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THE "BIG BANG" IN LEARNING: BRAIN CHANGES AND CHILDHOOD LEARNING

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THE "BIG BANG" IN LEARNING:
BRAIN CHANGES AND CHILDHOOD LEARNING

SPEAKER: Good morning, everyone. I want you to get the most out of this session and I am not big on long-winded introductions anyway. But it's my pleasure to introduce you to Andy Meltzoff and Pat Kuhl who have come out with some extraordinary research and probably are the rock stars in America around early brain understanding.

And what they have – are going to present today, and I hope it includes your latest findings, is about the baby brain in action. And we've been studying this week, and why they are here is how we learn and believe me it starts probably before you are born. So I'm going to turn this over to them and thank you so much for coming. I'm really, really thrilled, they are very, very important in this field. Thank you.

MS. KUHL: Thanks Kitty (phonetic). And welcome everyone.

(Applause)

MS. KUHL: So good morning, Aspen Ideas Festival. Andy Meltzoff and I are co-directors of the Institute for Learning and Brain Sciences at the University of Washington in Seattle. We are really excited to be here today to share an idea with you. And we're going to take turns describing the newest findings from the baby laboratories at I-LABS, Institute for Learning and Brain Sciences.

The new idea is this, there is a big bang in learning, and it happens during the first 2,000 days. Now we all know about the universe's big bang, right. A stunning beginning to the planet as we know it, perfect for the Fourth of July, don't you think. Well, there is a big bang in learning and it is taking place in this first 2,000 days and that's what we want to share with you.

It's during the first 5 years, the first 2,000 days, there is a wonderful explosion of activity and growth in the brain that sets the stage for future learning. What happens in that first 5 years stays with you all your life. This big bang in early development is a period that no child should miss and no society can ignore.

So what are we seeing when we look at the adult brain. This is an adult brain with its 433 areas all color-coded. What the neuroscientists in our laboratories and others are finding is that there is very special areas for faces, fear, for motor, is the language areas, Wernicke's and Broca's. Wernicke is for listening and Broca is for talking and planning.

Executive function areas, this is the basal ganglia where you are making decisions and directing your attention whether you are listening to me or looking at your smartphone. The social reward systems that give you the escort of dopamine, when you think about your child or ice cream or any number of things. So what we are seeing is a brain very, very coded in its areas, but the new findings are the connections, the importance of the connections between areas in the adult brain. Without the connections the specialty knowledge stays in that area and doesn't connect.

These are the pathways for language, executive function, and social reward. We're going to be talking about them today. What we wondered in the adult brain is, are we all walking around with the same pathways. Do our pathways, our super neuro highways look identical across the individuals say in this room? Here is the answer.

This is the brain of a bilingual person. We are contrasting bilingual connections with monolingual connections; every little node in that mesh diagram is a difference between bilingual people's brains and monolinguals. At every point in this mesh, there are more connections in the bilingual brain being made at that node than in the monolingual brain.

We've wondered for years why are bilingual people, babies and adults more creative, more inventive, more cognitively flexible; look at their brains. Experience is forging not only the information in the areas, but is forging the differences between connections across the brain. Each of us is walking around with a totally unique brain.

Okay, but what about development. Technology has not been tremendously, you know, nice to the developmentalist. We are trying to study babies because look at the growth in the baby brain. By the age of 5, the brain has reached 92 percent of its growth. There are things happening during those first 5 years that are really critical. So how could we take the technologies used with adults and apply them to babies.

Well, I-Labs has dedicated its work during the past 3 years to developing a toolbox for the analysis of the baby brain. And the key to our toolbox is this machine. This looks like a hairdryer from Mars, it's a Magnetoencephalography machine, MEG for short, looks like a hairdryer from Mars, but it's totally safe and noninvasive. What it does is measure the activity of millions of cells when they fire and current starts to flow it changes the magnetic fields in the brain.

And this device, with 306 sensors that are squid devices, these are superconducting quantum interference devices, they pick up the magnetic field changes in the brain as we do our thinking. So it gives you millisecond by millisecond precision, and one millimeter and millisecond resolution in the brain. It's an engineer and biophysicist's dream to take the tsunami of data from the brain and understand where the cortical dynamics are taking place.

Well, here is our goal. We are the first in the world to put a baby in an MEG machine because it is totally safe, totally noninvasive. What you are seeing is a 6-monther who is sitting in an MEG machine free to move, we are tracking her little head as she is looking at something and listening, in this case she is listening to the sounds of various languages. And we are tracking her head movements with a little cap that has four pellets in it, so we always know where her brain structures are, but as you can see it's totally silent and she is free to move.

So this is producing a miracle, a tsunami of data that allows us to get in and see what's happening in the baby brain as they are engaged in a task looking at something or listening to something. What are we seeing? Here's the brain of an 11-month old baby. What we see – and astoundingly, all the areas are in place. They all seem to be reporting the same kind of data the language areas, Wernicke's, Broca's. They are not well formulated yet and they are changing by experience, but the executive function areas, social reward areas, they are all in place in the baby brain. And the connections, these bushy connections that you see in a baby, this is only 15 percent of this 11-monthers connections. We know that synapses are being created at 700 per second in the early period, 700 new connections per second.

So the pathways for language, the pathways for executive function, the pathways for social reward, they are there and in place in the 11-monther brain, but now with MEG we can see the explosion of activity. And what you are going to see next are bubbles that are representing the current flow in the brain as a word comes in.

Here is a "big bang" that word gets into the language areas and then information about that gets sent all over. It's though the connections are providing social media for the baby brain. So Andy is going to continue the story, what we can see is the brain at this time in development is totally in place.

MR. MELTZOFF: Okay. Thanks, Pat. So I need to switch this to number two and hopefully it will work. So Pat talked a lot about the social – about brain development. I want to show you what this brain development supports especially by talking little bit about social behavior. Human beings are very, very special species. We make art, do science, and have designed an elaborate formal educational system to teach our young. And no other species on the planet has this.

Evolutionary biologists have wondered why this is so, what makes us so smart. And you might think it's because we have big brains, but biologists think that that's not the reason. The secret sauce lies in our children. Our children are born immature, have an extended period where we care for them and they are dependent upon us and we teach. So it's nature's trick for making us smart, is to not build everything in, but rather to save some of the wiring of the brain that Pat showed so that wiring can be done outside the womb in interaction with social others. And this makes us more adaptable and able to adjust and be responsive to cultural learning than other species.

Now nature also has a trick for making sure that adults do their part. Adult brains are wired to react to infants in a very, very special way. This assembly of pictures was constructed by Komader Lens (phonetic), and it obviously shows babies on the left and then adults on the right. The baby has a big round forehead and large eyes and the adult's brain – head shape is more elongated. Adults find the baby being highly attractive, very lovable, and it draws us to want to take care of them, we regard it as cute.

The adult sense of beauty may not be culturally universal, but in all cultures tested so far, adults rate the baby pictures as highly attractive. And neuroscientists have recently discovered that the word system becomes active within one-seventh of a second after seeing the picture of the baby. And it does so and shows more activity looking at baby pictures than it does at adult pictures.

So we have adults who are trying to approach babies and to teach. We have a complementary system in the baby. The baby is born to learn. Humans learn more in the first 5 years of life than they do in any other 5 years from 0 to 5, 20 to 25, 30 to 35, and the last from 60 to 65. And during childhood, they learn for the pure joy of learning. They don't solve problems to earn stock options or win Nobel Prizes or to get into the Little Nell, but just because they are curious and driven to learn.

And there are two important mechanisms for learning before linguistic instruction. The first is imitation and that begins at birth. We study newborn babies in a hospital setting; this is a 19-hour old baby girl looking up at an adult. You can see that how small the baby's brain is, it's going to develop into the large adult brain, but I want to show you what social behavior this baby brain supports, especially with regard to imitation.

Babies can't use their hands, they are wrapped in a blanket so we show simple tongue movements or mouth movements to the baby and check their imitation. And I want to show you this little 19-hour old baby when she looks up and sees the strange movement her eyes converge, she looks at the adult, and then she responds with tongue protrusion of her own. When the adult opens his mouth the baby's eyes again converge on that and she responds with tongue protrusion.

But I said that babies were born learning and I meant it. The youngest baby that I tested was 42 minutes old and I vividly remember sitting face to face with this newborn putting out my tongue, she put out her tongue back opening my mouth and she responded with mouth opening. So babies are literally born learning and born social. They look out there and recognize that the person out there is like me and this shows the connectivity and the basic humanity that can access to each other is in place to begin with.

Now a second mechanism for learning that takes place before language has to do with gaze following. Information is not evenly distributed in the world. And babies have a special trick for discovering what we call information hotspots, places in the world that have information that they can learn that adults as yet can't give them linguistic instruction to pay attention.

So babies trick for running into these information hotspots is to follow the gaze of adults and here is how we test that. We have an adult sitting across from a 12-month old and there is colorful objects one on each side. They don't make noise, but the adult can highlight them by turning to look at one or the other. First, the adult makes eye contact with the baby then the adult turns this object and the baby turns that object as if attached like a little – with a bungee cord. The adult will also turn to the other object and the baby will follow line of regard there.

Now so far, I have talked about infancy as if it's a Garden of Eden and close infant adult contact and social interaction with synchrony between the two, but soon children go to preschool and there they encounter large sets of other children, social groups and a very interesting social dynamic emerges even in the first five years of life. Children, like adults, begin to divide others in to us and them, into in-groups and out-groups.

And scientists are very interested in this inter group relations and how they form. Recently, scientists have come up with a clever way of studying that in very young kids, and that has to do with arbitrarily assigning kids to meaningless groups. What they do is have a child comes into the lab and they give the first child for instance an orange t-shirt and asks them to wear it. And give the next child a green t-shirt and ask them to wear it, completely arbitrary and meaningless.

Then they show them pictures of other children who are said to be in the green group or in the orange group. And remarkably when you test the children they show more positive attitudes, more feeling that they really, really like the child if they are wearing an orange t-shirt. They say they really like the child with the orange t-shirt and they don't like so much the child with the green t-shirt.

They also do resource distribution differently. If you give them coins to distribute or goodies to distribute they distribute more to the child wearing the in-group t-shirt than the out-group t-shirt. And when researchers tell them a story about the children they even have distorted memories. If you tell a story and some of the children are doing good things and some are doing bad things and ask the children to recall the story, they have distorted memories and recall that more of the kids wearing the same t-shirt is them are doing the good things and not the bad things. And it's those other kids in the out-group who had done all the bad things.

It doesn't take much to see this as the basis of bias, and stereotype, and prejudice that's already beginning to emerge in these first 5 years. So all this happens in the first 5 years of life; the baby is born and somehow able to recognize the other person as like me in a sense and then they encounter larger groups of kids and divide into us and them, in-group and out-group and develop positive attitudes for in-group, negative to the out-group.

This profoundly highlights the responsibility of parents. Children are born to learn, but they are not born knowing who to treat as an in-group member. Parents, society, and teachers need to help them learn that all humans are like me. All humans no matter what the color of their t-shirts deserve attention, care, and dignity. The children are born learning and neurally plastic, want to absorb information, but the ethics and values that they absorb come from us. And it's our responsibility to teach them they are learning rapidly whatever we do, it's our responsibility to put the right things in front of them.

MS. KUHL: Okay. So Andy says that the social brain is extremely powerful. So let's look at the role of the social brain in the acquisition of language. So we said earlier that the brain has its structures and areas in place. It's building connections at a rate of 700 per second, so this brain is throbbing and waiting for experience to shape its final course.

One of the things that biologists have taught us about in the animal kingdom is that there are critical periods in development where the brain is waiting for experience to craft the architecture of the brain. Language is one of these areas in which there is a critical period. So if you look at this graph it describes in cartoon form what we know about the critical period.

The way to read the graph is to look at your age at the bottom of the curve and then look at the vertical axis to see your skill in acquiring a second language. And you can see that the babies are geniuses between 0 and the age of 7. They absorb a new language with complete facility, but with each 2-year period past the age of 7 their ability to acquire that language declines. It doesn't mean that you can't acquire a language beyond puberty, but it means that you won't use the same brain mechanisms to do it and you won't learn with the same facility.

So there is another area, and that's music where we think there is a critical period that operates on almost the same timetable which is very, very interesting. The studies that are in hand – but careful ones have not been done in infancy, we are just beginning them – appear to show that if children are exposed to music, either listening and practicing, but doing both is better, before the age of 7 their skills grow at a rate that's faster than if they start after the age of 7.

So that needs to be explored, but what we are trying to understand as scientists is what opens those windows and then what closes them. So how does it operate where the window is open and experience comes to flood in. One of our best examples is in the earliest period of language acquisition where infants have a critical period for the acquisition of the sounds of their language. We've learned by studying babies all over the world that there is a window that opens at about 6 months of age and it narrows at 12 months of age right before first words.

What you see in this graph is performance of babies in Tokyo and in Seattle, on the discrimination of two sounds R and L as in Rake an Lake that are very important to English, but not important at all to Japanese. And what you can see by the graph is that at 6 to 8 months whether you are using a brain measure or a behavioral measure, the babies in both countries are totally equal.

About 65 percent of the time they can hear a switch from "ra" to "la," but two months later something really amazing happens; the American children get better, the Japanese children get worse and both of them are performing exactly as they need to, to acquire their respective languages. Japanese children shouldn't be paying attention to the difference between R and L, but American children should.

So between this, the front end of this blue period here which is the critical period for sound acquisition, babies are citizens of the world on the left-hand side of it. They start out being able to do everything. All the children in all the countries can hear all the differences between the sounds used in any language in the world. And then between 6 to 12 months, right in that 8 to 10-month window, their brains shape by listening to us talk.

So what's going on during that little 2-month period; that's a critical window of opportunity that's opening. So there is two things going on. One of them is computational and the other one is social. The computational one is the discovery that babies are really master pattern detectors. We are calling them statistical learners because before they know words and they listen to us talk, they are taking into account the statistics of the sounds that we present when we talk to them. They are sensitive to the distribution of frequencies.

And I'll illustrate that by letting you listen to two women speaking motherese, the first one in English and the second one in Japanese. Now, this is mother's milk to the baby brain; children will do anything to turn on motherese signals. And you will see how pleasant they sound, and then I will show you how they are doing the computational magic.

(Video being played)

MS. KUHL: Okay. So this is what's going on in the baby brain as they listen. As they listen to an American speaker speaking English they are noticing that the frequency of R and L sounds is very high to the bimodal distribution that you see on the left. As you listen to the woman speaking motherese in Japanese, this frequency of the Japanese R, which is midway between R and L, but not American English R and L.

The baby brain is getting impressed, this is a critical window, environment is coming in to flood the brain and the brain is locking on to the distribution of the sounds. So without knowing any words, the statistics of the incoming sounds are shaping their brains. Okay, so that's the computational piece. Who would have known that babies are really sensitive to statistics and patterns in that way, they are geniuses at it.

So we decided at 9 months of age with an infant we wanted to test whether or not giving babies a new statistic, give them a new language, can they calculate the statistics of a new language when exposed to that language for the first time at 9 months. So we brought American babies into the lab and for 12 sessions they played on the floor with my mandarin speaking graduate students.

I'll show you what the sessions look like. It was like having mandarin relatives come visit, stay for 4 weeks. And over that 4-week period, play on the floor with the babies for 12 sessions. And each time just speaking solely in mandarin. So here is what they were like.

(Video being played)

MS. KUHL: Okay. So what did this experience do to their little brains? What we found is that the babies who had had 12 sessions of mandarin were so good at the sounds of mandarin – and not only the sounds, the word forms of mandarin, that they equaled the children growing up in Taipei. Twelve sessions at 9 months of age would give the brain critical information at the right time. And they look just like native speakers of that language.

We have run a control group of babies who were just listening to the American graduate students speaking English, same dosage, same rooms, same arrangement, but English was going into their brains. And we tested them also on mandarin. It wasn't just visiting the laboratory that made them so good at acquiring mandarin, they were able to, you know, calculate the statistics of mandarin and learn, but we noticed also that the children were so interested in their mandarin tutors.

We wondered what the human beings, what was the role of the human being. So we ran another condition with 32 new babies in which we exposed them over a DVD, beautiful DVDs, the same room, same dosage, 32 new babies, but now they are looking at a television screen. They stared at the screen and looked like they were learning, but the tests after, the brain tests and the behavioral tests following the 12 sessions of TV exposure showed that the brain had learned nothing. They were engaged by the visual information, but they learned nothing.

So babies need a social other, as Andy said, they are very, very locked on. The social brain is controlling when the babies take their statistics, but excitingly, we can now look at the brains of babies after they've had the experience, compare them to monolinguals. And I want to give you an example of what the new technology can show us about learning in the brain. So here is a 12-monther, a monolingual baby, as you know from what I showed you, by 12 months they already know that English is their language.

So here we have the 433 areas, two areas of the auditory system, two areas of Broca's area which is responsible for listening and talking. And the arcuate that connects them. Now I am going to show you what does the brain do. The bubbles that you see as the current flow as a word in English comes by, the red bar at the bottom, the auditory activity. The blue bar is Broca's area which is getting ready to talk back. You can see that both are active. Here is a new English word, again, auditory area is very active, Broca's area also active at the same time.

That pathway is active.

Now here's a Spanish test word. So Spanish is not this child's language. What we see is same activity in auditory, the auditory system is reporting it, but actually greater activity in Broca's. What we are interpreting this finding as showing, babies as they listen to us talk, want to talk back. Broca's area is getting ready to talk back, it is trying to simulate. It's like analysis by synthesis. They are getting ready to talk back. If it's a brand new language, it's harder for the child to know, "How would I talk back to that Spanish sound?"

At 12 months, the child already knows the difference between Spanish and English, and is reacting differently to the two. So the baby brain is being shaped in this early period; by 12 months of age babies have sorted out the languages. They are ready for a new language, they could operate with two. In bilinguals, you see activity, in Broca's that's equal for the two languages. In 6-monthers, it's equal, but at 12 months they've begun to select which is the language that I am learning, which is the language that I am going to respond to.

Okay, more from Andy.

MR. MELTZOFF: Good. That was exciting, Pat. I've heard that before, but it's still good. I mean there were some new diagrams up there that I think we just produced last week, so that was fun to see.

Okay, in addition to language humans have another very special ability which is called perspective taking or sometimes theory of mind. We understand other people as more than dynamic sacks of skin moving around, but attribute to them beliefs, desires, intentions, and emotions that underlie and animate those movements that we see, but this poses a dramatic and profound developmental puzzle.

The puzzle is that you can't see inside somebody else's mind, you can't see what their inner thoughts are. And so because the child can't use vision, or hearing, or touch, taste or smell to sense the inner thoughts of others, the question is how did children ever come to attribute those to others. And the research is showing that between 2 and 5 years of age, the children are working out that these dynamic moving biological beings that they see also have an interior world.

And one of the internal states that babies learn about first, not surprisingly, is the goals and intentions of others. The way we tested that was to have an 18-month old baby, before they could speak, watch an adult try to do something, but the adult failed. They had a goal, but didn't succeed. So they might pick up a loop and try to put it on a post, but they overshoot or undershoot and failed to succeed. Or they'd have a dumbbell-shaped object and they try to pull it apart, but their hand would slip off to one side or the other side.

And to a person watching the actor's goal or intention was quite clear, we want to know what the 18-month old thought of that. So for instance, we'd give the baby the dumbbell-shape and they did a very interesting thing. They wrapped their hands firmly around the edge and gave it a good yank or sometimes put it between their knees and pulled it up. So it looked like they could understand the person's goals and intentions and reenacted that. They didn't simply imitate what the person did do, but copied what the adults intention was, what their goals were.

Now one remarkable thing is as soon as children begin to understand other peoples' goals and intention, the children use that to help other people. I have a movie here of an 18-month old using – judging what a person is trying to do when they fail and then toddling over and helping the person. So I want to show you this.

(Video being played)

(Applause)

MR. MELTZOFF: Now, 4-1/2-year olds show even more sophisticated helping behavior. As adults, we are able to give up some things that we are doing in order to help others. We act altruistically, and we're interested in when that begins with 4-1/2-year olds, with young kids. And so we tested 4-1/2-year olds, where we have them playing a favorite activity, playing with blocks which they had to give up to help the person behind them. And I want to show you a 4-1/2-year old girl who does quite well at this.

(Video being played)

MR. MELTZOFF: Spontaneous helping by a 4-1/2-year old. Now, not all children are able to detach themselves from their current activity; to give up something they like to help another person despite the racket behind them. I want to show you this 4-1/2-year old boy.

(Video being played)

MR. MELTZOFF: No comments on your husbands, okay.

(Laughter)

MR. MELTZOFF: There is scientific evidence that pre-scores (phonetic) even begin to engage in empathetic helping. And the way that's tested by researchers is they might do studies where you have a picture that you are trying to hang up on the wall and you have a hammer, and a child is playing across the room and you might tack up the corners of the pictures going bang, bang, bang, tapping in the tack, tapping in the next tack, and then on third one you are tapping, oh, ouch, I hurt my hand, ouch.

And the films show the little toddler is toddling across the room, putting their hand on your shoulder, and if that doesn't work they often go back, pick up their blanket or teddy bear and come and give it to the adult. So the big question is, how does it get this way, how can we arrange family environments, what do we do to help raise empathetic children. Alas, we don't have the answer today, that will be next Aspen Festival, but we have a big, "what if."

And the scientific big "what if" is what if learning about empathy bears some resemblance to learning about language that Pat talked about. There is a critical period for language where there is an explosion of learning early. Children learn automatically easily and without effort a language very early in life and it's more difficult later. What if empathy is like that? What if you're lacking experiences early, it becomes more difficult later.

This is something that brain scientists are very, very interested in exploring and we're next going to be doing helping studies with children in a MEG machine to find out what part of the brain is lighting up as they have that emotional a-ha experience that other person needs help. I'm going to go out of my way to help them. We want to see that in the brain.

I want to switch now from social to talking about cognitive abilities and especially what's called executive function. Executive function is the deliberate and full control of our thoughts and our attentions. And it's very, very important for success in school and life, especially, in the American school system where you don't want to be impulsive in the classrooms, want to delay gratification, take turns, and so forth. And the question is how children learn it, how to measure it.

In order to give you an experience about that, I want to show you the famous "Stroop Effect," one of most famous demonstrations in psychology. And this would give you an experience again of what it's like to be a kid. And so I want to give you directions and we're going to do audience participation here. I have two columns of words, and what I would like you to do, follow these directions, only name the color of the font, your job is just to say the color of the ink that these words were printed in. Do not – you don't pay attention to the word meaning, just read the ink.

Most people can do this fairly easily. So in class participation can everybody just read down that column? Ready, go.

(Audience participation)

MR. MELTZOFF: Great, good going class. Now the second column will be more difficult, most people make mistakes. Again, the directions are just name the color of the font, ignore the word meaning. Ready, go.

(Audience participation)

(Laughter)

MR. MELTZOFF: A-ha, it shows you what it's like to be a kid again. It's difficult to follow instructions. Your frontal lobe should be throbbing now because that's the part of your brain that helps you succeed on this test. The reason the second column is of course more difficult is there is an -- it's incongruent. The color of the font mismatches the meaning of the words and you have to devote great attention to avoid paying attention to word meaning.

Of course, psychologists are interested in testing executive function in young children. And we've come up where there is variety of people who have come up with some very, very interesting tests. One of the biggest pieces of executive function for 0 to 5-year-old kids to solve is inhibitory control. And the next film shows a little 3-1/2-year old girl who can't quite inhibit herself as much as she wants to.

We know there is great development in the frontal lobes in the first 5 years of life, 3-1/2 years is on the very early age and this child can't control herself try as she might where the task is -- an adult behind her is wrapping a present, making a racket, making a lot of noise, and her directions are don't peek, don't turn around.

(Video being played)

MR. MELTZOFF: Okay. Five-year-olds have more developed frontal lobes and there are tasks we can do with 5-year-olds that show that they can succeed. In the next film, I'm going to show there is a 5-year-old boy who has a purple box that has a present in it. And we say to the 5-year-old, "Don't peek, don't open the box. If you open, you can't have what's in it, but if you wait for 3 minutes you can have what's in the box. Okay, I'm going to leave the room, make sure you wait."

And this little 5-year-old does something brilliant. He sings a song to himself so he can bridge the gap and delay gratification. I want to show you what he spontaneously does. I am waiting.

(Video being played)

MR. MELTZOFF: Now there may be some sex differences in how children solve this task when confronted with delay of gratification. Here's a little girl.

(Video being played)

MR. MELTZOFF: So she too is able to bridge the entire 3 minutes, she uses a different technique. Now we know if we tell other children this technique they might not think of it spontaneously, they look at you like you are a genius when you say if you want to delay gratification try singing a song or try just turning your back. And the kid's like, "Oh, I never thought of that." And it helps them delay gratification and wait.

We are interested of course in tracking the very earliest routes of the origins of executive functions. And scientists are also interested in what sort of family environment and experience will help bring about strong executive function skills and delay of gratification in young kids. And this of course brings us to a profound practical question. We're undoubtedly in the midst of a revolution and understanding just how important early learning and brain development is.

We know that the first 2000 days of life are amazingly important. Society ought to pay more attention to it and devote more resources to this period. Education doesn't just begin in first grade; it begins as we saw at birth. What we are going to do now – need to do now in parallel with making these scientific advances is to merge or bring together the science of learning on the one hand and the practice of learning on the other hand, so there can be more bidirectional interaction between those.

And Pat's next section here, the last portion of the talk, is our attempt to try to bridge from the brain science and laboratory science to practical applications in education.

MS. KUHL: Okay. So we have shown you that the brain is ready in early development. Connections are forming; the brain is waiting for experiences that produce all of this complicated linguistic, cognitive, and social behavior. And there are implications for all of us in how we treat this information and what we do with it. I think one of the things that Andy and I talk about a lot is the responsibility that all of us have if you understand how brains are developing and how they are waiting for experience to shape the architecture of their brains. It means that we have to provide the information that children need.

Children are growing up in a world that can be any place. They can be operating in a culture, and with a language, and with values and systems that are being supplied by the culture that surrounds them, but we know all of us, especially in this room, that the opportunities for learning are not equal. Children growing up in poverty have fewer opportunities to learn. And we've been interested in what effects the brain shows us of that lack of experience on their brains.

One of the studies that we published recently is very surprising, but given the data, understandable, the fact that the brain is learning so early, and the brain is waiting for information. In this study, we had children measured in very frequent ways with regard to their linguistic abilities, cognitive and social abilities. And also the socioeconomic status of their families, of the educational preparation of their parents, and the job opportunities that their parents had.

What we discovered is that this is again Broca's area in the brain on the right, what we discovered is of all the measures that we took on the children, the most powerful one to predict the sophistication of brain development at the age of 5 was not the children's abilities, but the family's socio-economic status.

So we all know – that's very surprising; socioeconomic status is an opportunity, it's a proxy for the opportunities to learn. And when we looked at the data with regard to the families and measured the amount of words being spoken at the dinner table, and the complexity of grammar that the children heard throughout the day, sure enough, SES was indeed a proxy in this study for the number of the books in the home. The kind of language that the children heard, the complexity of the social conversations that they had.

And what we see in this graph a co-relation graph is SES running on a standardized scale from about mid-scale, not even the lower half of the scale, mid-scale to high scale, that each child on it, who is a dot on this graph, that with higher SES the brain function in Broca's at the age of 5 was more sophisticated, more ready to learn, better prepared for language and literacy.

So of course, this isn't a level playing field. And it's not the child's fault at 5 years of age, that child was not given the opportunities to learn. So as a society, we have to take into account that children's brains are ready and that if we don't provide them with the right kind of information, if they are growing up in adverse conditions, and worse yet than poverty if they are growing up in a situation in which they are neglected or abused.

We are now studying children at 5 who are in the foster care system in Seattle, and we are seeing dramatic brain differences at the age of 5 between children who are in the foster care system as opposed to typical controls. This is something that we need to take into account. Many studies are now going on to look at the effects of toxic stress on the brain.

What's happening as these 700 connections per second are being formed early in development, as the areas of the brain that are reporting the right, ready to receive language, ready to receive social information ready to learn executive functions. If the information isn't there, those brain areas don't develop in the same way.

Now secondly, there are big implications for developmental disorders. Not all children come into the world fully prepared to learn; genetic differences and other differences cause children's brains not to be ready at the right times in development when the window is open. We've been using these same brain measures which are really sophisticated and being used to study typical children to try to provide biomarkers on children with developmental disabilities.

As you can imagine, if we could detect children at risk for autism really early in development or children at risk for dyslexia really early when the brain is plastic and forming its architecture, we could get in with novel interventions to change the course of that child's and that family's life. We have published just a couple of weeks ago, a very exciting finding on 2-year-olds diagnosed with autism.

The brain measure is the detection of known words. Known words has a particular signature in the brain. When we measure this signature effect in typical kids, we see it in the left hemisphere exactly where it should be. When we measure it in children with autism, it varied greatly. That predictor – the signature response to known words showed at 2 to be a fabulous predictor of outcomes at 4 and at 6. And I will show you in a minute, 4 years later not only the linguistic abilities of these children, but their cognitive abilities and their adaptive behavior.

So here is the graph, fairly complex. The top row of boxes is their outcomes at year 4, they are 4 years of age, they were measured at 2. The bottom row shows their abilities at the age of 6. And the various columns show cognitive ability, then adaptive behavior and receptive language. What's amazing about this graph is that the measure taken at 2, gets to be a better predictor over time.

What we think is happening is that the measure at 2 – the ability to acquire the name of a thing, it depends on your attraction to people. You have to learn from people to know that the name of this in English is watch, you have to interact with humans speaking English. In Japan, it's named differently. In Russia, it's named differently. So this probe, at the age of 2 to learn words is a kind of probe of your ability to learn socially, learn this language that's being used to communicate in one country as opposed to another.

That measure predicts the brain's ability to learn socially. If you can learn socially at the age of 2, we can show you how the outcomes will look 4 years later because learning socially not only in language predicts how you'll learn across the board. So that's very exciting. The idea that we can some day identify risks early so that we can change the course of children's lives. Brains will tell us not only give us an early biomarker, but show us where in the brain things are not happening in the way that we'd expect them to happen.

So given the difficulties of reading in the United States, English is a very difficult language to read, 20 percent of our children have trouble and there is an 80 percent chance that if you are not being – reading is not easy for you in first grade, it will not be easy for you in third grade and fifth grade. So again measures early that early measure of sound perception at the age of 7 months that I showed you, that predicts reading readiness at the age of 5. So brain science is producing biomarkers for developmental disabilities and showing us how our children are heading. And we may be able to change the world because of these measures.

As we envision the future, we want to share with you some of the places we think this brain science will take us with regard to our society, and our children. The first is that I think you are convinced when you listen to Andy and I talk that we think social others are really important, particularly for children. The idea that brains react differently when they are in front of other people is really something that we'd like to see in the brain.

We are now doing studies where babies are in the MEG machine and their mothers are talking to them with an EEG cap on. And these two brain measurements are co-registered. We can see as the babies and the mothers smile at each other, their brain rhythms get in sync. And we can actually visualize when they get out of sync, when mother turns away or looks down.

So we have the opportunity to see what's special when humans face other humans, we think some magic happens in the brain. We don't know exactly why and where, but we've got some predictions that we think will show us where in the brain we're going to see these differences. We think this kind of learning is extremely special.

It's very important in the first 2 years of life that we spend a lot of time face to face with our kids. We're their best toy. We do all the things that they love to do, we help them explore their curiosity. We help them remain resilient in the face of adversity if you set that stage for trust in the early period.

Now in the context of our importance of social learning, we have family time 21st century. So we all know that technology – we are all addicted to technology and technology that as we discussed last night at the Colter's House (phonetic), the technology has brought wonderful changes to the world. We are bringing the knowledge worldwide, sharing the knowledge worldwide. It also has consequences with regard to families.

When all of us are staring down at our phones and devices, we're not doing this special kind of social interaction. So when, and where, and how our social technologies can help us learn in a way that's equal to face to face time, this is something that has to be studied. We are great fans of technology, but it's something that has to be understood. We are also fascinated by the adolescent brain. If any of you –

(Laughter)

MS. KUHL: – we were all teenagers once, we all took risks. The adolescent brain – there are three times in development. The early period that we've been talking about today, the adolescent brain which is a time when the pruning is finishing up. This brain is being crafted for the rest of their lives, that adolescent brain would be a fascinating next step to study, also the aging brain. So these three times when revolutions in the brain are happening; early infancy, that first 5 years, adolescence and the aging brain as we all cognitively decline.

Genes play a role in all of this. Genes open the windows for opportunities to learn and close the windows. And so gene expression and being able to put these brain tools together with genetic studies of gene expression which are now really possible. We are teaming up with geneticists to do these studies and that's going to be the next decade's work. Fabulous understanding will await us as we see genes, and brains, and environments interact.

And finally, we've been visiting other countries. Other countries seem to get it in a way that our country still hasn't gotten it. This is a Hong

Kong school for Infants, Toddlers & Twos, it's a Saturday morning. The requirement for being in the school is that dads have to show up on Saturday mornings. So here you see all of the dads with the little 2 and 3-year-olds in Hong Kong.

This is a fabulous school where informal learning meaning everything is fun, everything is informal, and they are dissecting fish, and they are learning. It's a trilingual school, they are doing music and they are doing science, and they are having a blast. And I love watching them play and imagining their brains going to it.

So thank you for listening. Happy Fourth of July; when you see the fireworks this year, think of that child's brain, same thing is going on.

(Applause)

MS. KUHL: So there may be time for a couple of questions, 3 minutes for questions. So if you have one. There is someone right up here, go ahead.

SPEAKER: Thank you. So in the first 30 months or in the first 12 months of this whole cognition piece, as far as a face to face with the mother being so important or the father in this case, what is the surrogate? I work in Detroit a lot where parents don't have that ability because of jobs or transportation ever to spend all the time they need with their child. So from the research that you've seen, is there a surrogate with another adult, is there a surrogate with something that's not a television which is the most common form of interaction?

MS. KUHL: Right. So Andy and I would both say, it's face to face communication with other people. It doesn't have to be a parent, it has to be a caring, loving adult that really wants to interact with that child, that's what allows the brain to flourish. And of course parents are the first ones on the line, but others can play that role as well.

MR. MELTZOFF: Lots of hands.

MS. KUHL: Yeah.

SPEAKER: Yesterday, we saw with Joe Klein and Walter, this demonstration on amplify which showed the interaction using the technology in the iPad right there in the classroom, but the students were not interacting human-wise with the teacher, but with the pad and the teacher was providing to each of the children. That flies right somewhat into the face of what you are saying that they got nothing from watching it on the video versus dealing with the teacher. Where do you think that takes us?

MS. KUHL: Well, so it's early -- under 16, 18 months, our studies are showing they are not learning from television, but after that time they are. So it's not as though we don't learn from technologies, but early in development people are your best teachers for children. And I'm going to tell you one brand new finding. So don't tell anybody else, right.

(Laughter)

MS. KUHL: Okay. We are doing some experiments in the laboratory with technologies and babies. We've learned some phenomenal things. As soon as you make the technology more responsive to the child, more like a social other, they learn more. So having a baby touch a screen to turn on the language snippets increases their learning. It's never as good as face to face, but it does change things.

And the second finding is if you put two babies together and let them collaborate on turning on the touch screen technology, they learn twice as much. So we excite each other and our brains when we are together. So if all the technology gurus can figure out how we can learn from technology together, I think we've got a miracle on our hands.

MR. MELTZOFF: Lots of hands.

MS. KUHL: Hi.

MR. MELTZOFF: Do you have a microphone?

SPEAKER: Just a quick one on pre-maturity and brain development. I know often times premature babies especially super preemie's have developmental delays. Does that last for life or are there things you can do to help that?

MS. KUHL: Yeah. So premature baby, that's – they are very, very interesting because they have been, you know, they are out of the womb early, so you would think they are getting, you know, longer bits of experience, but the brain hasn't had the chance to build the connections in the safety environment of the womb. So yes, it makes a difference, but not always. It depends on the system.

So in the language area we've seen that pre-maturity does not change the timing of this transition from 6 to 12 months, interestingly enough. So if you have been born 3 to 6 weeks premature, but you're healthy otherwise, then the transition happens at the same time. So that's very interesting. We also know from recent studies that babies are learning in the womb. They are learning from their mother's voices.

We just published a study in comparing newborns in the nursery, in the first 48 hours in Stockholm and Seattle, and we played novel sounds from Swedish and English. And in each case, talk about born curious, the babies preferred, they sucked on a nipple more to hear the foreign language sounds, right. They've been listening to their moms for 10 weeks and it's like, "Hey, I want something new."

(Laughter)

MS. KUHL: And so, you know –

MR. MELTZOFF: What's interesting about that is they also had agency. These are new born babies. You have to realize this sort of born curious, born learning. These are new born babies and the study involves having a nonnutritive nipple in the mouth of a new born where it's connected by a wire to a computer. And when the baby suck, they can choose to turn on one sound or another sound.

And the baby sucks faster to hear the foreign sound. They get very excited to turn on the foreign sound, foreign compared to what they heard in the womb. So people who had known that babies do that postnatally, but this translation – transition from prenatal to postnatal is a new thing. There is a person back here.

SPEAKER: I'm interested in the differentiation between the "us" and "them." Obviously, this is built-in evolutionary process that we built over many, many years. I wanted to know how you follow that up, how it evolves?

MR. MELTZOFF: Well, there are lots – there are several teams around the world working for this. It's a very good question. I mean one of the most amazing things and troubling things about human beings is this idea that we automatically form social categories into us and them. We have negative attitudes towards the "them," often go to war over this division of us and them that need not be over physical characteristics like orange t-shirts and green t-shirts, but sometimes around nationality or religion.

We seem to be fighting about the people who are in the out group demonizing them and interestingly often denigrating them to be something like less than human that allows us to engage in warfare. So developmental psychologists have been interested in where this begins, whether there is somehow a natural tendency in humans to recognize others as like me and her and then to collect others around you who fit this category as like me.

So I think what developmental psychologists want to do is understand where that motivation comes from. And the way their parents, teachers, and culture play a role might not be in teaching the brain not to divide into us and them, but to widen the circle of what counts as us. And also to make this division where there can be in group positivity which seems to happen naturally, but not necessarily out group negativity.

There may be us and them, but you can possibly change the attitudes towards the "them" group through experience. It's a very, very fascinating process. It seems to have biological roots because researchers around the world are finding it in such young kids, profoundly important.

One other thing, I want to say is that languages turn out also to be a division for us and them, not only gender which young kids use, not only race which young kids use, but if you hear somebody else who is of the same gender and race, you might think they'd be in the in group, but if they speak a foreign language even young children shun them as being in the out group. So the dimensions that humans use for that are profoundly important to study.

MS. KUHL: We are out of time. Thanks very much.

(Applause)

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