Improving Head Start Children's Understanding of Numbers

Gail Joseph: Well, Happy Monday and welcome to another installment of the NCQTL Front Porch series. So, I'm Gail Joseph and I'm the Co-Director of the National Center on Quality Teaching and Learning. And on behalf of all of my colleagues here at NCQTL, I'd like to thank you all for joining us this Monday morning or afternoon, depending on what coast you're tuning in from. So for those of you joining us for the first time, the goal of this Front Porch series is to feature national experts who are doing innovative and applied work that's really focused on improving the quality of teaching and learning in Head Start and other early learning settings, and in turn these outcomes for young children and their families.

So, today's topic is one that I think we are all really excited to hear more about and that is about early math learning. And we are going to be joined by an actual national expert, somebody whose vita is incredibly long and very impressive, Dr. Robert Siegler.

So before I turn it over to him, I just want to tell you a little bit about him and why we're so excited that he's here. Robert Siegler is the Teresa Heinz Professor of Cognitive Psychology at Carnegie Mellon and his research focuses on children's thinking, particularly their mathematical and scientific thinking. He has published hundreds of articles and chapters. He's written numerous books. I'm guessing that all of us have read at least one of them in our bachelor's program, probably, or master's program, and he's edited several more. He actually also has a center named after him, the Siegler Center for Innovative Learning, or SCIL. It's the first center that Beijing Normal University has named for a foreign scholar, so clearly a very incredible expert in our presence here.

So, Dr. Siegler's research focuses on the development of problem solving and reasoning in general, and more specific topics of how children learn mathematics, which is, of course, why we have him here today, and how that understanding can be applied to improving the learning of preschoolers from low-income backgrounds. So I personally have been really looking forward to hearing about this work and learning more about how we can support this important aspect of children's math learning. And so before I turn it over to our esteemed speaker, let me just remind you that, as always, we save a few minutes at the end to field your questions. But feel free to start writing those in throughout Dr. Siegler's presentation today at any point and we will make sure that we get to as many as we can at the end. So without further ado, I will turn this over to our presenter, Dr. Robert Siegler.

Dr. Robert Siegler: Well, thank you very much, Gail, for that gracious introduction and thanks for all of you who are listening, who are taking all this time out of your very busy Mondays. So, the work I'm going to be talking about today is on a board game that we found improves math learning, largely of children

in Head Start and other low-income childcare facilities. There're two different problems, just to provide a little overview of what the United States is dealing with. There're two different kinds of problems that we're facing and these problems are evident, not just with young children, but with older ones as well. And the data that you're looking at on the screen come from the Organisation of Economic Cooperation and Development and they were collected 20 years ago, but they still are very much the same.

And what we're looking at is eighth-grade math achievement as a function of father's education; so, the least well-educated father, maybe someone who dropped out of sixth grade, would be at the 0th percentile and someone with a Ph.D. or M.D. would be at the 100th percentile. And when you look at the U.S. data, which are in blue, you see two different kinds of problems. One is that we score lower, in general, than countries that are pretty comparable to us, such as Germany and Canada. And the other is that we do particularly badly with children from low socioeconomic backgrounds, in this case, children whose fathers are poorly educated. And this is a big part of the Head Start population. And so we don't do too bad toward people who are very well educated, but for people whose parents are poorly educated, we have a really serious problem.

This problem starts very early in the preschool period. These are some data that a researcher named Prentice Starkey, who's at University of California, Berkeley, reported in 2004. And these are with four-year olds, similar to the age group in Head Start and the graphs show the difference between low-income and middle-income children. And regardless of whether you're talking about counting objects, or knowing what the next number is, or comparing which of two numbers is bigger, or adding objects to objects that are already present, or solving abstract arithmetic problems, like just asking the children two plus four, or naming different shapes, you see there're large differences between the children from low-income backgrounds and the children from middle-income backgrounds. No great surprise there.

Now, an interesting finding is that the differences between children from low-income and middle-income backgrounds, or in this case, between children from African-American and Caucasian families, they're already present early on, but they get bigger and bigger over the course of schooling. And so a lot of our logic of our intervention is to prevent these difficulties that are there from the beginning from arising then and, hopefully, that will keep the kids more motivated and able to focus on the math that they're learning and, therefore, the labor differences will be reduced or, ideally, eliminated as well.

So, in light of these background findings, we started with a pretty basic question: Might low-income preschool children's poor numerical performance reflect inadequate representations of numerical magnitudes? So, you might ask yourself, well, what are representations of numerical magnitudes? And this is about the sizes of numbers and I think most people think that when you say 6 or 600, that people automatically think of a quantity that is like 6 or 600. But in fact, there's many, many, many studies that

show that this isn’t necessarily the case, that very often when people talk about numbers, they just think of them as names and they actually are not very accurate in matching them to the quantities that those number names represent.

One task that we found particularly useful for getting at how good very young children and actually, with bigger numbers, older children's numerical representations are, is the number line estimation task. And what we do on this task -- we give children, this is the kind of version we would do with four- and five-year-olds – we show them a line with zero at one end, ten at the other, and we give them a number like seven. And they have to estimate, usually, with young children with pencil and paper and older children with a computer cursor, they have to indicate where that number would go on the line. And then when they've done that, they get another identical number line except with a different number, maybe, two, and then we give them another number line, perhaps with nine on it, until we've sampled all the numbers in the range. Now, what do children do on this test? So, these are middle-income four-year-olds versus low-income four-year-olds. And what you can see here is that the middle-income four-year-olds are doing pretty much what you would want them to do.

So, that ideally, you would match the actual magnitude, which is on the x-axis, the part going horizontally, to the average estimate, the part on the y-axis. What you actually get is the middle-income kids come pretty close to doing that. Their estimates in general are very accurate. But the low-income kids have very little idea where the numbers are. So, when you present "one" to these low-income children, ask where it is, they give an average estimate that's somewhere between four and five. And when you ask them, “Where is ten?” they give an average estimate that's around seven. So, they have a little bit of an idea of how big the numbers are, but a very, very imprecise one. So, knowing this, we asked ourselves, well, what leads children to ever form accurate representations of very small numerical magnitudes like those that go with the numbers one through ten?

So, the obvious experience that suggests itself is counting. And there's no question that counting is helpful and important, but it's also insufficient and we know this because children can count one through ten perfectly fine more than a year before they can generate a linear representation of that range. In other words, a representation, a set of estimates like the one you saw for the middle-income children on the last slide. So, that tells us that knowing how to count isn't good enough to understand the magnitudes that go with those counting numbers. Very often, the children learn the counting numbers the way that some classic rock and roll groups in foreign countries, who didn't know English, would sing songs in English, but they had no idea what they meant.

So, we started thinking about other kinds of experiences that might be important and one that struck us as likely to be important is playing board games. So, these board games aren't usually intended to teach

about numbers. They actually are more to promote pleasant interactions between parents and children. But they also, sometimes, provide rich experiences with numbers. And one game that you're probably familiar with, it's actually – we've learned the second-most commonly played game in preschool households, is Chutes and Ladders, a very common game. Probably pretty much all of you have seen it and most of you have probably played it. And what you do, you start out at one and you spin a spinner or roll the dice and you move your token along the numbers and a variety of things happen. Sometimes, you go on a ladder and that helps you zoom up and sometimes you go on a chute and then you go down. It's a very pleasant game that many children play with their parents.

Now, an interesting property of this board game, thinking about Chutes and Ladders in particular, is that it is perfectly designed for teaching children about numerical magnitudes, because think about this, the first row of Chutes and Ladders, where you're going from one through ten. So, the greater the number that your token reaches, the greater the distance that the child has moved the token. So, if they're on eight, they've moved the token twice as far as if they're on four, the greater the number of discrete hand movements the child has made with the token and again, it's exactly twice as great to get to eight as to four, the greater the number of number names the child has spoken and heard – and again, it's exactly proportional – and also the greater the time spent playing the game, so it takes longer to get to eight than to four.

So, all these different kinds of cues provide useful information for the child to figure out how big these numbers really are. It provides visual-spatial information, so you can see how great the distance is, kinesthetic information, so you can feel with your hands how often you've moved the token, auditory information, you can hear the number words and temporal cues, you can tell how long the time has gone by, so that you learn about the numerical magnitudes and you learn on all of these dimensions, to continue our example, that eight is about twice as big as four.

So, after we did this analysis, we designed a number board game that we called "The Great Race." There was a rabbit and a bear that were racing and the child could pick whichever one they wanted and the child could pick whether to go first or second and they always chose to go first, which created something we wanted to do, which meant that because it's a game of chance and they would spin the spinner and either get a one or a two, about 80 or 85 percent of the time, the child who went first would be the winner in the game. And so children choosing to go first would usually win, which made it fun for them, but they wouldn't always win, which gets boring after a while.

And then as a control group, to see whether it was just that the children were getting older or interacting with an adult or learning about one move per turn, we had a similar game except with colors, so the children, if they were playing the number board game and they were on a four, say, and they

spun a two, they would say five, six. If they were on purple in the color board game and they spun a two – or spun a red, rather, they would go blue, red. And so the children in both cases, if they didn't know what to do, the experimenter would help them. So, they would say if they didn't know what the word for blue was, the experimenter would say, "Blue." So "Blue" and then wait for the child to say "Red" and if the child couldn't, the experimenter would say, "Blue, Red. Now you do it." Or if they were on a four and they spun a two and they didn't know what numbers to say, the experimenter would say, "Five, six. Now you do it." So, that's the way the game was played.

So, one of our experiments that shows the benefits of playing this numerical board game, this, like all of the research in the series, Geetha Ramani, who was a former post-doctoral student working with me and who is now a professor at the University of Maryland, she and I conducted this study a few years ago. And we were interested in whether playing the board game would produce gains in fundamental numerical skills and concepts and whether it would produce gains that continue over time. So, to find this out, we had 130 children, four- and five-year-olds, from Head Start classrooms. Their mean age at the time they played the game was four years, eight months. A small majority were African-American. A large minority were Caucasian. This is the two dominant groups in the Pittsburgh area where we conducted this experiment. We've also run subsequently, in Maryland, studies with Latino children and they also benefit just like the children in this experiment. And we randomly assigned children to either the number board group or the color group. And each child would spend two weeks. They would play four different sessions, 15 minutes per session. They would play the games and they typically, over these four sessions, played about 20 games. Each game takes about two or three minutes. And so on the pre-test in the first session and on the post-test of the last session, the children would do number line estimation from zero to ten, as I explained to you, that task before. They would play the numerical magnitude comparison game, where they were asked which is bigger, six or four? Which is bigger, three or seven? They would have to indicate which was bigger. They were asked to count one to ten and they were asked to identify numbers from one to ten. So, we would hold up a number such as six and we'd say, "What number is this?" The child would say and then we told them another number and continued. And in this study, we also had a follow-up session; so, nine weeks after the final in-play session, we brought the children back and we presented these same post-test tasks that we had given them nine weeks previously, to see if they still benefit, because a lot of times, you teach children something and then they forget it, just like adults.

So, the way that this works, and I'm going to show you the results from each of the tasks. So, this is the number line estimation task and what happened was that at the pre-test, there was no difference between the number board group and the color board group, because this was before the children had any experience with either of the games. At the post-test, the children in the number board group did quite a bit better and at the follow up, they still did better, not quite as much better, but still significantly better. The same was true in terms of the children's ability to compare the numerical magnitudes. Which is bigger, three or five? The same was true for counting. The children who played the number board game improved more in counting and all of these gains are still present nine weeks later.

And it's also true in identifying numbers, so that the children could identify numbers better after playing the number board game.

Now, in a subsequent study, Geetha and I looked at the children's ability to learn new arithmetic problems after playing the board game, because we've shown, and other people have shown, that when you understand the magnitudes of numbers, it's easier to remember the answers to arithmetic problems. And so we were curious whether playing the game, which we believed improved their understanding of the sizes of these numbers, would help them learn more from arithmetic problems. And so we gave the children several arithmetic problems after they had played the board game in the fifth session. And we repeated the problems several times and then we tested them to see if they had learned the answers better if they had played the linear board game than if they had gotten other numerical activities or whether they had played a circular board game, because we didn't think that the circle would do as much good. And indeed, the children who benefited the most were the ones who played the linear board game, that is, the game where the numbers are all in a row, rather than the two who played either circular board game or who just practiced counting and identifying numbers.

Now, in the same study, Geetha and I did another experiment in which we continued with a large majority of children who had been in the first experiment, from Head Start and we also recruited 30 children from middle- and upper-middle-income families. And we asked them about their experience playing board games, playing card games, which we thought might also be useful, and playing video games. And all of these outside of school. We asked them a lot of different questions. We asked them who they played with, if they played with their brothers or sisters, with their parents, with their grandparents, with anyone else, friends, and we also asked them to name the different games that they played of each type. So, what we found was that, along with the idea that this game-playing experience matters in the everyday world, not just in the laboratory, we found that the middle-income children had a real lot more experience playing the board games and quite a bit more playing card games.

Interestingly, the children at Head Start had more experience playing video games by a fair amount, a two to one ratio, so that this was consistent with our belief that playing the board games was part of the reason why middle-income children do better when they start school in numerical activities than children from low-income backgrounds. And here, these are correlations for the Head Start sample between how much they knew on these different problems in the Experiment One and how many board games, how many card games and how many video games they said they'd played. And as you can see, the children who, the more board games the children said they had played, the better they were at all four of the other numerical tasks, indicating that there's some relation between the two. The relation with card games and video games was much weaker. Only one correlation in each of those two activities was significantly correlated with their card game or video game experience. So, this evidence converged with our experimental evidence from the lab to show that it looks like playing board games, and

especially, numerical board games, in the every-day environment is very helpful for the children for learning math.

Now, we followed up this study in a variety of different ways, as have a number of other groups throughout the world. And I'm just going to summarize the findings briefly. One thing we've found is that playing these games also helps middle-income preschoolers, but not as much as the Head Start children. And our belief is that middle-income preschoolers probably have already gotten a fair amount of what they can get from the board-game experience, just in their homes. But the low-income children, who have much less experience with board games, can learn a lot more from these numerical games. We've also found that the game is effective in other countries, such as Britain and China and also Italy and Portugal and some others. The game is effective in small groups when played with paraprofessionals at Head Start centers.

So, we were interested in whether, in a more every-day situation where the game could be implemented, whether it would work. And we thought, well, it'll probably be impractical for one adult to play with one child in a Head Start classroom, because there's too much to do for adults. And so we had groups of usually three children playing with one adult. And the adults, rather than being research personnel, were paraprofessionals working in the Head Start center. And the game was effective in that context as well, which we were very encouraged to find out.

Now, ours is not the only preschool mathematics intervention that's produced impressive results. Just to name a few others, there's the "Building Blocks" curriculum that Doug Clements and Julie Sarama developed. There's "Pre-Kindergarten Mathematics" that Prentice Starkey and Alice Klein developed. There's "Number Worlds" that Sharon Griffin and Robbie Case developed. They all produced very impressive gains and here's an example of the gains. So, you might remember at the beginning of the talk, we discussed from the Starkey, et al. data about how different the low-income kids were from the middle-income kids. Now, that was true on the pre-test, as again, this slide shows on the left side. When you look on the right side, you see that on the post-test, the low-income kids had just about caught up with the middle-income kids. And notice this is not because everyone knows everything, since both groups are about 70 percent correct. So, they could have done better, but at the end of the experience with that curriculum, both groups were very similar.

Same thing happens, not quite as dramatically, but same trend, in terms of a catching-up effect for children in the Starkey et al. study, two-set addition and on many other tests. And so we started asking ourselves, so why is it that preschool math curricula can produce such large effects, whereas many other areas, such as trying to improve literacy, tends to be a lot harder to do? And here's our explanation: Most American preschoolers, regardless of their social class background, receive very little math

experience. This is even more true of children from low-income families than from ones from middle-income families. Now, the gap between the low- and middle-income children's math knowledge is substantial in preschool, but not impossible to get rid of. You can really get the low-income kids to catch up or just about catch up to the middle-income kids at that time, whereas when you're talking about much later in their education, for example in fifth grade or eighth grade, it may be impossible to totally overcome the gap or even reduce it greatly, because the children who know more are learning more all the time, too. They're not standing still. So really, catching up is very, very difficult.

So, our basic conclusion is that well-designed early programs can greatly reduce the gap between low-income and middle-income children. So, just to conclude, playing a number board game for about an hour improved low-income children's numerical estimation, their magnitude comparison, their counting, their number identification and even their arithmetic, as you saw. The benefits were stable over time, at least over this nine-week period. The children from low-income backgrounds played fewer board games at home and the board game experience is positively correlated with numerical knowledge, so that this isn't just something that happens in the lab. It happens in the everyday world as well.

So, the bottom line is that numerical board games, like the Great Race, are a practical means for reducing these differences in early numerical knowledge. They're effective. They cost nothing. You can make a piece of cardboard and do it and it requires little training of parents and Head Start personnel. So, we provided about a half-hour training of Head Start personnel in the study I mentioned that we did with them, and they did fine with it. So, any questions that you have, I'd be happy to answer and thank you for listening.