal system. The Institute of Educational Sciences launched a website to serve as a clearinghouse for effective mechanisms, so we do have the answers. That is the equivalent of FDA approval for reading programs. It is a step in the right direction.

In the end, parents and scientists need to be able to work with teams of professionals. At the International Dyslexia Association, we try to make information available, so professionals and parents can understand what to look for, what questions to ask, and when to choose an avenue for your child. It is very hard as a parent, even once you understand those principles, to stick with them, because it is a very emotional problem. In neuroscience, we have seen interesting programs in reading, executive function, and working memory that seem to change behavior. After a few years, once more research has been done, the excitement wanes because it did not live up to the promised expectations. Another disappointment is programs that rely only on internal claims with no control groups. They are very seductive because they are based on statements. They will cite publications saying, "This paper is evidence that our program works," when in fact the paper has nothing to do with their program.

People are very convinced when they hear that this program changes the brain. It is not just changing the brain; you are trying to change a child's behavior. You can teach people to become better at staying on task. How well do they generalize on skills that are important to success in the classroom? That is where scientists are hesitant and not good at communicating findings to the educational community. In the absence of that communication, a void opens for people more interested in making money than education. People in education then grasp for these programs, even though they have not been validated.

Jay Giedd
I am much more in line with Laura-Ann. I think we have made amazing progress. But as a parent, I am frustrated as to why my child has not seen this in action yet. Brett, to return to your retrospective notion, what do we need to overcome to get these advances into the classroom? What gets in the way; why is a paper that discusses how to memorize things, decades later, not implemented in classrooms?

Brett Miller
There is an expectation that there will be a delay in going from the lab to the classroom. Part of that is a good thing. We want an opportunity to replicate and to have a better understanding of the phenomenon. We will have a better understanding if we are thinking in the context of intervention. We need to decide how to train interventions, what to transfer, and how it will all fit into a broader context. That aside, there is a host of barriers to getting something efficacious into practice. The education system is not optimally designed for easy penetration of information. The system has multiple different levels. There is a local level, a state level, and a federal level. There is a system where individuals at each level are making decisions. There was a comment about the Common Core state standards, which is a state-driven process. There has been some encouragement of these standards from the Department of Education. But it is a standard, not a policy; it does not tell you how to enact those standards, and you have individual school-level implementation. We need information about what the implications of these practices are. We need to understand state-level professional development, and we need to make sure this information gets to policymakers so that informs their policies.

The idea is to provide flexibility where flexibility is appropriate, while constraining to give policymakers a scope for what we want them to focus on. We give flexibility on the implementation of an intervention, but we expect feedback regarding each of the groups. For instance, for individuals with learning disabilities, we need to make sure we are seeing movements within each subset, such as individuals from an impoverished background. Then you have monetary aspects. You can imagine a training scenario where there is professional development available, but it is difficult for teachers and educators to find time to fit it in. Administrators must make difficult decisions about where to put their resources. Then you have issues following that training. Say someone has been introduced to certain concepts and what the ramifications are for instruction. But there is no follow-up for the professional development. That teacher may not have the opportunity to come back and fully reflect and discuss some of the challenges they had because there was no money for that extended training. Behavioral change is slow: it takes time, and it takes resources.

Jay Giedd
I think some high-level policy changes could potentially be helpful. In the community here, an issue is the public schools. The private schools have games and enriching activities. In public schools, this is not how they are assessed, so there is significant resistance. But with something like the AP psychology curriculum, we could do something like this in fifteen minutes and get a huge number of data points that would greatly improve our understanding. But there is tremendous resistance to this, which I do not understand, because it would be great for the students, the teachers and ultimately the country.

Brett Miller
I do not think we do as good of a job at articulating similarities in message when policies change. We have this underlying current of understanding what good practices are, but it is not enough. We switch from one initiative to a different initiative at the policy level without fully explaining to the practitioners that we are retaining the efficacious parts and adjusting them in light of what we have already learned. A second point is that if we are implementing a program in practice, we do not have data regarding its efficacy. We are essentially doing a natural experiment. This is not necessarily a bad thing, but it is important to keep in mind.

Robert Slavin
I am not a neuroscientist, but I follow education interventions. In making the link from neuroscience to education, a lot of the conversation has been unrealistic. Anything you do in the lab is establishing the basic science. Forget the concept that it will impact schools, it simply will not, and if it does it may impact them negatively. When things actually impact schools, they have been created to impact schools, tested in schools, and found effective in randomized control trials. Often people try to skip that step, but doing so causes disaster. With a colleague, I did a study on technology strategies intended to improve reading, another one for struggling readers, and another one for math. All of the evidence suggests that these technology programs are not making much of a difference in improving outcomes. They were all based on great theory, and they made a lot of sense. In fact, there is hardly any program that does not have a good theoretical base and lab studies to support it. Until these technology programs have been formulated into something that can be evaluated and replicated it is not ready for schools. A researcher, until that point, is simply giving opinions. Your guess is as good as anyone's, and should not be presented as any better than anyone else's.

Martha Denckla
I do not think that anybody disagrees with that. I do not think any of us believes that any of this should be directly imported into a classroom. We struggle for cooperation and to perform these ideas in the large universe of public education. We also have the problem of generalization. Studies done in private school are not accepted, as they are found as a poor representative sample. There is also the cohort effect, in that case we have a good sample to observe. For example, the epidemic of ADHD is quite popular. In the case of ADHD diagnosis were made based on inappropriate expectations for age, when they should have been made on the basis of grade level. Through the cohort effect of research there is a burgeoning diagnostic category.

I am worried that the same thing is going to happen with learning disabilities. We are asking children to do things that they are not neurobiologically able to do. We are going to see an increase in pathologizing children. There have been unfortunate guinea pig experiments of arbitrarily doing things too soon. I am terrified of universal pre-K; it emphasizes the wrong things. Like Dr. Pettito said, everyone needs musical training and another language very early in life to help their development. Play is also critical for human development.

Bill O'Brien
There have been two summits on what you have been talking about over the last couple of weeks. One was a brain health summit on how learners can be taught to think, rather than taught to test. The other was an AAAS panel on science, technology, and arts and how they connect to future workforce competencies. Both of these events talked about the pragmatic concerns of invigorating future economies and how to think about the necessary skills. These necessary skills being STEM, critical thinking, creativity, and imagination. Johns Hopkins was very involved in a data consortium in 2008, which Laura-Ann was a part, that looked at arts and brain. What is the working knowledge about neuroscience that might inform policy on things related to imagination, critical thinking, collaboration, empathy, and other similar topics?

Laura-Ann Pettito
I was involved in the DANA Foundation's grant that asked questions about whether aspects of training in the arts - defined broadly as performance, visual, and musical arts - spills over and impacts children's ability to learn things that are non-art. Does it ramp up their capacity to do any complex cognitive analytical thinking? Does the pressure to comprehend complex patterns in music facilitate their acquisition of math or language? My partners and I were interested in higher cognition and critical thinking. Our goal was create a context that facilitated creativity. Using the grant, we all did individual studies. I researched dance and the impact of knowledge of dance. How does the knowledge you gain from movement sequences impact the acquisition of languages? In summary, the conclusion from the many studies was that education in the arts is vital to human brain development. It is not an encapsulated benefit. The facilitative knowledge that someone gets in a specific art has a significant effect on higher cognitive functions, analytical reasoning, and relational thought. Why then under financial stress is arts so quickly cut? Our findings demonstrated that the benefits of arts training extended far beyond the boundaries of the specific art. The computational processes and cognitive analyses enhanced their abilities to learn geography, science, and math. The kind of traditional subjects near and dear to our hearts.

This had a very broad impact on these children. We need to preserve and maintain this classical training because it has far-reaching benefits. We published a monograph which you can find on my website. With regard to the question, I agree entirely. When is the ball dropped? Scientists know that their studies have to be replicated, efficacy studies need to be completed, schools must get involved, and proper science done. But where is the gap to facilitate communication with policymakers who are making decisions at the state level and at the standards level?

Jay Giedd
Physical education is getting cut along with the arts. This is a significant problem. I was speaking to a wealthy entrepreneur who told me that ten years ago, he used to ask job applicants for the day's stock figures. Today, he said, anyone with a smartphone can find that information. The future will not require memorizing facts and figures. How do we use these technologies to advance use instead of simply replacing old skills? We need to search through this ocean of information to find the key facts and patterns. The arts help us do this.

People sometimes think creativity is like magic. That is not true. You can do a great deal to increase creativity in your life and the lives of your children. The arts and academics are not warring factions. They are inseparable and synergistic.

Martha Denckla
Reward systems are crucial to general learning theory. By removing the arts, we have eliminated the rewarding part of going to school for many kids. Research shows that learning movement and movement patterns is a neurodevelopmental substrate for conceptualizing 3D spatial rotation. This, in turn, is important in many aspects of math and science. There is a neurodevelopmental linkage between body movement in space and spatial awareness. It is as fundamental to spatial representation as pattern input is to language.

Jay Giedd
Should playing videogames be included as an art? Is there evidence that they are better for the brain than playing the cello?

Martha Denckla
You do not use as many muscles, so no. Even playing the cello requires two hands.

Guinevere Eden
We have done some research on this, and it shows that video games do enhance some aspects of attention. But that in many ways goes back to the issue of what works in the classroom as opposed to the laboratory setting. It touches up against what we theoretically think is possible, as opposed to what we see in a classroom setting. When we talk about brain research, a teacher responds by saying: "So what do I do Monday morning? How should that change my approach?" This is why our approach has to be reciprocal. Validating our results through large-scale randomized studies can ensure that our approach is even more robust and informed. Another concept that comes to mind, which Dr. Denckla referenced this morning, is that of predicting success. Why do schools not give every child a series of tests that predict his or her success in reading when they enter school? In China, a strong predictor of your reading success is how well you can

copy Chinese characters. There is a motor component that is an important aspect of that task. When people learn Chinese as a second language, the learning method of copying characters leads to a different neural signature in the student's brain as opposed to students who use a different method for learning the language. Different approaches can lead to a different brain system being used. Neuroscience is a method for validating teachers' approaches. Randomized controlled studies are proof of whether an approach works or not.

Dorothy Jones-Davis
We have learned that science communication is key with the public, not just among scientists. We have also learned that we can influence policy both top-down and bottom-up, but sometimes bottom-up is more effective. While it would be useful to tell Arne Duncan how important neuroscience is in informing education, there is plenty that can be done from the bottom-up. Plenty of things neuroscientists have validated with different studies and different cohorts are still not in education. I am speaking as the parent of a 5-year-old girl who is learning how to read while aware of the processes going on in her brain. What are the roles of parents and other community advocates in the classroom? People are hungry and excited to hear about neuroscience research, and they are eager to implement things that do work. No one likes to see their child struggling in the classroom with work given to them at the wrong time, and parents need the data that backs that up. Can we develop a toolkit that communicates neuroscience research?

Martha Denckla
I invite myself to parent association and teacher meetings all the time. I have been teaching teachers for the last five years in a master's program. Not only are you a parent, you are a voter. You can have an impact on policy if you incorporate some of these principles, such as the benefits of keeping art. To cite some learning theory, there has to be some positivity about school. Invite people who like to communicate in simple terms to meet with parents and explain it.

Laura-Ann Pettito
I agree that parents and teachers are hungry for information. They are excited and interested, and they understand how information applies to development. I am in the NSF's Center for the Study of Learning at Gallaudet, and we are working to ensure that there is a timely revolution in our thinking. We have tried the typical range of research briefs and seminars and tweets and fancy webpages. We are still searching for the magical bridge that affects change. Maybe, as Dr. Denckla said, your vote can help ensure that your politicians are knowledgeable about the same things that you are. And if they aren't, you should demand that they are. I think it requires high-level involvement. Share information with the President. Share information with Arne Duncan. But make sure these people understand the data at hand.

Alex Denker
I specialized in neuroscience and artwork as an undergraduate. The control I had over my program helped me realize that our pre-college education program is not student-centric. We do not give students the opportunity to choose how they want to study and learn. How can neuroscience be used to demonstrate that our brains are capable of deciding how we want to learn.

Guinevere Eden
Today we have focused on teachers and parents, but not so much on students. When I went to a private school for children with learning disabilities a few weeks ago, they were teaching the children about their brain. Doing that gets them excited, just like teachers. It gives them a framework to understand where they may have deficiencies and areas where they may excel. Teaching neuroscience early on is an important aspect of this process. It is not just bringing it to the parents, but involving students early on. The power to understand one's range of skills, strengths, and weaknesses and a mechanism to map it out is critical. Although these things have strongly been advocated for by schools that specialize in learning differences, it is applicable to all students.

Laura-Ann Pettito
Neuroscience does have insights into this. Specifically focused on concepts like reward systems and motivational systems and their influence on short and long term memory. Emotional impact and motivation certainly influence the durability and longevity of long-term memory. These isolated facts are not integrated in a meaningful way able to change a school system. Students benefit from sculpting and contributing to how they learn.

Phyllis Klein
My group lives more in the informal learning environment. We deal with lifelong learners. It is an opportunity to explore self-directed, project-based learning. Through our network, we have seen anecdotally that the type of effect that our work has on people and are trying to incorporate this into mainstream education. We would like to see schools add this as a resource, much like gym or art class. It is not just about the students teaching themselves or each other. It is more like distributed learning where we all come to learn together. Would places like ours be a possible research environment for your field? Having a repository for us laypeople to access your information would be tremendously helpful.

Juliana Pare-Blagoev
There are studies that show the brain can predict future outcomes better than any behavioral correlates. Have those studies caused big ripples in neuroimaging? Have papers explored which neural regions can better predict outcomes than behavioral studies, and then tracked those back to change behavioral interventions?

Guinevere Eden
This is an arena where we see a potentially pivotal change. It seems that the neural correlate has better predictive patterns than behavior. We cannot put an MRI machine in every school, but it has spurred the research community to investigate. We do not have longitudinal fMRI studies on children with dyslexia. There are some studies in the works, but there is a surprising lack of publications. This is difficult and expensive work to do. Ten years ago, we would have just done a careful behavioral evaluation. Today the costs of an MRI have come down and behavioral evaluations are still expensive.

It has stimulated a lot of interest and research. Many of these studies are done in groups and large populations to get the statistical relevance needed, but now we are transitioning to doing individual evaluations. Can we take a single person and apply our broad conclusions? We are trying to see if we can take a single scan and apply it to the algorithms we have derived from these groups. It is not there yet, but it is too enticing to ignore.

KEYNOTE SPEAKER WHY NEUROEDUCATION MATTERS: HOW THE SCIENCE OF LEARNING INFLUENCES EDUCATION PRACTICES

MARIALE HARDIMAN

Thank you for the invitation to foster discussion on why neuroeducation matters and I hope you will see how this conversation will expand on what was discussed in the first panel. I would like to begin by sharing what we are doing at Johns Hopkins to advance neuroeducation and then look at the field of education broadly, considering how the science of learning can inform pedagogy. I'll share some studies we have been doing as we train cohorts of teachers in topics related to the learning sciences and finally show components of a translational model that I designed to bridge relevant research with educational practice.

As Heather said, my background is in educational practice as a teacher and school leader, and I have been at Johns Hopkins as a faculty member since 2006. The idea of connecting brain research to teaching and learning was not all that new to me when I first joined the faculty. Early in my career, I earned a master's degree in learning disabilities and developmental reading. At that time, we knew that it was research from the field of neurology that led to the classification of learning disabilities and later the examination of reading development in children. Before the field of learning disabilities was recognized, educators thought that children who were not learning to read as well as their peers lacked cognitive capacity. In other words, students who had normal intellectual capacity were expected to acquire reading skills appropriate to their developmental level; if they did not, then a teacher might suspect that the student had some type of intellectual limitation.

Early definitions of what became known as learning disabilities (minimal brain dysfunction) focused on neuroanatomical differences in how information was received, processed, and expressed. Thus, we learned from researchers from multiple fields of the learning sciences that some students might have normal or superior intelligence but still not acquire reading skills at the same rate and the same way as their peers.

This knowledge really changed education in general and the approach to diagnosis of children with disabilities in particular. As Martha Denckla pointed, out the term minimal brain dysfunction arose because researchers suspected that something was going on differentially in the brains of children who experienced difficulties acquiring reading skills but who were otherwise quite capable of learning; the term "minimal" was used because scientists had notions but could not identify specific regions or processes that were affected; but as we heard this morning, so much research now supports what scientists suspected years ago about the neurobiology of reading dysfunction.

With this background early in my career, it was natural for me to turn to the learning sciences to continue to find research that could inform how students think and learn. The Neuro-Education Initiative at Johns Hopkins was designed to be a bridge between findings from the learning sciences and education. I listed here on this slide the many units and schools that have been involved over time with this initiative, which include the School of Medicine, Brain Science Institute, Department of Cognitive Science, Psychology and Brain Science, the School of Public Health and more.

During my first year at Hopkins, I was amazed to learn that there were about five hundred and forty brain researchers across all of these schools, and few collaborating to craft translation research that could inform education. So we started holding "learning lunches" to invite interested researchers to come together to share ideas and brainstorm how to craft translational studies that could inform teaching and learning. Luckily, Martha Denckla was a regular attendee at our meeting, and many researchers came just to pick her brain. At least three important and interdisciplinary studies grew from this work. Now, Johns Hopkins has instituted a university-wide Science of Learning initiative to address how basic and translational research can address formal and informal learning at all stages in life.

Our hopes with the Neuro-Education Initiative was to engage in the very activities that were mentioned in this morning's panel – the collaboration between scientists and educators. To that end, our first summit, "Learning, Arts, and the Brain," brought together researchers involved in studies funded by the Dana Foundation on the how the arts support brain development and learning. Over 300 educators and researchers attended a full-day symposium which included panel presentations and then smaller round-table discussions about how to move to the next phase of research and discovery on this topic. The discussions were recorded and formed the basis of the publication, Neuroeducation: Learning, Arts and the Brain. Similar summits in subsequent years focused on topics such as Attention and Engagement in Learning and the following year Stress and the Brain, which was co-sponsored by our School of Public Health and focused on the biology of toxic stress and interventions for children living in poverty. We also explored the topic of technology in education, examining whether cognitive training programs transferred to other domains of learning. The last summit that we held was "Executive Function in School Age Children."

At the same time, we developed a 15 credit graduate certificate titled Mind, Brain, and Teaching. Beginning as a regional face-to-face cohort, the program now is online and serves an international community of educators. The program is also now a specialization in our online doctorate of education degree. In our course work and professional development, we draw from interdisciplinary fields from the brain sciences, including cognitive neuroscience, cognitive science, and experimental psychology.

Now, I'd like us to look at the field of education broadly then consider what information from the learning sciences should be part of teacher training. So, I like to think about what we do in education as falling into one of three buckets. One, what are we teaching students (which leads to discussions about standards, especially the Common Core State Standards and curriculum). Second, how are we teaching children (and here we are focusing on instruction). And then, have students learned (focusing on assessments, especially standardized testing).

In education today, we are putting a lot of attention on the "what" of teaching through adoption of the Common Core State Standards. And I would propose that the last bucket – assessment – has in the last 10 years or more come to dominate our educational culture: Standardized testing and high stakes accountability initiatives seems to drive most educational decisions today. Some may argue that teaching kindergarten children to do academic skills too soon, as Martha pointed out earlier, comes from such school and teacher accountability initiatives.

By the way, I have never heard teachers express that they didn't want to be held accountable for their jobs or that we should not be telling the public how students are doing through assessments. Yet, I think the best use of assessment data is for instructional adjustment, not to decide whether or not teachers and principals get pay raises.

Finally, let's look what seems to be left behind in education initiatives: how do we teach students? I believe that transforming education for 21st century learners will best occur if we focus on how to teach students based on research-based strategies centered on what we know about how students acquire, retain, and apply information. And this is where the field of neuroeducation can make a difference. I believe that we should expand translational research and disseminate to educators relevant research on how students think and learn to inform instructional practices.

So now, let's consider what we believe teachers should know from the learning sciences. Our courses and professional development programs introduce teachers to content that we find is fairly new to them. These topics include the concept of plasticity – that the brain changes with experience – and neurogenesis, new cells can be generated at any age. We also focus on research on the effects of emotions on cognition. We find that in current teacher preparation programs, there is very little emphasis on the importance of social-emotional learning environments. In fact, many teachers still believe that there is no connection between the cognitive and affective systems. Just recently I heard a teacher telling students to 'leave your emotions at the door you are here to learn.'

Other topics that we explore include research about memory, attention, creativity, the effects of physical health, physical activity, and sleep on learning, and, as was discussed earlier this morning, potential relationships between the arts and cognition.

I show you this quotation from Nobel Prize winner Eric Kandel from his book In Search of Memory, "If you remember anything from reading this book, it will be because your brain is slightly different after you have finished reading it." I have heard him tell educators that when you teach children information that moves into their long-term memory systems, you are changing their brain chemistry. That is pretty empowering for teachers and it underscores the importance of understanding fundamental information about the brain and for strong research-based teaching strategies.

We also share with teachers what is not true about the brain that they may have heard from sources such as popular media – what is referred to as "neuromyths." Interestingly, when we administer a simple neuromyth quiz at the beginning of our training, we find that many teachers still believe in most of the myths. It's really eye-opening for them to learn that what they believed to be true is complete nonsense and they should not waste time and resources on trying to teach, for example, to the left or right side of the brain.

Teachers are also a bit jarred when learning that teaching to individual learning styles is now considered a neuromyth. This was a practice widely adopted in education although it had no significant research behind it. The concept is that some students learn best through a visual channel, through an auditory channel, or through kinesthetic experiences. To get teachers thinking, I asked them to raise a hand if they go home every night and write separate lesson plans for their visual learners, auditory learners, and kinesthetic learners. They typically laugh because, in reality, this would be a pretty time-consuming and difficult task; yet, interestingly, they uphold the belief that they should. We find that teachers do what makes sense by combining modalities to give students differentiated experiences and letting the task drive the mode of teaching. For example, when teaching a map skill, one would be largely using the visual channel, but in teaching the phonology of a foreign language, the auditory channel would clearly be the preferred mode of instsruction.

Finally, I'll share with you the framework that I designed to help teachers see how the research from the learning sciences could inform instruction in a systematic way. But first I'll share why I called the model Brain-Targeted Teaching. While a doctoral student at Johns Hopkins School of Education, one of my professors knew I had an interest in "brain-based learning." He told me that he that thought that was a rather silly term. He said, "Isn't all learning brain-based? After all, we don't think with our feet." So my response was that, indeed, we know that all learning occurs in the brain, but we also know that all teaching does not result in learning. Therefore, my idea was to design a model of teaching, targeted to what we know about how the brain thinks and learns. Therefore, the name "Brain Targeted Teaching."

In 2004, when I initially designed this model, I drew from thinking skills frameworks such as the Dimensions of Learning, Multiple Intelligences, Bloom's Taxonomy, and the meta-analysis of well-researched educational practices--works like Marzano's Classroom Instruction that Works. I showed how research from the learning sciences could further inform educational best practices.

In my first book, I suggested that understanding fundamental brain structure and function as well as the underlying research supporting educational practice was not necessary to implementing the model. About 10 years later, I now say the opposite. I believe that it is important for teachers to understand at least fundamental information about brain structure and function and research that can inform instruction. I believe that the more teachers understand reliable information about the brain, the less likely they will be to believe "neuromyths" that can cause them to adopt practices or programs that will waste valuable time and money. Additionally, as we learned this morning, neuroscience in areas such as reading disabilities combine behavior and biological findings to make diagnosis and interventions more precise. We need more of this type of research across multiple domains of learning.

We also have to acknowledge that it is important to be cautious in how we build the bridge from science to educational applications. As Bob Slavin pointed out, there are some great studies coming out of research labs that have been replicated in a variety of settings; however, there have been few subsequent randomized control trials in schools to test the findings on a larger scale. Clearly, it would be a mistake to widely promote a teaching strategy that has not been well researched in a school setting. On the other hand, I believe that teachers should not ignore the research.

What is the balance as we move the field of neuroeducation forward? Perhaps one solution is for teachers to become action researchers and test learning theories in authentic settings. For example, if scientists are learning about how to mediate toxic stress through certain interventions, why should we not try these out in our classrooms and schools? I also agree with what I heard this morning: teachers are intensely interested in information on brain research. We see evidence of this through the growing number of students who want to take our programs as well as the proliferation of books, workshops, blogs, etc. Yet, we know that it is important to provide teachers with reliable information and train them to be savvy consumers of any research, and to be especially wary of marketed programs that make claims that are not grounded in research.

So, while for many teachers, there is interest in this emerging field of neuroeducation, at the same time, they often feel confused by the plethora of information about brain research that they are learning from multiple sources, some of which are not particularly reliable. Based on my experience in working with teachers, many express the need for help with making sense of the research; they'd like to know ways to pull it all together and make this knowledge more accessible.

Solving this problem was one of my motivations for designing the Brain-Targeted Teaching Model. My goal was to present to teachers a cogent, organized structure for using relevant research from the learning sciences in teaching. In our academic programs and professional development, teachers examine research studies and then consider how findings can inform instruction within the organizational structure of the model. Over the years, teachers would tell us how this information has been important to their work. Yet, I still wondered what evidence existed that this information actually was making any substantial changes in teaching and learning. In examining the literature, I found several studies that surveyed teachers to determine if they believe that content from the learning sciences is important for the teaching and learning process. However few studies have been conducted to show if knowing this information actually makes a difference in instructional practice.

So our research team began to conduct studies to determine if robust training in topics relevant to the brain sciences produces any changes in teachers' knowledge of the science and their attitude about using research to inform instruction. We designed a professional development series and delivered the content to multiple cohorts of teachers in Baltimore. In addition to pre and post training surveys, we also observed instruction in a sample of classrooms pre and post training. At the end of the program, we conducted semi-structured interviews. Overall, in all cohorts we found significant differences on the knowledge and attitude surveys; through interviews we found that teachers were very purposeful in constructing teaching strategies that aligned with research findings they learned during the training sessions.

After the first cohort, we then conduced the same training for three more cohorts of teachers and added surveys on teacher efficacy beliefs to determine if knowledge and understand of how children think and learn changes what they believe about teaching. General teaching efficacy is the belief that good teaching can make a difference in student learning, and personal efficacy is the belief that one possesses the teaching skills to provide sound instruction. We felt that this was important to measure because efficacy beliefs have been shown to be correlated with and predictive of student achievement.

In cohort two, we compared the efficacy scores of the teachers in our training to a large sample of 600 teachers from a neighboring state who had taken the same survey but had not received our training. We also then compared our sample to a demographically matched control sample from the larger sample.

These slides show examples of questions from the survey. This question asked teachers whether they agreed with the statement, "When I really try, I can get through to the most difficult students." Ninety-two percent of the teachers who participated in our professional development agreed with that statement versus 66% of the large control sample and 68% of the matched control.

In another example, we asked teachers, "If the student did not remember previous information, I would know how to increase his or her retention." You would expect that teachers would know how to increase retention if a student didn't get something the first time. But about half of the teachers in the control group were either uncertain or in disagreement with this statement. Yet, 92% of the teachers in our training agreed with the statement. This suggests that the training may have increased teachers' understanding and competency to design alternative strategies to increase retention for students who did not remember previously taught content or skills.

Here is another example. First, let me underscore that we know that a child's home environment influences achievement, yet we still want teachers to feel empowered that what they do in the classroom can make a difference for all students. Again, you see that there is a big difference between teachers who received training and those who did not. The statement is "The influence of a student's experience can be overcome by good teaching." Up to 63% of the control teachers were uncertain or in disagreement that they could do anything to overcome a student's home environment, but 85% of the trained teachers felt that they could make a difference.

When we offered the professional development to two more cohorts, (cohorts 3 and 4), we conducted pre-surveys and post-surveys in teacher efficacy along with the other measures of knowledge and attitude. We found significant differences in pre- and post- scores on all surveys, including efficacy. It was interesting to note that novice teachers showed the greatest increase in efficacy beliefs post training. We think this is an important point as many teachers leave the profession in the first 3 to 5 years.

Regarding surveys about the usefulness of the training, as you see in the charts, surveys showed that 62% strongly agreed and 37% agreed that the information from the professional development had informed their understanding of how students learned. Scores on the question of 'Improved my overall practice' were almost equally divided between strongly agree and agree. Impressively, 79% of teachers strongly agreed that the strategies taught were easy to incorporate in their teaching.

This next study was conducted by doctoral student using a mix-method research design, which included comparing two demographically matched schools, one that used the Brain-Targeted Teaching Model and a control. He compared advanced reading scores on the Maryland School Assessment in six fifth-grade classrooms. You can see in the graphs how over time, the scores in the treatment school improved compared to the control. The most striking part of the study was that the most change in achievement gains in the treatment school occurred with students receiving free and reduced meals. This is interesting because learning disparities typically are greatest between students from families with low and higher incomes. While the study was correlational, we think it is interesting that using the model may influence how teachers provide instruction for all students.

Now looking at the Brain-Targeted Teaching Model, the framework focuses on six areas of teaching and learning that I call brain targets, and I'll briefly explain each one. The first area explains to teachers that there is a connection between the affective and cognitive systems. Dr. Jill Bolt Taylor says it well in her book, A Stroke of Insight. For those of you not familiar with her work, Dr. Taylor is a neuroscientist who had a stroke and then wrote the book describing her recovery. My favorite quotation from that work is "we think of ourselves as thinking creatures that feel, but biologically we are feeling creatures that think."

While studying the influence of emotions on learning, we review what happens when the brain processes stress. There is a growing body of research on the notion of toxic stress, and this information is especially important for teachers teaching working with children from high poverty homes and communities. We share research about how stress has been correlated with poor memory, diminished executive function skills, and poor self-regulation. After they review research in that area, we asked teachers to reflect on how they can provide instruction to address the special needs of students who may be exposed to toxic stress.

In the second target we focus on how the physical environment can contribute to attention and engagement. We explore how novelty in the environment can trigger attention and how to use this idea purposefully through changing displays, seating, and using alternate learning spaces. We also look at research on environmental factors such as light, sound, scent, order and how these aspects influence cognitive processes involved with executive function.

The next target focuses on using schema theory and the idea posited by Bransford that knowledge is not a list of facts but is organized around core concepts or big ideas. Research suggests that understanding connections among elements supports abstract thinking and conceptual development. Here we encourage the use of graphic organizers to give students big picture concepts of what they are studying. Our experience with using graphic organizers through concept mapping supports the research that it appears to promote a deeper conceptual understanding of content.

Moving to the next target, brain-target four focuses on teaching for mastery of content, skills, and concepts. Here we address how memories are encoded, processed, stored, and retrieved in working and long-term memory systems. Educators examine studies from the learning sciences that suggest ways to enhance long-term retention of important content.

In the panel earlier today, our panelists discussed the arts in relation to how learning an art form might transfer to other domains of learning and memory. During the Johns Hopkins summit on the topic, we found that educators were interested in knowing how the arts might also enhance the teaching of content instruction (known as arts integration). As we reviewed the literature, we found some quasi-experimental and correlational studies that suggested that arts integration might enhance engagement in learning and promote learning in broad areas. We were interested in how using the arts as a teaching tool might improve memory for what students were learning in non-arts subjects. Our theoretical framework derived from various "memory effects" studied in the fields of cognitive and experimental psychology that showed improved memory when students engaged rehearsal, generated information and engaged in certain types of elaborations. We believed that the arts naturally recruit a combination of these memory effects.

To test this, we conducted a small randomized control trial with about 100 students in a Baltimore city school. We developed 5th grade units in ecology and astronomy; one version used conventional instruction and the other embedded arts-based activities. The units were tightly matched for content, dosage (time teaching each content topic), order of presentation, and group or individual activity. The study was designed so that each group of randomized students received one unit taught through arts integration and one through conventional means. Four teachers taught one of the two content areas in both conditions to two different groups of randomized students so we could control for teacher effect. Observers were in the classrooms 60% of the time to make sure the units were being taught as designed. Examples of arts integration included acting out the process of the Big Bang, using dance movements to depict shapes of galaxies, and visual vocabulary journals in which students sketched the meaning of vocabulary words. For measures, we designed curriculum-based assessments that were administered before the start of each unit, after students completed the unit, then, as a delayed measure of memory approximately two months after the units were taught.

As we predicted, students learned about the same amount of information regardless of condition. We found no differences between treatment and control conditions in the post tests. But in delayed testing, the art-integrated condition produced significantly better retention. When we disaggregated the data by students' reading level, we found that the biggest gain using arts-integrated instruction occurred for students at the basic reading level. This makes sense, as we think that perhaps children with reading difficulties had a chance to express what they knew and learned through alternate pathways. While this group learned less than their peers at initial learning, delayed testing showed that they retained more of what they learned than peers.

We expanded this study with a grant from IES, increasing the study from 4 to 16 classrooms and designing two additional sets of units matched in the same way as the preliminary study. We are in the process of coding and analyzing results.

We hope that others will replicate this study and perhaps test not only memory but other constructs such as creative thinking and problem-solving.

So this now brings us to the next brain target. Here we focus on not just the acquisition of knowledge but the application of that information in creative problem-solving. I often hear teachers debate whether we should directly 'teach to mastery' or have children engage in learning through experiential projects. I believe that it is critical that we do both.

The science we focus on with this target is the growing body of research on how the brain processes ordinary thinking differently from creative, improvisational activities. Most of us know the work of Charles Limb and others who are researching creativity in behavioral and biological ways. In this target we encourage teachers to give students more opportunities for divergent thinking and to apply learning in real world contexts.

Finally, the last brain target focuses on evaluating learning. Here, we draw on the studies from researchers such Pashler, Roediger, Karpicke, and Butler who have done work in feedback, active retrieval, and spacing of learning events. Findings from studies on these topics can inform when and how teachers provide feedback and how they can design activities that recruits active retrieval of information.

So, as you can see, the Brain-Targeted Teaching Model covers a wide range of topics related to the learning sciences and provides teachers with an organized way to consider how findings might inform classroom instruction.

KEYNOTE QUESTION & ANSWER

Heather Dean
I found this presentation very refreshing. I appreciate that you have brain research from a broad base and are looking at how the teachers' attitudes are shifting. Could you elaborate a little more on teachers' reactions when they are exposed to neuromyths? How do you explain that the tentacles of neuromyth can reach deep into their own teaching? How do you help them start to extract them?

Mariale Hardiman
That is a great question. The left-right brain neuromyth is one that, unfortunately, many teachers still believe. It is not unusual for teachers to tell us that they think they are supposed to design learning activities to develop different sides of students' brains. So this is an example of how teachers are relieved when they learn that this is not relevant and they don't need to waste time designing learning that way. The same is true about learning styles, which typically provokes interesting discussions. Some even get angry because they bought into this neuromyth for so long. I find that sometimes teachers confuse this with the practice of differentiation, so we explore important ways that differentiation can occur outside of thinking of a student as a visual or auditory learner.

Ultimately, I believe the answer is to provide teachers with this information early in their career training so that they are not using strategies that have little evidence that they really work. Also, I believe that when teachers learn more about how learning occurs, they become more purposeful practitioners.

Audience Member
Your sense is that reduction in neuromyths is tied to classroom changes. Do you have measures that let you observe that trend and how their teaching changes related to that reduction, or is it based on the 'aha' moments in the sessions?

Mariale Hardiman
We definitely see 'aha' moments in our training sessions. Additionally, looking at neuromyths in instruction is the subject of recent research. Once study by Decker and her colleagues found that teachers who reported having some knowledge of brain research were most likely to believe in neuromyths. This seems contradictory, but the authors believe that the subjects in the study obtained the information on brain research from popular media and not from sound translation of research. This is a good reason to provide robust teacher training and professional development programs. Our research shows that teachers do change efficacy beliefs after our training. I believe that addressing neuromyths may account for some of the changes that we see in practice and in beliefs.

Audience Member
Are you getting a lot of attention from teachers? I would imagine that they would be interested. but don't know about it. Are you getting any interest from those who are training the teachers, and what is available to them? Are there modules that they download?

Mariale Hardiman
Teachers can study with us in Hopkins online in our five-course certificate program. They learn this model first and read research across a broad array of topics. Our courses focusing on cognitive development research and, in Martha Denckla's course, 'Neurobiology of Learning Differences' as well as a course in cognitive processes of literacy and numeracy. The certificate ends with a capstone project. They take one area that they are very interested in, perform an extensive literature review, try their own intervention, and share findings with colleagues.

There are other options available including a newly released professional development online module, Eduplant21. This was just launched and there are teachers now piloting it. It includes content and is a social learning network allowing teachers to dialogue with others about their work. We are piloting it with Johns Hopkins schools associated with the Center for Social Organization of Schools.

Mary Ann Gorman
You spoke about teacher efficacy beliefs and their ability to change, along with mindfulness training. Have you looked at changes in student efficacy beliefs, after they learned about their brains?

Mariale Hardiman
We have not done that research, but there are a growing number of investigations looking at student beliefs and their effects on learning and engagement. In partnership with our School of Public Health, we are conducting a feasibility study in a DC school, in which we are collecting saliva samples and assessing levels of cortisol in students at different times during the school year. We are also collecting stress and efficacy surveys. We are looking to see if there is a correlation with biomarkers and self- reports of stress. This study is occurring in a charter school that is

specifically designed to provide a protective environment for students in poverty. Results will be compared to a control school in the same area.

Jay Giedd
When talking about how to get neuroscientists into schools, we usually focus on the students. Do you think teachers will be receptive to being scanned? Can we identify good teachers, ones that are more empathetic, or better able to identify students emotional state with brain imaging? Much of teaching is about forming connections. Should you not focus on teachers, and not only students?

Jay Giedd
My final question is about feedback in terms of spacing, and how frequently it should be done? I assume actual frequencies might be quite different for a third grader, a sixth grader, or a high school student, but that is probably something that could be assessed by looking at different feedback frequencies.

Mariale Hardiman
I can think of a number of teachers who might be interested in participating in a study that looks at how their own emotional states influences student efficacy.

Frequency and spacing would be interesting to know developmentally. We are only at the beginning of understanding how that research might inform practice, thus informing teachers about those studies is a first step. If teachers know that a method has been replicated a few times in the lab, they might try a similar intervention in their own classroom. Again, our programs really encourage our teachers to constantly think of themselves as researchers. Teachers should actively look at their students and design their own action research to test theories to see what works best. And one of the best ways to do this is, as we have been discussing today, to provide opportunities for meaning collaboration between educators and researchers.Panel 2: Reshaping the future of education through neuroscience.

PANEL 2: RESHAPING THE FUTURE OF EDUCATION THROUGH NEUROSCIENCE

The speakers at the second panel supported their discussion of research findings with institutional perspectives on education. Neuroscience has equal influence on primary, secondary education, and post-graduate education. There is a similar evidence-based need for strong mentorship experiences, collaborative classrooms, and competency development. Education needs to adopt the concept that its programs and practices have strong neuroscience evidence behind them. Neuroscience can help to personalize education in similar capacities to the way that we attempt to personalize medicine. The summation of these practices can help to ensure that education provides long-term changes in academic achievement and quality of life.

GARTH FOWLER

Panelist

There is a lot of commonality amongst the panelist here. I too used to work here at AAAS for a couple years. I am very excited to be here. I am the Associate Executive Director for Education at the American Psychological Association. I am directly responsible for our office and our programs in graduate and postgraduate education. When I was listening to the presentations this morning, I thought I might be the odd man out. What I do and what I study is graduate education, how we get undergraduates ready for graduate education, and how to improve our masters, Ph.D. and professional programs. I will tell you about some big trends that are coming up in higher education administration. I will explain the motivation behind them and my thoughts on where neuroscience could be involved. I think it would be interesting to see how neuroscience guides these policies. Some are here to stay, some are experimental, and some are happening on campuses now.

To start that off, I would like to point that there is another office at the APA that does a lot of work in psychology and neuroscience in schools. A colleague of mine, Rena Subotnik, who is the director of the APA's Center for Psychology in the Schools and Education, co-authored a book, *Malleable Minds: Translating Insights from Psychology and Neuroscience to Gifted Education*. This is a theme consistent with the APA: how do we bring good science from psychology and neuroscience into education? With that said, I have four concepts I will discuss. The first is that higher education is experiencing a big shift from students as consumers of content to creators of content. The second is that learning and teaching are becoming increasingly decoupled from the traditional classroom experience. The third is that competencies and personalized outcome assessments are challenging and changing credit hours in traditional testing. The last one, which I find the most intriguing, is that students report that a strong emotional relationship with a mentor on campus correlated heavily with their job performance and their own well-being. This is independent across environments, whether they went to an Ivy League school or a community college.

The first idea is that students are shifting from consumers of content to creators of content. What does that mean? In some regards, in a traditional way, this is not new. Think about anyone who has a masters or a Ph.D. degree. They are creators of content in that they engaged in unique and new research to become experts in their fields. It is different now because colleges are renovating classrooms and laboratory spaces together so that students can actually learn something in the classroom and move straight to the laboratory to start investigating ideas. When I was a faculty member at Northwestern, we rewrote our pre-med biology curriculum. It was almost reversed. Our new approach tried to teach the students what the kidney must do to keep the body alive through lectures. We then went to the laboratory and asked the students to come up with possible ways for the kidney to achieve this goal. All of the lectures I had written before that time taught the students about the structure and shapes of the kidney, and therefore what they did. It was a switching of the lesson plan, but the idea was to give students the opportunity to create their own explanation for the function of the kidney and the learning mechanisms behind that exercise.

Colleges are also investing in “hacker spaces” or “maker spaces”. The idea behind these investments is similar to free-form industrial arts class in high school but instead, it creates spaces where there are 3D printers and graphing tables. Students can go to these spaces and create objects for classes or just as an extracurricular activity. It is a place for resources and a space for students to create things that apply to their own learning. Students are no longer consumers as students; they create their own learning methods.

Another trend is that learning is becoming increasingly decoupled from the traditional classroom. Massively open online courses present the idea that you do not necessarily need to sit in a classroom to learn. In the fall of 2012, around 2.6 million students were enrolled exclusively on an online distant learning program. They were getting some kind credential or degree, completely online. There are hybrid classrooms that promote an environment where students can independently learn through the multimedia resource of their choice. They can buy a book, they can watch set of lectures, and they can combine it in any way they want. When they come into the classroom, the the professor spends time guiding the conversation in a collaborative way to help everyone formulate or encode the information. The students do not get a lecture about it, but they learn it on their own, and the classroom space is spent trying to help them consolidate and bring it together. Colleges are completely renovating their residence halls. At Northwestern, I went through a renovation process where we were trying to create a living and learning center. In one of these spaces, there was a dining hall, classrooms, bedrooms, and computer labs. The idea was everything happened in one place. I was going to teach one of my classes in my residence hall. Instead of my students coming to me, I would go to them and teach to them in their environment.

The next trend is that competencies and outcome assessments are challenging credit hours. This trend is being led by professional societies and the idea here is that you do not get credit hours anymore. You set up a list of competencies, things and skills you must be able to display, and then we test them individually. Once you achieve all the competencies, you are done. You can be assessed on them individually and repeatedly. There are programs out there that just got permission from the Department of Education to offer complete competency based programs with no more credit hours. I think this is interesting because it is asynchronous. The students can approach these concepts and competencies on their own. I think this is intriguing. Is there linearity to how we should build concepts to make sure that we develop competent students? Does cognitive science have something to say about that? I think that it does.

That last trend is the idea of students who talk about strong emotional ties and the idea of mentoring while in school. These students succeed very well after a strong mentorship experience. They report that they have greater job satisfaction, they seem more engaged and happier in their careers and in the long term, they are less likely to have credit history problems. So there is some kind of social and emotional attachment that is occurring at the undergraduate and postgraduate level that is really affecting how well these students perform.

Where are the ideas and concepts in cognitive neuroscience? I think some of this falls into predictive planning, scientific reasoning, effective communication, and adaptability to scenarios. Those are the ideas behind a lot of these changes, especially for things like the "maker classes" and for the competencies. Students are more adaptive to scenarios when we let them practice on their own and give them feedback. My question is: what do we know about some of these executive functions in college and post-college students? Almost a third of undergraduate students are over the age of 25 now. Let us not think that all college students are 18-year old adolescents who have just finished all their neurocognitive development. We have heard earlier today that plasticity and development continues well past the adolescent ages. Some of the resources I have read say they continue into age 25. So what do we know about refining these concepts? I think at this point, it is mostly acquisition, which has been the focus of traditional neuroscience. How does acquisition occur at the graduate and post-graduate level? Then, it is important to consider the continuation of refinement of cognitive processes. People kept telling me that they were a sharper thinker after graduate school. What does that mean and how can we use this information to improve our education system? Thank you very much.

LAURIE CUTTING

Panelist

Thank you very much; it is neat to be back here. As Elizabeth was saying, we were both AAAS fellows, which brings back fond memories. It is particularly exciting to discuss neuroscience education because Vanderbilt University has been focused on how to build an educational neuroscience program, particularly a Ph.D. graduate program.

At the fundamental level educational neuroscience combines neuroscience and education. It takes research on brain development and uses it to better understand how to educate children. Nevertheless, it is a bidirectional relationship in that educational research also informs neuroscience, including how the environment may shape brain development. One thing I think no one has discussed so far is the amount of team effort necessary to do educational neuroscience research. It is clear that it takes collaboration between the educational establishments and neuroscientists for this type of work to happen. Thinking about all the different techniques, there is a broad range of things compiled into a neuroscience study that relates to education (and vice versa). This can include traditional paper-pencil testing, animal models, academic interventions, and even pharmacological interventions. There are many different types of neuroimaging studies that have been published examining both structure and functional systems in the brain across many different fields of cognition, thus illustrating the rich set of possibilities when we combine these two fields.

We need to think about development and growth in brain and education as dynamic and interactive process. Our brain is impacted by environmental factors, but also naturally changes over time. Neuroscience has the potential to reveal more about education. There are four principles that I think will help both fields inform each other. First, the outside does not always look like the inside. The second principle focuses on the wiring of the brain. The third focuses on how the brain can change over short time periods. Fourth, some studies have shown that the brain can predict behavior better than behavior itself can.

What do I mean by this outside and inside dichotomy? A simple example is males and females. A question we have asked is, "Do males and females process language or visual spatial information differently, even when they appear "the same" on the outside?" To test this we had individuals look at two words and asked them if they rhymed. We also presented them with a visual spatial task, a modification of the classic Judgment of Line Orientation task, which participants were asked whether a set of lines matched in orientation with another set of lines.

How are females and males not different on the outside? They showed almost identical levels of accuracy and reaction time for both of these tasks; however, when we looked at the activity in their brains, we saw differences. During the rhyme task, females showed more bilateral activation, whereas males showed left-lateralized activation. In contrast, for the visual spatial task, we found that males showed bilateral activation, while females showed more right-lateralized activation. This illustrates the idea of both groups performing at the same level, but the process by which each does it is different.. Therefore, although behavior may look the same, the underlying mechanism may be different.

What about the wiring? We have used a type of neuroimaging called diffusion tensor imaging that provides indices of white matter integrity, thus allowing us to focus on understanding the architecture of the brain. In the case of those with dyslexia we have examined the number of connections in one area of the brain known to be important for reading, the left occipital temporal region. In this study, we compared the connection patterns between this particular area and other cortical regions. We have found that those who are typically developing readers showed more connections from the critical left occipital temporal region to other reading and language related regions. In contrast, those with dyslexia showed more connections to the back of the brain, including an area that encompassed the primary the occipital cortex. These studies may help us understand further why some students have difficulty learning.

In terms of plasticity, what do we know about how the brain changes in short time periods? Do brain patterns modify if we implement techniques to help children learn how to read? Research suggests that we can predict behavior from brain activity better than from behavior itself. A study by a colleague of mine at UCSF explored using neuroimaging to predict reading growth over a year. She found that the neuroimaging measures were better predictors of reading growth than behavioral measures. Our own preliminary work has focused on examining the brain correlates of short-term reading interventions, where individuals receive 15-hours of reading intervention. Our findings show that although the individuals were not cured of their reading struggles, they did improve greatly; we even found statistically significant differences in this very short amount of time and on standardized measures. Interestingly, when we divided those individuals who grew in their reading skills versus those who did not, we found that the left occipital temporal region was predictive of those who responded to reading intervention.

So, where are we in educational neuroscience? We know that the brain reveals things we cannot observe from the outside. We know that the brain can be modified over very short time periods. We know it can be used to predict future performance. Furthermore, even beyond that which has been already mentioned, some are beginning to expand the already interdisciplinary work in educational neuroscience; for example, some of my colleagues and I are currently using information from educational, neuroscience and genetics perspectives with the goal of gaining a better understanding between the distinction and overlap of math and reading.

In summary, where are we going in educational neuroscience, and where might we be able to go? One area of potentially high value would be to use neuroscience methodologies to define the boundaries of developmental disorders. What I mean by that is that when you look at, for example, Attention Deficit Hyperactivity Disorder or other learning disabilities, you see that they exist on a continuum with inexact cutoff points. This is true for a lot of developmental disabilities, and is more problematic than other types of disorders, such as high cholesterol or high blood pressure, where the research can demonstrate a critical cutoff point leading to a catastrophic event (e.g., a heart attack). I think it is a lot harder to do that in education, in terms of pinpointing the ultimate end point we should be targeting. If we were able to figure out that level of refinement, it would be a major contribution of neuroscience to the field of education and child development. Better diagnoses typically lead to enhanced treatments, with the ability to greater tailor them to specific needs. Thus, one way that educational neuroscience can contribute is in helping facilitate an ultimate goal of, "Can we personalize education the way we want to personalize medicine?"

ROBERT SLAVIN

Panelist

This could be a historic moment or possibly a forgettable one. I have never given a speech on neuroscience before, so I am making this up as I go along. I am not a neuroscientist; I am a researcher who is applying principles of education and psychology to reform education at considerable scale. As Elizabeth mentioned, we have a program called Success for All that works in about a thousand elementary and middle schools in the U.S. and about another 130 in the U.K. If we put it in terms of a widely distributed school district, then we would be the third largest school district in America. So you could think of me as being the superintendent of such a district, constantly looking to find effective tools to try to make sure kids are going to be successful in school.

With the collaboration and assistance of other colleagues, I do a lot of reviewing of research in all different areas of education. I contribute to writing an educational psychology textbook and we just came out with the 11th edition. Each edition has included a section on the latest developments in neuroscience on the brain and its relationship to educational psychology. Every three years, I review this research. Each time, I learn that neuroscience is on the verge of discoveries that will transform teaching, but not quite yet. In any case, educational psychology textbooks, by their nature, are full of suggestions. They are not hard facts and they are not programs and practices that have been extensively evaluated and found to be effective. We work almost entirely in poverty areas, where kids must succeed. They are not going to get another chance to succeed as others might. Therefore, these are places where you do not want to be experimenting unless you are sure they are going to make a difference.

The problem is simply that we are not getting anywhere in education in America. The levels of performance in reading are just about the same as they were in 1980. Math has gone up a little bit but it is not a lot to take pride in. The gap between the performance of white, African-American, and Latino students has also been around the same level since 1980. It may be due to the different policy interventions by different administrations. My personal belief is that this will keep happening indefinitely until we adopt the concept that the individual programs and practices we use in schools should have strong evidence behind them. The difficulty is that there are not many such programs. They are growing, due to programs like Investing in Innovation and Institute of Education Sciences funded research that are focusing on pragmatic approaches that can be replicated. Evaluating these programs at scale is adding to the store of things that can make a difference. However, this list is still too small and many of the things that are on it do not make a massive difference.

So the point of intersection between neuroscience and education reform is that we need your help and we need it now. If neuroscientists can put effective tools in our hands, then we can put them to use. It is not an easy task but it must be done. We have to use science to establish the basic principles and form them into pragmatic and replicable forms for teachers. This can change if the neuroscience field can focus and lead to effective and replicable models. One huge factor in making this more likely now than what was possible before is the coming revolution of technology. Technology is improving rapidly and it can enable and improve learning. This ensures neuroscience has a greater potential impact and it provides entry points for large disruptive solutions for schools.

Current proposals about how to apply findings from neuroscience to education are drawn from tiny and controlled lab studies. They should not be ignored but they are not quite ready for primetime. We need to develop situations in which we can rigorously evaluate lessons that are drawn from neuroscience in education. I believe that there are research projects that show particular promise. One of these is the subject of kindergarten mathematics and its relationship to embodied cognition. In this case, children's kindergarten mathematics lessons can be supplemented by using their bodies to help them understand and retain ideas. This is derived from research that shows that when adults do mental math, the part of the brain they use is very closely related to the part that operates their fingers. Another solution is linking symbolic and non-symbolic representations of quantity. The idea here is that you can perform tasks like estimation by incorporating your whole body. Students are getting a sense that will stick in ways that ordinary teachings might not. There are many different areas that are worth exploring and I encourage investigation that can be done such a way that is pragmatic, practical and replicable for actual teachers in the field. Thank you very much.

LAYNE KALBFLEISCH

Panelist

Good afternoon. Thank you to AAAS and the Potomac Institute for the invitation. I am excited to talk with you about a body of work that has gone on since the mid 90's when the possibilities of a relationship between neuroscience and education first attracted my attention. As a former middle school teacher, I have taught in classrooms where I had inadequate resources to convey knowledge or, the students in front of me did not have adequate internal resources to process that knowledge. Those experiences led me to neuroscience. I thought about focusing on the learning environment: educational psychology asks what is happening in the environment, what is inhibiting learning, and what can we do to promote it? Then the other half of the equation is cognitive neuroscience: what is happening from the inside out and what clues can our brains and nervous systems give us about the optimization of learning?

In our enthusiasm for the endeavor, we, as scientists and subject matter experts, have missed a key step. As we move forward, we need to inform and teach people what we know. Scientific literacy is not common knowledge to the general population. We need to start educating people at a deeper level, so that we have scientifically literate consumers and people who can be our partners in problem solving. My first opportunity to comment in a public way about the potential for neuroscience to inform education was back in graduate school with my mentor Carol Tomlinson. She asked what some of the guiding principles might be that we could eventually apply on the educational psychology side of the problem? The following three principles became the basis for an article in *Educational Leadership*. First, intellectual and emotional safety are crucial to enabling what is inside the mind to come out and what is outside to go in. We know this from research that examines the relationships among learning, memory, stress and cortisol. Toxic stress is probably the greatest barrier to learning in this country today. The second suggestion was to devise an operational definition of stress. What is challenging to one person may be exciting for the person next to them. How do we mediate those differences in a group social setting? Finally, there is the idea that each person has to make sense of things in their own way and through their own experience. The theoretical term for that is constructivist learning. I always thought of it this way: you cannot digest someone's food for them, why would you think you can digest their knowledge? Examining those three principles were the beginning of my career in cognitive neuroscience.

Fast forward to a decade later, and the *Roeper Review*, a gifted education journal, asked if I would guest edit a special issue on the cognitive neuroscience of giftedness. It took over two years to put that issue together because I really wanted people to contribute from the bench and cognitive science. I did not want the issue to feed into the layers of neuromyth and fears about understanding individual differences. My contribution to that issue was a neuroscience primer written for education researchers and practitioners. It was meant to create a literate consumer base in education about cognitive neuroscience, the types of methodologies used, and our realistic limitations and expectations. As an example, let me show you a figure from that article that illustrates the time course of the blood oxygenation level dependent signal (BOLD) in the brain. It is the metabolic cue as to what activity is happening and where it is happening in the brain. Yet, that signal takes anywhere from three to sixteen seconds to peak *after* you have performed the action, answered the math problem, or read the word. When we look at the time course of observable activity in our brains and the metabolic processes underneath neural encoding, we lose a degree of sensitivity. Certainly, there are more time-sensitive methods like EEG and near-infrared spectroscopy that allow us to see more in real time, but we do not have the perfect method yet.

Appreciating this, I think of our central nervous system as an 'endogenous heuristic'. It is endogenous because that is the biological term for a system inside of us. It is a heuristic because we are fond of heuristics in education for figuring out how to create problem- solving methods. A few years ago, at the Potomac Institute, I was asked to talk about neurotechnology in education and whether we are intervening, enabling, or enhancing. In a subsequent book chapter, I talked about incremental change and understanding the social time course of learning in a classroom versus measuring the time course of learning in a laboratory and the status of intervention science. The idea that we know the brain is plastic: it is designed to respond to experience, we can measure it in a short time course and even over the course of an intervention. Yet, the ultimate question for us in 2014 still is, "Is there long term change?" This question applies to long term change extending into academic achievement as well as to quality of life. Did that person's life change as a result of this intervention? Are they happier, more stable, or more prosperous? The emotional connection, as well as the things that are predictive of that, that should be part of the gold standard for intervention science.

This year, I guest edited a special issue for *Frontiers* on constructivist learning. It focused on this idea that we learn from our own experience. It was conceptually and intentionally broad in order to capture as many different entry points as possible that would apply to this theory of learning. I searched for cutting-edge science from around the world that might constructively inform policy and practice in educational neuroscience. Between October of 2012 and just a few months ago, research was published on topics as diverse as the measurement of creativity, the potential benefits of music training, non-verbal reasoning, interventions in math, reading, and writing processes, and the genetic basis of reading disorders.

In a review called the 'Functional Anatomy of Talent', I provide a working definition of that construct. Talent is the word I use to describe giftedness. People say that is awfully general. To me, it is not as general as it sounds because it encompasses both intelligence and creativity. We tend to study these constructs separately from one another and I think the boundary condition between the two is where the insights might be. Also, talent is not a new commodity; there are artifacts of human talent that precede you and me by several hundreds of years. Talent is not confined to just our species. Indeed, there are broad literatures of cross-species expertise that inform our knowledge about our own intelligence. A future educational neuroscience should balance the applications of intervention and optimization to improve school learning, but also transfer to the quality of life.

To move forward into talking a little bit more about scientific literacy is the example of the notion of time. It is important to understand how different time is between a lab and the social environment of school or everyday learning. We all have been behind the wheel of our cars when all of a sudden a small animal runs out in front of us. You do not want to hit it, but you do not want to be rear-ended if you put on the brakes. In under a quarter of a second, in approximately 200 milliseconds, your brain calculates this information to help you decide what you are going to do. Yet, a cognitive neuroscientist would look at that same incident and think, "What part(s) of the visual cortex was localized?" Vision for something that seems straightforward and very fast is actually a highly complex computation in our cortex. In that example, even just a tiny fraction of a second can be looked at differently.

Now, I would like to focus on the OECD-CERI (Office of Economic and Cooperation and Development-Centre for Educational Research and Innovation) publication, *Understanding the Brain: The Birth of a Learning Science* (2007). The first version of this book originated back in the early 2000s, and illustrates how this agency helped define and prioritize educational neuroscience. The OECD thought it was important to bring together teachers, educators, and neuroscientists from around the world to talk about what knowledge was appropriate for the time. In otherwords, what do we think we know 'now' that is not going to be overstated or overgeneralized? That led to the 2007 publication – an exercise that I was fortunate enough to be part of in the 100+ people that participated in this second edition of the volume.

As we have heard many examples of neuromyth in today's session, the one that got my attention most recently is the left brain/right brain neuromyth, the notion that analytical processes are generated in the left hemisphere and that creative processes are generated in the right hemisphere. A recent special issue of *Roeper Review* on visual-spatial talent posits that those skills have high relevance for practice in the STEM fields. I had the honor and pleasure of working with Temple Grandin and we examined why visual-spatial talent is so important. Because school is a highly linguistic exercise driven by reading and writing, a balance has to be struck between nurturing those skills and recognizing and supporting nonverbal problem-solving skills. We have to think carefully about the difference between the science of schooling and the science of learning. If you take our education system today at face value, then it might be a request of policy makers to say to neuroscientists, "Could you optimize children to be successful within our current education framework?" We could be asked to set our minds to that. We could work harder to learn more about the processes of memory and practice, which are things we know a good deal about. However, the other side of that coin is that we are more focused and interested in the science of learning and shifting the paradigm. What cues can we take from the brain in its natural state to help educate better and improve quality of life?

A current priority in the policy world is devoted to the development of STEM education and supporting success in those fields. In that proposition, those fields are tied to our national prosperity. Visual-spatial talent is important for success in STEM and involves three main skills: mental rotation, pattern recognition and spatial navigation. In that special issue on visual spatial talent, we attempted to explain the left brain/right brain myth as it pertains to visual and spatial skills. Neuroscientists can tell people to not believe neuromyths, but we have to be able to give compelling justification for what is behind them.

If we parse that myth, we know that language is localized in the left hemisphere, particularly in males. To play devil's advocate, certain brain lesion studies have been able to localize function in the right or the left hemisphere, and you can see functional asymmetries in brain imaging studies. However, functional asymmetry does not equal dominance. The brain's two hemispheres coordinate activity. We understand that even when you observe activity on the surface of the left cortex that it is probably wired to some place deeper in the right hemisphere. In general, we have to get better at educating people about neuromyths as well as the reasons why people should dismiss them.

Back to these different visual spatial skills. First, mental rotation is the ability to recognize an object if it is moved to different orientations or angles. Research evidence illustrates that both left and right hemispheres of the brain contribute to mental rotation. Second, pattern recognition is the ability form internal mental representations of visual patterns and use those representations to solve spatial problems. Each of these involves the occipital and parietal cortices in the back of the brain and these pathways involve both hemispheres. Finally, spatial navigation is the ability to find your way around using cues from the environment. For all three of these skill sets, which make up the capacity to process and manipulate visual and spatial information, evidence shows that they involve both hemispheres of the brain, not just the left or the right.

A final point in parsing the myth, is something called the 'gift' of hemispheric cooperation. We looked at functional MRI studies on abilities, talents and expertise in adolescents and adults performing visual spatial and mathematical tasks. Research shows that people who have high levels of expertise draw from neural activity involving both hemispheres. The left brain/right brain story does not belong in the population's general understanding of neuroscience. Expertise and high-performance during visual problem solving are affiliated with neural activity in both hemispheres.

This brings me to my lab's research on matrix reasoning tasks. Psychologists use these tasks to identify aptitude in the general population and particularly with people who do not speak English as a first language or who have a learning disability. This task is touted as the way we measure human aptitude, it is the most universal measure of its kind. It is not perfect but it is our gold standard for how we measure aptitude outside of the traditional intelligence test. The educator in me noticed that many of the early matrix tasks (and neuroscience studies that use them) are based on matrix problems that are drawn more simply with black and white lines. As a constructivist, I applied this to the rooms where we educate our students. Classrooms are not made of black and white lines. Our world does not appear that way. The world has color and visual contrast. I thought we should use those black and white line matrices as a baseline to look at the contributions from the visual environment examining the importance of visual contrast and color in the human reasoning process. The ability to detect contrast is an important survival skill. As an infant, you do not want to crawl off of an edge (i.e. a step) and you learn very quickly not to go beyond certain boundaries because of contrast.

Color, on the other hand, is much more complex. It informs our art, design, and the pleasure we might feel or see in a space. If we are learning by experience, then we are influenced by context. Perhaps this is a good baseline measure for parsing the environment and how the environment might influence what is happening in the frontal lobes, where reasoning skills coalesce? We gave approximately 100 subjects a matrix task based on black and white lines. We added a color condition to the same set, and then we added a visual contrast condition to control for the addition of color. We also varied how complex those matrices appear by iteratively increasing the visual complexity or level of change. For one relation, we see that only one property changes across each of the three levels of the matrix problem. Then, there is complexity that changes down each of the three levels and across each of the three levels within the matrix problem. Previous research demonstrates that the frontal lobes do not process a complexity level of zero (where each level of the matrix is visually the same) or necessarily one relation, but it does get interesting at two relations. What we found in the color condition was that when the matrix starts getting complex (at one change with color), color speeds up and improves accuracy in performance in a way that the black and white lines and the contrast conditions do not. The take home message is that color boosts salience and helps organize what you are seeing. It allows visual complexity to collapse and supports optimal reasoning in your frontal lobes. The contrast results showed that the visual cortex was firing in tandem with the lateral frontal cortex, which supports working memory. Visual contrast was adding 'load' to the brain's computations for solving the matrix problem, but color was actually 'collapsing' that complexity and activating parts of the frontal lobe devoted to reasoning and problem solving. We concluded that color engages a 'reasoning heuristic' (efficient) while contrast engages a 'sensory heuristic' (less efficient).

In sum, one potential future of educational neuroscience involves collecting and applying information about how the brain behaves in its natural state within specific contexts and in knowing how specific contexts hinder or support learning. We need to find ways to meaningfully connect insight generated from the time course of the laboratory with insight gleaned from formal and informal learning processes that occur in complex social environments. A future educational neuroscience prioritizes the science of learning, setting goals to perhaps sharpen existing pedagogies while being mindful that a renovation is necessary in how we "do" school. In closing, I bring your attention to the American Educational Research Association Brain, Neurosciences, and Education Special Interest Group (AERA BNE SIG) that has been working assertively over the past three years to help bring together like-minded groups from across the world. Thank you for your consideration today.

PANEL 2 QUESTION & ANSWER

This panel focused on using neuroscience research to restructure curriculum, to inspire policies, and to implement new technologies. Neuroscience shows that using strategies like emotional appeal, spacing, and repetition are helpful in capturing attention and remembering information. Neuroscience can predict behavior, identify early weakness, and inspire rapid intervention. Performance and learning are also greatly influenced by social and economic factors. Training teachers in these fundamental neuroscience findings as well as in functional biology and neural anatomy helps them understand that the brain is one complex system. Funding for neuroeducation research cannot only come from the Department of Education. Support must continue to come from the NSF, NIH, and NICHD to allow research and teacher education. To maximize the benefits of a widespread approach, information and findings must be shared between these different agencies.

The change in curriculum can be coupled with available technology to create an enhanced education system. Disruptive technology changes how children learn and interact with the world. Technology like iPads gives students the ability to manipulate their learning, empower themselves, and activate their motor centers. "Flipped" classroom structures and Internet technologies can make education more universally available, but research evaluations of their efficacy are still needed. An important tool for neuroscience research is neuroimaging. These neuroimaging studies are difficult to translate into the classroom, but as technology is refined, more and more data will be provide an understanding of the learning brain.

Elizabeth Albro
This morning my fellow panelists have discussed how to test this research in schools and how to effectively bridge cognitive science, neuroscience, and the classroom. I work at the Institute of Education Sciences. Within IES, we have a program of research called Cognition and Student Learning, which intends to accomplish its namesake. The program is focused not only on education and the classroom, but also on the learning aspect of education. Currently, we are funding two large-scale research and development centers. These centers take principles of cognitive science, learning, and the spacing and assessment principles to change the way curriculum is delivered. One project is focused on science instruction. From it I am glad to say that the cognitive science interventions appear to have positive outcomes on middle school science learning.

Now, I am going to ask each panelist one question, and then I will open the floor for others to ask questions. As the parent of someone who just finished her first year of college, I enjoy thinking about post-secondary work. I am curious about your comment on how learning changes from high school to college. Could you elaborate on the process of students going from passive learners to creators of content, and whether the ability to create content should be limited to undergraduate students? Do you think there is something developmentally that makes that change occur? I might argue with you that it happens earlier on, but I would love to hear your thoughts on that.

Garth Fowler
I would say that this is a new trend. When I attended college I sat in a classroom, listened to someone lecture, then I went into the lab to try and employ those ideas. However, in graduate school or a master's program, I believe that's when you become the creator of content. It's an evolving concept.

The constructivist ideas behind learning are very interesting, which is that you "learn by doing." The proponents of constructivist learning suggest that students learn better by engaging in these things. I ask them please be thoughtful about your experiments. It would be different if you repeated an experiment 10 times; in most case though, only the final time is successful, which suggests that a lot of thought went into every retrial. Repetition is a higher-level function that engages executive function. Should this behavior be happening just at the higher education levels, i.e. in college and in graduate studies? Probably not. There is some application at the undergraduate or K – 12 levels.

What do we know about what is happening at the higher levels? I'd love it if they came in and did those same studies with our college and graduate students. It would allow us to see if they are exactly at the expected stage and principles for their age group.

Elizabeth Albro
My question for Laurie stems from what you said about the brain making predications for behavior than behavior alone. I think that is one of the most interesting findings from neuroscience. As a behavioral cognition person, I often argue with my colleagues who are neuroscientists and ask, "how is neuroscience going to add to what we do in the classroom?" My question for you has to do with the practical components of that. How do you actually use the predictions that you get from the brain in the context of school?

Laurie Cutting
I do not know. I think maybe what you're getting at is the idea that every scan taken is going to tell us lots of things. I believe that neuroscience will add additional predictability to behavior. From my perspective, the most useful ability of neuroscience research would be to refine behavior, thus eventually it becomes an iterative process. Predicting weakness in reading, math, and everything else may evolve during scanning, but at this point I see neuroscience as a useful and productive possibility.

Elizabeth Albro
Bob, you fit in a different category due to your neuroscience research. Might you elaborate a little bit on reshaping the future of education with neuroscience? Help us think through who should sit at that table. Laurie talked about the teaming pieces, a spectrum with cognitive science researches on one-end, teachers, and policy makers on the other end. Taking information acquired through research and giving it directly to teachers isn't a straightforward process. Who are the other players in this conversation or who should be a part of this conversation?

Robert Slavin
The other players that have to be involved in this conversation, in addition to the basic researchers, are the applied researchers. They are the people working directly with schools, creating programs,

putting everything together, and deriving information from basic research. They put the research into a practical form, pilot them in real schools, and evaluate them in studies, such as what we have seen in randomized controlled trials. The applied researchers have great purpose and understand the basic research. The teacher and policy makers must be in the conversation as well, in order to drive the whole process. They should work for the outcomes they care about, the society they want, and the school system of the future. The basic researchers inform the applied researchers on how to make things practical for teachers.

Elizabeth Albro

Layne, I have a question for you. I noticed in your presentation that you gave a history of the different ways you have tried to share information through the different components. I noticed many of these aren't targeted towards the teachers and policy makers. Your discussion on right-brain and left-brain work made me think of the nuanced way you are trained to think about neuroscience. I attended graduate school at the University of Chicago in the 80s. I remember taking classes on cognitive neuroscience and spending a lot of time learning about right-brain and left-brain. In class, we talked a lot about specialization and the need for coordination across the two hemispheres. The challenge became how do we best convey those kinds of nuances to teachers and policy makers?

Layne Kalbfleisch

I think we have some massive unlearning to do. We are going to have to start talking about how we train teachers, which is a question that has been raised a few times. How much do teachers need to know about neuroscience? I think they need some significant training, at least in functional biology and neuroanatomy. Once you start to learn about neuroscience, you realize that it's all the same brain. We don't have an emotional brain and a social brain. The brain knows what stress is, but stress is a unified construct to the brain.

How do we share what we know as specialists and translate it across the board? This is where I think policy is right to influence not only public education, but also teacher education. I think there are gaps in those processes where they connect. I have been working with elementary school teachers this semester; who are taking my class as the last one before they graduate. They say that they wish they had my class first. In the end, we have control over what we teach teachers. My efforts have been directed towards creating platforms where people can come together, talk, and create a discourse. You have also heard today that teachers are hungry for this information and want guidance. Our biology is as complex as our questions are, but we just need to start talking about it. The purpose of those platforms is to create entry points to garner good concepts. How many entry points can we create for people to enter from multiple directions and inform teachers on what they need to know? I believe we are ready to do this.

Laurie Cutting

I agree with everything that Layne said. Another benefit of giving teachers information is that it enables them to be good consumers of a different curricular and provides a foundation for gaining future knowledge. They are then able to evaluate information 10 to 15 years from now.

Heather Dean

The idea of disruptive technology has come up a little bit from this panel and from the earlier panel. We actually had a great symposium here last summer on disruptive technology in education. Everyone tends to focus on how it changes how children learn and interact with the world. Do you think that it is possible for disruptive technologies to change how students develop and learn?

Layne Kalbfleisch

It took a long time to institutionalize co-ops for reading. I don't think we are endanger of rapid evolution from that point of view; however, I know from my work with kids that touchpad technology works for students that are struggling in school. I had a nine year old say to me, "I want an iPad because I want to go like this and do like this." Students want to reach and touch things; there is a motor aspect to learning. Martha even talked about it at a clinical level, how motor learning informs higher-level learning in ways that we don't even appreciate. It engages a sense that isn't a typical vernacular in school right now. The ability to grab and touch knowledge can be accomplished with new technology.

Heather Dean

One could even argue the opposite. If students are learning more online, then lets flip the classroom to where the students receive the content before they enter the classroom. In that case, the students might encode the information in slightly different ways. Thoughts on this new flipped classroom structure and the research on this?

Audience Member

This is something that I study. It's astonishing how much conversation there is on blended learning, flipped classrooms, and things along those lines. No one has a remote idea what the impact is. For example, what is impact of the Khan Academy on education? Millions of people use it, but no one has the slightest inkling of what type of impact this might have. I believe that things are changing and moving in this direction. The big change is not in the nature of the technology, the nature of the software, or even how it's used; instead, it will be the universal accessibility of technology. The possibilities will be rather extraordinary when everyone has a computer at his or her desk and a computer at home. Whether those possibilities will be taken advantage of is a completely different question. Based on the history of technology you can almost be certain that it will not, but it's possible.

Audience Member

There has been a lot of research on visual and spatial manipulation in gamers. There is evidence that their time spent in front of these computers and monitors playing games contributes to their abilities for recognizing different visual shapes and rotations.

Robert Slavin

I think that is true and we are only going to see more students learning online. How can we set up processes to make sure students are getting content in the most efficient way? What if they are sitting in their own house and something crashes behind them or something draws their attention away? The Khan Academy's argument, in regards to student learning, is that a student should watch something 90 times until it is learned. Is watching something 90 times efficient?

Laurie Cutting
I think you are right, and those are the types of questions that technology and cognitive neuroscience can really help push. Neuroscience will give us the right tools to determine if things are effective. If we are going to do it, then what is the best way to do it?

Audience Member
In relation to what we are learning from neuroscience, the effects of stress on learning, and the best ways to use assessment to promote learning how can neuroscience support the direction that education is taking towards standard based learning? In addition, to what extent is this approach hindering the translation of neuroscience research into the classroom to enhance education?

Robert Slavin
All of what you just said has to happen. Each part of the system has to inform the other parts, in order for everyone to move forward together. In the last 20 to 30 years, neuroscience has often given after the fact explanations. People have tried to use the standards of learning (SOL) to justify many of the things they already believed. We have to get to the point where we trust the SOL. We need to ask questions of it that can give us answers, even if we may prefer not to have them.

Elizabeth Albro
How do we translate what we are doing in neuroscience into the classroom? It is very difficult to replicate the rigor of a lab in a classroom setting. This is because there are all types of things happening with varying dimensions that need to be taken into consideration. Standards' based learning sets a shared understanding of the content of knowledge.

For example, let's look at the differences of what happened between Mississippi and Massachusetts. Conducting an applied study and research study in Mississippi and Massachusetts for 7th graders would be difficult because the content being studied is widely different. With that said, you can't begin to conduct studies that evaluate generalizability of knowledge. The conversation has shifted to what we hope children will learn. It has nothing to do with how you teach it, but what we hope kids will learn. This notion provides opportunities for researchers to think about what is happening across the same developmental time points in children.

Erin Higgins
Neuroimaging studies have held us back from getting into classroom settings and doing neuroscience-like work. This is an issue across all applied neuroscience. Perhaps the technology of neuroimaging is an obstacle preventing applying research to the classroom. Due to the fact that technology is continually progressing, can someone comment on how the questions that we are asking now may be different 10 to 15 years down the line.

Laurie Cutting
Do you mean putting everyone in a scanner before and after kindergarten?

Erin Higgins
Technology is now available that is easier to use. For example, more movement is allowed, you can attach the equipment quickly, and you don't have to put gel in someone's hair. These kinds of things are allowing you to move neuroscience methodologies into environments that are not so tightly controlled. The movement towards more simplified technologies will affect how educational neuroscience impacts the classroom.

Layne Kalbfleisch
The use of technology, such as EEG, has given us the opportunity to capture things in real time; however, we are limited as you will not be able to capture a map of the human brain. Neuroimaging is labor intensive and expensive, but it's the only norming tool we have to examine ourselves closely.

The NIMH is focused on clinical disorders, but in order for us to better understand and investigate these conditions we must understand the healthy brain first. Having a complete picture of what is really going on using neuroimaging techniques that are sensitive, specific, and reliable has taken a long time. Without this work, we can't go back into the classroom, into any ambiguous behavioral situation, or into more socially complex situation.

Audience Member
Bolton's law is true. It's nothing like the millisecond level that you might hope for. If you throw a stone into a pond and it makes a ripple, no matter when the ripple happens, you know that a stone went in.

Who ought to fund the kinds of applied research that might drive the connections between education and neuroscience into a place where they are actually in classrooms? It seems to me that the answer to this question could be problematic. The power could belong to the Department of Education; however, the DOE only spends a quarter of 1% of all education dollars on research. In that case, should education research be bumped over to the NIH or NSF?

Robert Slavin
There is a NSF program, called "Cyber learning" and it is designed to focus on math and science in these flipped classrooms models, the information is transferable. It is not clear whether students are performing at the same level as they would in a traditional classroom setting. Implementing the "flipped classroom" model is difficult because we don't know how effective it is. As the NSF becomes more interested in STEM, I believe that they will begin to focus other topics as well.

Laurie Cutting
There are several of us who have had pretty good success with NICHD. I would have to say that they have been a significant leader in thinking about how to bridge education and neuroscience.

Layne Kalbfleisch
My work has been about investigating mechanisms, as well as asking questions that pertain to ability and disabilities. I have done work under the NICHD. There is a Georgetown project using neuroimaging to study Autism Spectrum Disorder in children. We found that their behavior didn't tell us anything, as all of our kids on the spectrum were just as fast and accurate as typical

kids on an attention controlled task. Their brain mechanisms though were completely different. This explained why people on the spectrum experience sensory overload, the front and back of their brains are not connected like they should be. The back of the brain, which normally computes sensory and motor processing, is doing everything else or is trying to do so. There is an indication that behavior is not as predictive of individual differences as we once thought, thus teaching should change.

Elizabeth Albro

One of the things that has been very fascinating for me is to contemplate how decisions are made in our government and how resources are allocated. Knowledge that has to be generated across the different agencies has to be distributed. Also, agencies like the NIH have a very strong mission to drive fundamental and basic research, as well as conduct applied research. Their research can be applied at the individual classroom level, small group level, multiple classrooms, or across multiple districts. On that same note, the research is occurring at varying scales. The NIH has funded a lot of the basic work foundational for my work at the Institute for Educational Sciences (IES). A great portion of our applied research is dependent on the work from the National Science foundation and NICHD. The NSF and IES collaborated about a year and a half ago to create the "Common Guidelines for Education Research." This was an attempt at a conversation between the National Science Foundation, Institute for Education Sciences, and the Office of Innovation and Improvement. The guidelines attempt to categorize the different types of research and bring to everyone's attention that not everyone can support research in all places.

The Office and Management and Budget have been encouraging federal agencies to incorporate the generation of evidence and research into program dollars. The vast majority of the federal government budget goes to creating more educational programs. The DOE has sent funds to support Title One schools and Title Three schools. The OMB has made clear that if research dollars are being used, then research evidence will be generated as part of the process.

Investing in innovation programs is the Department of Education's first attempt at making education research happen in the context of scale up development and validation work.

Don Hantula

There are other ways to think about funding neuroscience and education research. The NSF has a division of Education and Human Resources, which is an obvious source of funding. There also not-so-obvious places, such as our programs that pertain to decision risk and management sciences. A NSF research proposal to apply neuroscience research in the classroom probably won't go very far; however, the NSF has two criteria when it comes to evaluating research proposals: intellectual merit and broader impact. The broader impact criteria are not well known, which can't be overlooked anymore.

I could envision someone doing a very basic neuroscience project. They could present the project though in way that has a significantly broader impact, such as better informing STEM education or redesigning a program for bright undergraduates. If you have education research and are partnering with a more basic scientist, then you have the best of both worlds going on.

Evan Heit
In the Education and Human Resources Directorate, we look at all the types of research that are mentioned in the Common Guidelines document. This is a really good document for those who are considering translational work into schools.

In our portfolio, at the Education and Human Resources, most of what happens for educational neuroscience is basic research. One such program is ECR, which is a core research. We are more receptive to applied programs, such as the DRK12, a school-based program.

Jeff Colombe
Various branches of government are interested in human performance enhancement. One of the themes is the invasion of cognitive science techniques is making people operate more effectively. This is commonly seen at the professional level and less in students.

They are biasing peoples' understandings of how they should fit in socially or how their performance will be used in a social or economic context, by dialing up or dialing down their intellectual performance. By constructing this sense of inclusion and how we fit in with other people, my question is, what incentives and disincentives do you expect them to have in response to performance? How does performance get better or worse?

Layne Kalbfleisch
We are never going to take the social aspect out of learning. I think those expectations have more concrete effects then we think they do. My lab has been looking at social groups, decision making, and how fast and accurate people are in networks. We are starting to understand more about self-monitoring and the role it plays in learning.

Garth Fowler
I have spent a lot of time training licensed psychologists and forensic psychologists in continuing education. For someone who works a lot with professional development, those are some of the questions we are really trying to drill home, even in training programs. There is a whole revolution of developing competencies. In our professional psychology group we have focused on cultural competency and group competency. We are now telling programs about this, but haven't figured out how to implement it, as it is a new concept. We struggle with figuring out the best way to measure assessment and outcome. It is difficult to measure lifelong learning. Education has become a longer process, as it results in badges and promotions. It may be different than what we are talking about here, but it is still a form of learning.

Erin Heath
Does neuroscience support informal learning or learning outside of the classroom? What might it look like?

Elizabeth Albro
What does neuroscience have to tell us about how we learn in informal settings, such as museum learning or field trips?

Katie Gould
We are looking at how our audience learns from what we are covering and what is the best way to present information. Someone mentioned ISO learning, which we are currently looking into. My question to panelist is, what can we take from what we already know about education and neuroscience to deliver our message more efficiently? How can we convey our messages to higher level audiences?

I would like to go back to the news hour and say that if we present information in a certain way or if we provide different interactive tools, then we would be able to reach farther and help society learn about neuroscience.

Laurie Cutting
There are neuroimaging studies that look at the different ways of learning the same information. There are approaches more helpful for learning certain types of information.

Robert Slavin
I think your producers already know the best way to capture an audience, which is through emotion. "If it bleeds, it leads." This approach involves including people's families and personalizing the information. These are things that are supported by neuroscience, which is trailing the long standing wisdom.

Elizabeth Albro
What is your desired outcome? For example, if you want people to pay attention and not turn the channel, then you have to engage your audience. You need to capture the emotion of your audience, so they will continue to listen. If on the other hand you want people to remember the story long term, then there are different things approaches from cognitive science and neuroscience. For instance, things like spacing and repetition, which is something good storytellers do. There is evidence to support ways of better communication, but we are approaching the problem in a way that impedes our ability to get the message across.

Laurie Cutting
Evidence is emerging that says executive function plays a significant role in how younger kids and college students learn. In addition, going back to executive function, I think one of the good things about common core standards is that expository and narrative text is emphasized. This is a good thing. Expository text draws upon executive function much more than narrative text.

Layne Kalbfleisch
The end goal is to make the person in the teaching position fluent and facile with information, while making them able to assess individual differences with a greater acuity. In a complex environment, it has a lot to do with empowering teachers to see themselves as engineers. They have kids longer than anyone else, thus they are in a position to study children and how they best learn. Ultimately, I think that if we focus on teachers as being the agents of information, then our science will change and thus so will our practice.

Robert Slavin
In my opinion, there have been studies done at the undergraduate level, but not a lot. There are many untapped areas. For example, we realize that undergraduates still continue to learn and have brain development into their 20's. Studies have been already been done in 3rd, 4th, and 5th graders; however, it's unclear whether we should reproduce these studies in undergraduates. Should these studies be redone in those going back to school at 27? There isn't enough information to guide better policy decisions or best practices.

Elizabeth Albro
I invite everyone to visit, whatworks.ed.gov. There we have a series of publications called practice guides, which are intended to go into the hands of teachers. The first one was written in 1997, called "Organizing Study to Support Learning and Instruction," and was intended to synthesize information on cognitive science and neuroscience and to act as translational materials for teachers.

CLOSING REMARKS

JENNIFER BUSS

I want to thank you all for coming today to share your research and thoughts on how we can transform our future with neuroscience. The discussion today from the remarkable speakers and audience has highlighted the need for continuing research, programs, and initiatives for educational neuroscience. Thank you to all of the volunteers who came to help, and special thank you to Brian Barnett who helped all the organizing and planning.

Neuroscience is one of the most influential fields that has been impacting and will continue to impact our society for years to come. This series, co-sponsored by AAAS and the Center for Neurotechnology Studies at the Potomac Institute for Policy Studies, is reflecting on how neuroscience will intersect with so many areas of society – and we could do the same with the field of education. It is only wise that we combine the two in a manner that allows us to highlight the benefits of their impacts on society.

The Potomac Institute for Policy Studies is an independent, bipartisan, not-for-profit, science and technology policy think tank. We use science and technology to create policy, and likewise encourage policy that supports science and technology. To do this, we research the science and technology trends, identify the current landscape, and make long-term predictions.

Historically, the trends in education have shown us that with each technological revolution, there has been a drastic shift in society.

In the days of tribes, the master taught the apprentice. Training, mentoring, and life lessons were taught through story telling. One on one teaching. Generation after generation, elders continued the tradition of teaching skills and educating the young in the tribe. Then advances in technology brought classroom teaching (one to many), the printing press, books, and libraries. Individuals can then train themselves; they can learn on their own. Technological advances provided the internet! YouTube! Technology has enabled us to do the teaching ourselves.

The next technology revolution will be that neurotechnology advances us another step futher so we can have the knowledge at any time, at any moment, without having to learn. When education becomes an ancient pastime and the output is instant knowledge.

The Potomac Institute has described technology impacts on society in three phases: Phase I – new technology makes the old tools work faster and better. Phase II – things happen differently with a new process and new tools. Phase III – technology has so drastically changed society that there are whole new systems in place, culture or society shifts, new markets or industries, etc.

The phase impacts of neurotechnology with respect to education are recognizable. Phase I – people will learn faster because neurotechnology will make the old tools (teachers and books) work better. Phase II – the emergence of new tools for learning, personalized curriculum using neurofeedback, and modern day teachers will become obsolete, Phase III – knowledge at your neurons, automatic downloads, a whole new domain and societal norms. Humans will be able to learn when they need it, on demand, without intervention of others.

Incorporating neuroscience and neurotechnology into our education system has the potential to revolutionize the way every student learns as an individual – a unique and personalized education, tailored to their interests and highly interactive, allowing each student to excel in their own capacity. Imagine a child, engaged with their iPad-like device, that is teaching the child basic algebra at the age of 6. The device is reading inputs from the child and making informed decisions on the pace to teach the next lesson, the screen color, the choice of examples to keep the child more absorbed, all because we can customize the learning system to this individual. As soon as this child becomes disengaged with the topic, as all children do, the system 'knows' to give the child a break, with a quick game, or an exercise, measuring heart rate and blood flow, prior to beginning a new subject with the child.

This is just the beginning. In that scenario, I described the first two of three phases of impacts technology can have on society. Phase one – old processes happening faster. Phase two – the whole new processes of learning – personalized curriculum.

Now, imagine a future where training and education can just be downloaded into the brain the whole education can be just automatic. Where we immediately have the information there. We won't need an education that requires rote memorization or facts. You no longer teach multiplication tables or have to learn the vocabulary for a new language – translation is a simple download of information to the brain. Education will mean problem solving and cognitive thinking. The phase three impact. A whole new type of society. The technology enables a whole new system of thinking, a new culture.

Education as we know it no longer exists. Neurotechnology has vastly changed the way we interact with each other and with the world.

Education of our children is our future. We do not have to accept education as a static, unchanging field. We should expect a constant improvement in our education system and now, neuroscience provides us with the best tool to effect such changes.

TOM KALIL

At the Office of Science & Technology Policy (OSTP), I am interested in ensuring that great ideas from the research community inform U.S. science, technology and innovation policy. For example, at a recent workshop for neuroscientists and nanoscientists, the neuroscientists observed how far we are from understanding how the brain encodes and processes information. One reason for this is that there is a "missing middle."

Researchers can either measure real-time activity of a small population of neurons or they obtain approximate data from the whole brain, but they cannot observe the electrical and chemical interactions of neurons within entire circuits. Being able to observe these interactions would be instrumental in understanding phenomena such as memory, perception, action, etc.

After developing the framework of this problem, the organizations at the workshop came to OSTP. They argued that an investment in neurotechnology (e.g. in areas such as would allow neuroscientists to ask and answer new types of questions about how the brain works. We were intrigued by this proposal and brought it to the attention of leadership at NSF, DARPA, and NIH.

Ultimately, President Obama included the topic in his State of the Union address, and launched the initiative in April 2013. The President's FY15 budget includes $200 million for this initiative. Agencies have already awarded grants and contracts under the BRAIN Initiative, which is stimulating collaboration between researchers in neuroscience and the physical sciences and engineering. For example, researchers are developing promising new neurotechnologies that could have the same revolutionary impact that DNA sequencing had for the field of genetics in the 1990s. This example outlines how our process at OSTP works in a general sense.

For most people in the research community, the federal government is a black box. It is important to demonstrate how interactions between policymakers and researchers can result in new initiatives. When we are presented with new ideas at OSTP, we ask questions like:

- Will it advance national priorities?
- Does the idea have a coherent relationship between "ends" and "means?
- What public and private actions would be required to achieve the goals of the proposed initiative (for example, budget, legislation, regulation, public-private partnerships, etc.)?
- How likely is it that an initiative in this area would be successful?

Publisher's note: During Tom Kalil's remarks, he provided the opportunity for members of the audience to pitch a policy idea to him as a demonstration of his process. These topics are outlined below.

- There needs to be a scale-up in public outreach and education for neuroscience research findings. As crucial research findings are published, the government should create press releases and open lines of communication to support them.
- The government can incentivize usage of evidence-based education practices by incorporating compliance into the grading scale that determines which schools are awarded funding. This provides administrators with direct motivation to seek out research-backed education programs and practices.

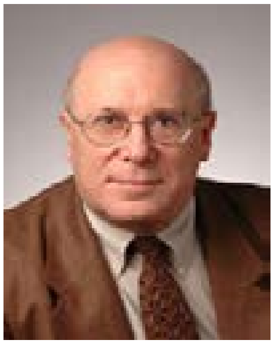
- Researchers should coordinate a multi-laboratory workshop on neuropsychological assessment databases. There is a scarcity of neuroimaging research, especially for longitudinal studies. Implementing collaborative research designs that increase the number of participants and reduce resource burdens will have a direct impact on the quality of neuroimaging and assessment of student populations.

- Focus on teaching to developmental readiness instead of teaching at standardized grade levels. Avoid adding additional layers of assessment and administration where students are not ready to take on these challenges.

ALAN LESHNER

Chief Executive Officer of AAAS and Executive Publisher of *Science*

Dr. Leshner is the Chief Executive Officer of the American Association for the Advancement of Science (AAAS) and Executive Publisher of the journal *Science*. Before this position, Dr. Leshner was Director of the National Institute on Drug Abuse at the National Institutes of Health. He also served as Deputy Director and Acting Director of the National Institute of Mental Health, and in several roles at the National Science Foundation. Before joining the government, Dr. Leshner was Professor of Psychology at Bucknell University. Dr. Leshner is an elected fellow of AAAS, the American Academy of Arts and Sciences, the National Academy of Public Administration, and many other professional societies. He is a member and served on the governing Council of the Institute of Medicine of the National Academies of Science. He was appointed by President Bush to the National Science Board in 2004, and then reappointed by President Obama in 2011. Dr. Leshner received Ph.D. and M.S. degrees in physiological psychology from Rutgers University and an A.B. in psychology from Franklin and Marshall College. He has been awarded six honorary Doctor of Science degrees.



PHILIP RUBIN

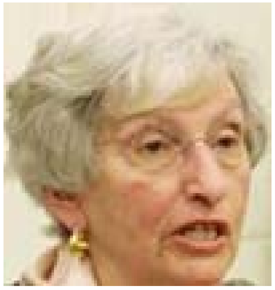
Principal Assistant Director for Science, Office of Science and Technology Policy

Dr. Philip Rubin is the Principal Assistant Director for Science at the Office of Science and Technology Policy (OSTP) in the Executive Office of the President of the United States, where he also leads the White House Neuroscience Initiative. His responsibilities also include serving as the Assistant Director for Social, Behavioral, and Economic Sciences and serving as the co-chair of the National Science and Technology Council (NSTC) Committee on Science with Dr. Francis Collins of NIH and Dr. Cora Marrett of NSF. He is on leave as the CEO of Haskins Laboratories in New Haven, Connecticut, where he remains as a Senior Scientist, and is also a Professor Adjunct in the Department of Surgery at Yale School of Medicine and a Fellow of Yale's Trumbull College. Rubin is a cognitive scientist, technologist, and science administrator who for many years has been involved with issues of science advocacy, education, funding, and policy. His research spans a number of disciplines, combining computational, engineering, linguistic, physiological, and psychological approaches to study embodied cognition, most particularly the biological bases of speech and language. He is best known for his work on articulatory synthesis (computational modeling of the physiology and acoustics of speech production), speech perception, sinewave synthesis, signal processing, perceptual organization, and theoretical approaches and modeling of complex temporal events. From 2000-2003 Rubin was the Director of the Division of Behavioral and Cognitive Sciences at the National Science Foundation (NSF), where he helped launch the Cognitive Neuroscience, Human Origins (HOMINID), and other programs and was the first chair of the Human and Social Dynamics priority area. He was the NSF ex officio member of the National Research Protections Advisory Committee (NHRPAC) and the Secretary's Advisory Committee on Human Subjects Protections, both advisory to the Secretary of the Department of Health and Human Services, and was the Chair of the inter-agency NSTC Committee on Human Subjects Research Subcommittee (HSRS). From 2006-2011 he was the chair of the National Academies Board on Behavioral, Cognitive, and Sensory Sciences. He is also the former Chairman of the Board of the Discovery Museum and Planetarium in Bridgeport, Connecticut. Rubin is a Fellow of the American Association for the Advancement of Science, the Acoustical Society of America, the American Psychological Association (APA), the Association for Psychological Science, a Senior Member of the IEEE, and an elected member of the Psychonomic Society and Sigma Xi. In 2010 he received the APA's Meritorious Research Service Commendation "...for his outstanding contributions to psychological science through his service as a leader in research management and policy development at the national level."

JAY N. GIEDD, M.D.

Chief of Brain Imaging at the Child Psychiatry Branch, National Institute of Mental Health

Jay N. Giedd, M.D. is a practicing Child and Adolescent Psychiatrist, adjunct Professor at Johns Hopkins School of Public Health (Dept. of Family and Reproductive Medicine), and Chief of Brain Imaging at the Child Psychiatry Branch of the National Institute of Mental Health (NIMH). Over the past 23 years he has combined brain imaging, genetics, and behavioral analysis to explore the path and influences of brain development in health and illness. As one of the most highly cited neuroscientists of his generation, his over 200 scientific publications have had a transformative impact on medicine, psychology, education, judicial, and public policy. His recent work has focused on how new insights from pediatric neuroscience can be used to optimize the environment for healthy brain development, particularly regarding education and the use of digital technologies that have transformed the way youth learn, play, and interact with each other. In addition to his numerous academic awards Dr. Giedd's work has been prominently featured in the general media with cover stories in *Time*, *National Geographic*, and national newspapers as well as over 30 television documentaries. For his outreach to students of all ages and frequent talks to parents, teachers, mental health workers, legislators, and the general public Dr. Giedd was honored as co-recipient of the 2012 Society for Neuroscience's Science Educator Award.



MARTHA BRIDGE DENCKLA, M.D.

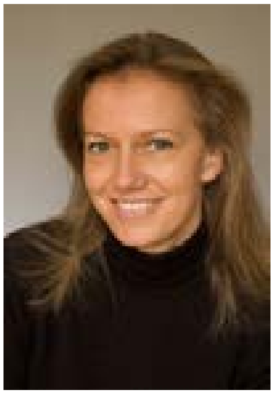
Research Scientist and Director of the Developmental Cognitive Neurology Clinic, Kennedy Krieger Institute and Professor, Johns Hopkins University School of Medicine

Dr. Denckla graduated *summa cum laude* from Bryn Mawr College and went on to graduate *cum laude* from Harvard Medical School in 1962, where she trained with Dr. Norman Geschwind in behavioral neurology. Dr. Denckla served residencies at Beth Israel Hospital and Veterans Administration Hospital, both in Boston, as well as Georgetown University Medical Center in Washington DC. After positions in neurology at the College of Physicians and Surgeons in New York and Harvard Medical School, she served as the director of the Learning Disabilities Clinic at the Children's Hospital. She came to the Maryland area in 1982 to serve as Chief of the Section on Autism and Related Disorders at the Developmental Neurology Branch of the Neurological Disorders Program at the National Institute of Neurological and Communicative Disorders and Stroke (NIH). She came to Johns Hopkins and KKI in 1987. Dr. Denckla's Unit (since 1987) is the Developmental Cognitive Neurology Department at the Kennedy Krieger Institute, and holds the Batza Emeritus Family Endowed Chair at Kennedy Krieger. Dr. Denckla is a past president of both the International Neuropsychology Society, and also of the Behavioral Neurology Society. Dr. Denckla has been awarded the Lucy G. Moses Prize in Clinical Neurology at Columbia University, the Norman Geschwind Memorial Lectureship at Orton Society, the Rita G. Rudel Memorial Lectureship at Columbia University, the Herbert Birch Memorial Lectureship at the International Neuropsychology Society, the Soriano Guest Lectureship of the American Neurological Association, the Bernard Sachs Lectureship of the Child Neurological Society and an American Academy of Mental Retardation Research Center awardee. In 2002, Dr. Denckla was among those who gave Grand Rounds at the NIH Clinical Center as part of the Great Teachers Series.

LAURA ANN PETITTO, Ph.D.

Science Director, Brain and Language Laboratory, Gallaudet University

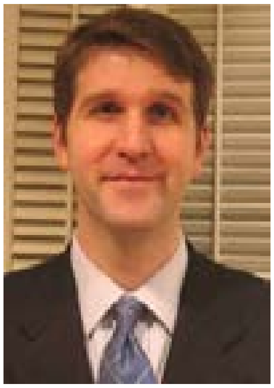
Professor Laura Ann Petitto, a cognitive neuroscientist, is the Co-Principal Investigator and Science Director of the National Science Foundation's Science of Learning Center, "Visual Language and Visual Learning, VL2" at Gallaudet University. She is also a Professor in the Department of Psychology at Gallaudet, an affiliated Professor in the Department of Psychology at Georgetown University, and the Scientific Director of her own "Brain and Language Laboratory for Neuroimaging". She is known for her role in the creation of the new discipline, educational neuroscience, as well as for her scientific discoveries concerning language and its neural representation in the human brain, how young children acquire language, the shared signed and spoken language processing sites and systems in the human brain, the bilingual brain, and the reading brain. Petitto received her masters and doctoral degrees from Harvard University in 1981 and 1984 (respectively). Petitto has won continuous federal and/or foundation funding for the past 30 years. She is the recipient of over 35 international prizes and awards for her scientific achievements and discoveries, including the 1998 Guggenheim Award for her "unusually distinguished achievements in the past and exceptional promise for future accomplishment" (neurosciences category). In 2009, Petitto was appointed a Fellow of the American Association for the Advancement of Science (AAAS), and a Fellow of the Association for Psychological Science (APS).



GUINEVERE EDEN, PH.D.

Professor, Center for the Study of Learning, Georgetown University

Guinevere Eden received her D.Phil. in Physiology from Oxford University, her postdoctoral training at the National Institutes of Health (NIH), and is currently a tenured full professor in the Department of Pediatrics at Georgetown University. Dr. Eden directs the Center for the Study of Learning (CSL), funded by the National Institutes of Child Health and Human Development (NICHD). The center's goal is to conduct research that will shed light on the causes and effects of cognitive disorders such as dyslexia, so that better programs for diagnosis and treatment can be developed. Dr. Eden was the first investigator to apply functional magnetic resonance imaging (fMRI) to the study of the common learning disability developmental dyslexia. CSL's researchers have identified some of the important neurophysiological mechanisms of reading acquisition, disorders of reading and its remediation (http://csl.georgetown.edu). Dr. Eden has published widely, including journals such as *Nature*, *Nature Neuroscience* and *Neuron*, and is a frequent speaker in the U.S. and internationally. At Georgetown University, Dr. Eden teaches undergraduate and graduate students and mentors students in the neuroscience Ph.D. program. Dr. Eden is past president of the International Dyslexia Association and serves on the editorial boards of *Developmental Cognitive Neuroscience*, *Annals of Dyslexia*, *Dyslexia*, and *Human Brain Mapping*. She has served as a permanent member of a standing NIH Study Section and as ad-hoc member and chair for several special emphasis panels.



BRETT MILLER, PH.D.

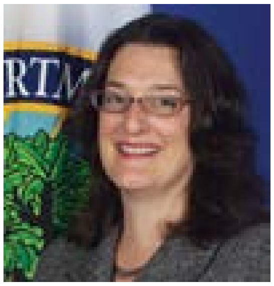
Program Director, Reading, Writing, and Related Learning Disabilities Research Program, Child Development and Behavior Branch, NIH

Brett Miller, Ph.D. directs the Reading, Writing, and Related Learning Disabilities Program in the Child Development and Behavior Branch of the National Institutes of Health. Dr. Miller completed his Ph.D. at the University of Massachusetts at Amherst in cognitive psychology and a postdoctoral fellowship at Haskins Laboratories in reading research. Dr. Miller's research portfolio focuses on developing and supporting research and training initiatives to increase knowledge relevant to the development of reading and written-language abilities for learners with and without disabilities. This program supports research that utilizes diverse methodologies (i.e., behavioral, neurobiological and/or genetic approaches), involves diverse groups of learners, and includes a range of ages across the lifespan. Before joining the NICHD, Dr. Miller held the position of associate research scientist at the Institute of Education Sciences at the U.S. Department of Education. In this capacity, he served as program official for the National Center for the Study of Adult Learning and Literacy, the Mathematics and Science Education Research Program, and co-program officer for the Cognition and Student Learning Program.

MARIALE HARDIMAN, Ed.D.

Professor, School of Education, Johns Hopkins University

Mariale Hardiman, Ed.D. is Professor of Clinical Education and co-founder and director of the School of Education's Neuro-Education Initiative, a cross-disciplinary program that brings to educators relevant research from the brain sciences to inform teaching and learning. Her research and publications focus on enhancing educational practices through techniques that foster innovation and creative problem-solving. Current research includes a randomized trial investigating the effects of arts integration on long-term retention of content and student engagement. She is also investigating how knowledge of neuro-and cognitive science influences teacher practice and teacher efficacy beliefs. Before joining Johns Hopkins in 2006, Hardiman served in the Baltimore City Public Schools for more than 30 years. As the principal of Roland Park Elementary/ Middle School, she led the school to its designation as a Blue Ribbon School of Excellence. With the use of the Brain-Targeted Teaching® Model that Hardiman developed, the school was recognized nationally for innovative arts programming. Hardiman presents nationally and internationally on topics related to the intersection of research in the neuro- and cognitive sciences with effective teaching strategies, including meaningful integration of the arts. Hardiman has significant experience in educational leadership development and education for children with disabilities. Hardiman earned undergraduate and Masters of Education degrees from Loyola University Maryland and a Doctorate of Education from Johns Hopkins University.



ELIZABETH ALBRO, Ph.D.

Associate Commissioner for the Teaching and Learning Division, National Center for Education ResearchInstitute of Education Sciences,

U.S. Department of Education

Elizabeth Albro is the Associate Commissioner for the Teaching and Learning Division of the National Center for Education Research, Institute of Education Sciences (IES), U.S. Department of Education. She recently served as Acting Commissioner for the National Center for Education Research and has been a federal program officer for several IES research grant programs. As program officer for the IES Cognition and Student Learning research grants program, Dr. Albro oversaw the preparation of an IES Practice Guide, Organizing Instruction and Study to Improve Student Learning, which identified a set of instructional principles for use in schools and classrooms that emerged from basic research on learning and memory. Prior to joining IES, Dr. Albro was a professor at Wheaton College in Norton, MA and at Whittier College in Whittier, CA. She holds a B.A. in behavioral sciences, a M.A. in the social sciences and a Ph.D. in psychology, with a focus on cognition and communication, from the University of Chicago.

GARTH A. FOWLER, PH.D.

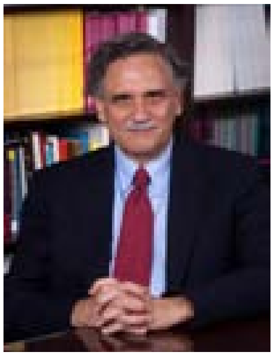
Education Directorate, American Psychological Association

Garth A. Fowler is the Associate Executive Director for Education and the Director of the Office for Graduate and Postgraduate Education and Training at the American Psychological Association. Garth joined the APA in May, 2012, after serving as the Assistant Chair and Director of the MS program in the Department of Neurobiology at Northwestern University. Prior to that, he was the Outreach Program Manager for *Science Careers*, the career component of *Science* magazine and AAAS. Throughout his career, Garth has been active in training & education at the graduate and postgraduate level. He was a co-founder of the University of Washington's student seminar, "What can you do with a Ph.D. in Biological Sciences," which provides career information for graduate students & postdoctoral scholars, now in its 15th year. He has served as a consultant for universities and research institutions on developing training grants for graduate students and postdoctoral scholars, and implementing Individual Development Plans (IDPs) for young scientists. He has twice served as a panelist for the National Academies of Science: in 2010 for the Committee on Research Universities, and in 2011 for the Committee on the State of the Postdoctoral Experience for Science and Engineers. A neuroscientist by training, Garth received a B.A. in psychology from The College of Wooster in 1993, his Ph.D. in behavioral neuroscience from the University of Washington – Seattle in 2001, and was a postdoctoral research in neural foundations of decision making at the Salk Institute for Biological Sciences from 2002 - 2005.

LAURIE E. CUTTING, Ph.D.

Patricia and Rodes Hart Professor of Education and Human Development, Radiology, and Pediatrics, Vanderbilt University

Laurie E. Cutting, Ph.D., is an Endowed Chair at Vanderbilt University. She is the Patricia and Rodes Hart Professor of Education and Human Development, Radiology, and Pediatrics. She is also head of the Vanderbilt Kennedy Center Reading Clinic, which serves children in need of tutoring in reading, including those with dyslexia. She is also a Senior Scientist at Haskins Laboratories and a member of the Vanderbilt Brain Institute as well as the Center for Cognitive and Integrative Neuroscience at Vanderbilt University. Her work encompasses both applied and theoretical underpinnings of reading development and disorders. Currently, she is the principal investigator of NIH-funded research projects on reading and reading comprehension and a co-investigator on other NIH-funded and Department of Education-funded projects on reading, reading disabilities, and ADHD. She focuses on brain-behavior relations in children and adolescents, with a particular emphasis on reading disabilities, language and executive function. Prior to joining the faculty at Vanderbilt, she was is a research scientist at the Kennedy Krieger Institute and an Associate Professor of Neurology at the Johns Hopkins School of Medicine and an Associate Professor of Education at Johns Hopkins University. During her doctoral work at Northwestern University, she completed internships at Yale University School of Medicine's Center for Learning and Attention and the National Institute of Child Health and Human Development. In 2002-2003, she completed an NIH science policy fellowship. She has authored or co-authored over 70 publications focusing on reading, reading disabilities, other learning disorders, and ADHD.

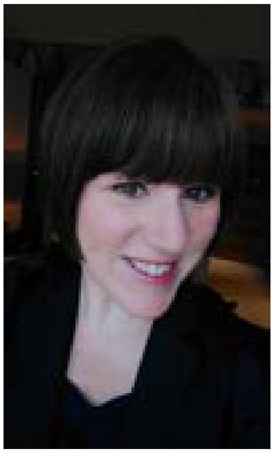


ROBERT E. SLAVIN, Ph.D.

Director of the Center for Research and Reform in Education ,

Center for Research and Reform in Education, Johns Hopkins University

Robert Slavin is currently Director of the Center for Research and Reform in Education at Johns Hopkins University, part-time Professor at the Institute for Effective Education at the University of York (England), and Chairman of the Success for All Foundation. He received his B.A. in psychology from Reed College in 1972, and his Ph.D. in social relations in 1975 from Johns Hopkins University. Dr. Slavin has authored or co-authored more than 300 articles and book chapters on such topics as cooperative learning, comprehensive school reform, ability grouping, school and classroom organization, desegregation, mainstreaming, research review, and evidence-based reform. Dr. Slavin is the author or co-author of 24 books, including *Educational Psychology: Theory into Practice* (Allyn & Bacon, 1986, 1988, 1991, 1994, 1997, 2000, 2003, 2006, 2009), *Cooperative Learning: Theory, Research, and Practice* (Allyn & Bacon, 1990, 1995), *Show Me the Evidence: Proven and Promising Programs for America's Schools* (Corwin, 1998), *Effective Programs for Latino Students* (Erlbaum, 2000), *Educational Research in the Age of Accountability* (Allyn & Bacon, 2007), and *Two Million Children: Success for All* (Corwin, 2009). He received the American Educational Research Association's Raymond B. Cattell Early Career Award for Programmatic Research in 1986, the Palmer O. Johnson award for the best article in an AERA journal in 1988, the Charles A. Dana award in 1994, the James Bryant Conant Award from the Education Commission of the States in 1998, the Outstanding Leadership in Education Award from the Horace Mann League in 1999, the Distinguished Services Award from the Council of Chief State School Officers in 2000, the AERA Review of Research Award in 2009, the Palmer O. Johnson Award for the best article in an AERA journal in 2008, and was appointed as a Member of the National Academy of Education in 2009 and an AERA Fellow in 2010.



LAYNE KALBFLEISCH, M.Ed., Ph.D.

Associate Professor, College of Education and Human Development, George Mason University

Layne Kalbfleisch, M.Ed., Ph.D. is an Associate Professor of educational psychology and cognitive neuroscience and the founder of KIDLAB at George Mason University and on the pediatrics faculty of The George Washington School of Medicine and Health Sciences. She is the outgoing Chair of the Brain, Neuroscience, and Education special interest group and a founding associate editor of *Frontiers in Educational Psychology*. Her recent guest-edited volume of *Roeper Review* covers the topic of visual spatial talent. Kalbfleisch's research examines the relationship between talent and disability in autism and attention disorders and uses neuroimaging to study how physical aspects of the environment, emotion, and social organization influence problem solving and inform our understanding of constructivist learning, or, learning by experience. Her research has been supported by organizations such as the National Institutes of Child Health and Human Development, the Defense Advanced Research Program Agency, Naval Postgraduate School, McDonnell Foundation Summer Institute on Cognitive Neuroscience, the Alfred P. Sloan Foundation, and the Pomata Term Professor of Cognitive Neuroscience in the Krasnow Institute for Advanced Study. She is a former middle school teacher, tutor of twice exceptional children, and service provider for university-level students with intellectual disabilities. Dr. Kalbfleisch received the inaugural 'Scientist Idol' award in 2010 for messaging science to the public from the National Science Foundation and contributed to the 2007 OECD-CERI publication, "Understanding the Brain: The Birth of a Learning Science". She has been featured on CNN with Dr. Sanjay Gupta, SiriusXM Doctor Radio, The Coffee Klatch – Special Needs Radio, and Rhode Island PBS 'School Talk'. In 2009, she gave the keynote speech, 'Literacy, Scientific and Otherwise, the Role of Story, and the Impact of Environment on the Brain and Behavior' during the FLICC Forum on Information Policies in the United States Library of Congress.

THOMAS KALIL

Deputy Director for Technology and Innovation, Office of Science and Technology Policy

Tom Kalil is the Deputy Director for Technology and Innovation for the White House Office of Science and Technology Policy and Senior Advisor for Science, Technology and Innovation for the National Economic Council. In this role, Tom serves as a senior White House staffer charged with coordinating the government's technology and innovation agenda. Prior to serving in the Obama Administration, Tom was Special Assistant to the Chancellor for Science and Technology at the University of California, Berkeley. In 2007 and 2008, Tom was Chair of the Global Health Working Group for the Clinton Global Initiative. Previously, Tom served for 8 years in the Clinton White House, ultimately as the Deputy Assistant to the President for Technology and Economic Policy, and the Deputy Director of the National Economic Council. Tom received a B.A. from the University of Wisconsin at Madison, and completed graduate work at Tufts University's Fletcher School.

JENNIFER BUSS, PH.D.

Research Fellow and Director, Center for Neurotechnology Studies

Potomac Institute for Policy Studies

Jennifer Buss, Ph.D. is a Research Fellow at Potomac Institute for Policy Studies. She is a member of the CEO's office and provides the scientific background for the think tank within the Potomac Institute, where she has been for two years. She is the Director of the Center for Neurotechnology Studies (CNS) at the Potomac Institute, having special interests in topics such as music and the brain as well as creativity and cognition. As Director of the CNS, she leads a team studying issues in neuroscience technology and policy and has been instrumental in organizing the Neuroscience Symposia Series 2014. Dr. Buss is a Fellow in the Center for Revolutionary Scientific Thought, a group at Potomac Institute that brings together individuals from a variety of backgrounds to foster discussion on science and technology futures from both an academic and policy perspective. In addition to these efforts, she has supported contracts for DMEA, OSD, and the Office of Corrosion Policy and Oversight. She is the Program Manager for the Rapid Reaction Technology Office contract for OSD in searching for innovative technologies to enhance government systems.

Dr. Jennifer Buss was awarded a doctorate in biochemistry from the University of Maryland Department of Chemistry and Biochemistry in 2012. Her dissertation was on iodide salvage in the thyroid and the evolution of halogen conservation in lower organisms. She performed graduate research in the areas of enzymology, bioinformatics, molecular and structural biology. Dr. Buss received her B.S. in biochemistry with a minor in mathematics from the University of Delaware. She is a member of the American Chemical Society, the American Association for the Advancement of Science and the American Society for Biochemistry and Molecular Biology.

HEATHER DEAN, Ph.D.

Symposium Organizer, AAAS Science and Technology Policy Fellow

Dr. Heather Dean is currently a AAAS Science and Technology Policy Fellow in the Directorate for Social, Behavioral, and Economic Sciences at the National Science Foundation. At NSF, she is working on big picture issues such as replicability of published scientific findings and broadening participation in science and technology fields. She founded a NeuroPolicy group and speaker series in Washington, DC that is building a neuroscience policy community. Dr. Dean is interested in issues related to cutting-edge interdisciplinary neuroscience, data sharing, science communication, new technologies in science education, and broadening participation.

Dr. Dean started out as an electrical engineering major at Caltech interested in neural networks and was soon exploring the biological side of such networks by studying locust olfaction with Dr. Gilles Laurent. She earned her Master's degree in computation and neural systems along with her Bachelor's degree in electrical engineering. This research experience also set her on the path of neuroscience research, and she went on to earn her Ph.D. in neurobiology at Duke University, where she went into monkey electrophysiology with Dr. Michael Platt. After graduate school, she spent six years at New York University helping to found the lab of Dr. Bijan Pesaran and studying the neural circuitry underlying hand-eye coordination in monkeys.

Dr. Dean currently serves as President of the Caltech Alumni Association and has previously served on the Duke Alumni Association Board and the Duke Board of Trustees.

BRIAN BARNETT

Policy Intern, Potomac Institute for Policy Studies

Brian Barnett is a policy intern at the Potomac Institute for Policy Studies. He performs research and coordinates initiatives within the Center for Neurotechnology Studies. Brian obtained his B.S. in neurobiology & physiology at the University of Maryland, College Park, where he participated in the Gemstone research program and the Global Semester program. At the university, he worked in Dr. Matthew Roesch's behavioral neuroscience laboratory. Brian completed a thesis that investigated the behavioral and neural components of an animal model of ADHD. He also contributed to publications on the valuation and representation of reward within the rat fronto-striatal circuit.

ABOUT THE SYMPOSIUM SPONSORS

The Potomac Institute for Policy Studies is an independent, 501(c)(3), not-for-profit public policy research institute. The Institute identifies and aggressively shepherds discussion on key science, technology, and national security issues facing our society. The Institute hosts academic centers to study related policy issues through research, discussions, and forums. From these discussions and forums, we develop meaningful policy options and ensure their implementation at the intersection of business and government. The Institute remains fiercely objective, owning no special allegiance to any single political party or private concern. With over nearly two decades of work on science and technology policy issues, the Potomac Institute has remained a leader in providing meaningful policy options for science and technology, national security, defense initiatives, and S&T forecasting.

Center for Neurotechnology Studies (CNS) provides neutral, in-depth analysis of matters at the intersection of neuroscience and technology—neurotechnology—and public policy. The Center anticipates ethical, legal, and social issues (ELSI) associated with emerging neurotechnology, and shepherds constructive discourse on these issues. The Center partners with the research community for discourse and consultation on ethically sound neurotechnology research and applications. CNS serves as authoritative counsel to government agencies pursuing neurotechnology by providing expertise in the sciences, law and social policy through discussion on the implications of neurotechnology in academic, administrative, entrepreneurial, regulatory, legislative and judicial enterprises.

The NeuroPolicy Affinity Group

The NeuroPolicy Affinity Group was established to connect and inform AAAS Science and Technology Policy Fellows who are working in or interested in learning about the intersection of neuroscience with policy, law, ethics, media, and society. The group has since expanded to include others from throughout government, industry, think tanks, and more. It is led by AAAS Policy Fellows Heather Dean, Dorothy Jones-Davis, Laurie Stepanek, and Tom Cheever.

NEUROSCIENCE AND EDUCATION SYMPOSIUM REPORT

The Potomac Institute for Policy Studies and the American Association for the Advancement of Science held a symposium on the topic of education neuroscience on May 14, 2014. This symposium tackled the issues of how to apply neuroscience research to the classroom and how to reshape the future of education through neuroscience. Incorporating neuroscience and neurotechnology into our education system has the potential to revolutionize the way every student learns as an individual – a unique and personalized education, tailored to their interests and highly interactive, allowing each student to excel in their own capacity. Education of our children is our future. We do not have to accept education as a static, unchanging field. We should expect a constant improvement in our education system and now, neuroscience provides us with the best tool to effect such changes.

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