The Teaching Brain and the End of the Empty Vessel

Vanessa Rodriguez[1]

ABSTRACT— I am excited to present this special section that explores the teaching brain. The goal of the series is to facilitate a transition in the lens on teaching from an empty vessel to a phenomenon as dynamic, variable, and context-dependent as learning. This transformation will likely push all of us to reevaluate our understanding and research on teaching. Over the coming year, each issue will provide several articles that seek to shed light on a different aspect of this burgeoning new area of research. This issue opens the series with a piece designed to lay out the conceptual framework and evidence base for a new way to think about teaching: the teaching brain. Next, Michael Chazan gives an archeological grounding for the existence of teaching in the earliest ancestors of *Homo sapiens*. Sidney Strauss and Margalit Ziv then describe how teaching is a fundamental human cognitive ability. Together, these articles begin to create a paradigm shift in the definition of teaching. We look forward to an exciting journey.

We must debunk the empty vessel theory of teaching and accept that a perfect teacher for all students is a myth. Continued exploration toward this goal will remain fruitless. Too often researchers and policymakers use their findings to attempt to simply pour knowledge about learning into the teacher's brain, as if those brains are "empty vessels." These efforts assume that to understand learning is to understand teaching. This is a grave mistake; teaching is not learning. Just as the field of mind, brain, and education (MBE) has debunked the empty vessel theory of learning, we need to do so for teaching.

To understand teaching is to understand the dynamic, variable, and context-dependent *teaching brain*. The *teaching brain* is a term that I use to encapsulate all of the processes invoked during the act of teaching. It is also a framework to guide research that is mindful of the complexity and depth of the human-specific endeavor of teaching. A teacher's context has infinite variables which dynamically interact with their teaching processes. Teachers must constantly change themselves based on the interactions they have with their learners in order to produce intellectual and behavioral success. Instinctively a teacher's goal is to maintain a productive social system; it is not a selfless act (Clark & Lampert, 1986). Rather than the mere mastery of content and skills this dynamic, interactive dimension of teaching requires that they know their own teaching brain as well as they know how their students learn (Clandinin & Connelly, 1984; Elbaz, 1983). If we hope to reform our educational system we must make serious efforts to explore the biological, psychological, and cognitive processes of the teaching brain. The process of reform begins with an examination and redefinition of the word "teaching" itself.

We need to re-conceptualize the definition of teaching not as a behavior inclusive of animals but as a highly evolved meta-cognitive skill specific to humans. Following this we can then embark on a new mission to define human-specific teaching characteristics. Research has been constrained by an insufficient paradigm for exploring teaching. Therefore we have yet to document a comprehensive understanding of these characteristics. In this article I will highlight promising first steps of research that begins to clarify teaching characteristics specific to humans. Additionally I will identify a framework for exploring and evaluating the wealth of understanding stored in the brains of teachers everywhere.

DEFINING TEACHING: IT IS NOT JUST SEMANTICS

The problem that we face today in teaching is that researchers and policymakers have accepted an inappropriate definition of this highly complex skill. To overcome this problem we need to re-conceptualize the definition of teaching.

Teaching as . . . Cooperative Behavior in Service of the Learner

Historically, biologists have identified teaching as cooperative behavior in which the "teacher" changes his or her actions to

[1]Harvard Graduate School of Education

Address correspondence to Vanessa Rodriguez, Harvard Graduate School of Education, Longfellow Hall, Room 213, 13 Appian Way, Cambridge, MA 02138, United States; e-mail: vanessa_rodriguez@mail.harvard.edu

aid a naïve "student" in acquiring knowledge or skills (Caro & Hauser, 1992). In line with a traditional empty vessel model (Lakoff & Johnson, 1980), knowledge here is an object of information to be transmitted from donor (teacher) to receiver (learner). The "teacher" can give the student feedback and as a result of this interaction the student will have learned the knowledge or skill more effectively and rapidly than had they no interaction (Thornton & Raihani, 2008). This interaction benefits the learner and incurs personal costs for the teacher (West, Griffin, & Gardner, 2007).

Notable in this traditional definition is the acknowledgment that teaching is an interaction between two beings and that the byproduct is effective learning through support. However, what goes against an understanding of complex dynamic systems, such as teaching, is the suggestion that a human skill would evolve independently although it has no benefit to the self. Evolutionarily speaking, why would humans develop a skill that is selfless? In reality individuals construct skills that support collaboration on specific tasks within their personal context.

Biologists argue that definitions of teaching that include unobservable cognitive processes are not useful for the purpose of research (Thornton & Raihani, 2008). If research were to happen in a vacuum perhaps this argument would be significant. This is not the case; research on teaching affects how we design and evaluate our teaching profession. In turn this has a great impact on our students, schools, and inevitably the cooperative system of our entire society. It is true that any definition of teaching requiring that teachers have a theory of the learner's mind restricts research primarily to humans (Thornton & Raihani, 2008). Nevertheless this does not eliminate the opportunity of conducting such research. It is of no consequence to tandem-running ants, pied babblers, or meerkats that their skill of cooperative behavior not be defined as teaching (Franks & Richardson, 2006; Raihani & Ridley, 2008; Thornton & McAuliffe, 2006). However, the definition of teaching greatly affects the role and responsibility we have given its namesake: the classroom teacher. Rather than changing the definition of human teaching (see Csibra & Gergely, 2011 for definition of natural pedagogy) to include animal subjects, we should insist on embracing these complex characteristics unique to humans.

We do not confuse the usefulness of animal studies for how we design and evaluate the medical profession. Imagine if we trained palliative care doctors using characteristics of how a wolf cares for a dying member of his pack. Or if we modeled the principles of human blood transfusions based on evidence of how mosquitoes extract blood from prey. While clearly there are many useful methods that we adapt from the animal kingdom we should not first define skills in the animal and then expect humans to live by those standards. By accepting an inadequate definition of teaching grounded in how animals teach, we have failed to appropriately study and therefore understand the evolution of teaching specific to humans.

Teaching with . . . a Theory of the Learner's Mind

In contrast, the common definition of teaching among many psychologists requires that teachers understand the minds of others. Premack has defined this necessary characteristic of teaching as Theory of Mind (ToM) (Premack, 1991). Developmental psychologists believe that ToM enables teachers to plan, evaluate, and reorganize their teaching to meet the needs of the learner (Strauss, Ziv, & Stein, 2002). Biologists agree that animals do not have ToM; animals do not modify their teaching based on the learner's ability and progress (Battro, 2010; Heyes, 1998; Penn & Povinelli, 2007; Premack & Premack, 1996; Premack, n.d.; Strauss et al., 2002; Thornton & Raihani, 2008). Generally, teaching among animals involves simple responses to behavioral cues; it does not adapt to individual variation (Strauss, 2005; Thornton & McAuliffe, 2006). Pearson (1989) has also described teaching as one's intention to help the learner attain knowledge. This human specific intention to teach goes well beyond the purpose of survival and toward a goal of closing the "knowledge gap" and creating a cohesive society (Frye & Ziv, 2005). In order to fulfill this goal humans have learned to adapt their teaching based on learner variation. Therefore, Premack and Premack 2003 and cognitivists alike argue that animals cannot and do not teach as humans teach (see Strauss & Ziv, this issue, for an updated review). By focusing on the adaptability of human teaching this definition follows an understanding of the dynamic and variable nature of the interaction and qualities specific to complex development.

However, the definition of teaching espoused by Premack and fellow cognivists does not fully encompass an appropriate motivation for why human beings teach. Why would a teacher want to support a learner in constructing knowledge? It's easier to consider the skill of teaching with an example outside of the classroom. If a five-year-old child, let's call him David, wants to play a board game with his friend who unfortunately does not know how to play the game, his instinct would be to teach his friend how to play. David does not teach because he hopes to get his friend to pass a mandated exam nor because he is in service of his friend. Unlike what some biologists would suggest, David is not incurring a cost by teaching his friend while receiving no immediate benefit (Caro & Hauser, 1992). Instead he has developed the skill of teaching because he wishes to participate in the task of playing a board game with his friend. In order to ensure that his friend knows how to play the game with him, David will most likely have to continually adapt his instruction. However David is more interested in being able to participate in playing the game with his friend than he is in ensuring that his friend knows the skill of rolling a die and moving a game piece.

Teaching Reclaimed . . . A Human-Specific Meta-Cognitive Skill

As cited in Strauss (2005) there are seven reasons, supported by research, that teaching is huma-specific: (1) ToM is species-typical (Hauser, 2000; Povinelli & Eddy, 1997; Premack, 1984, 1991; Premack & Premack, 1994; Tomasello, 1999; Tomasello & Call, 1997); (2) ToM is universal among human beings (Kruger & Tomasello, 1996; Tomasello, Kruger, & Ratner, 1993); (3) teaching is an extraordinarily complex enterprise having to do with mind, emotions, and motivation-reading (Strauss, 1993); (4) teaching is mostly invisible to the eye and difficult to observe in all its complexity (Strauss, 1993); (5) teaching is a specialized social interaction with distinct intentionality (Strauss et al., 2002; Ziv & Frye, 2004); (6) teaching is universal and learned without formal education although it must be learned; and (7) very young children teach and request to be taught. With these reasons in mind Strauss suggests that researchers consider the cognitive prerequisites of teaching.

The Institute for Research on Teaching (IRT) at Michigan State University, founded by the National Institute of Education, generated the most comprehensive body of literature on classroom teacher cognition. Under the umbrella of teacher education, IRT researchers from educational psychology, anthropology, sociology, and philosophy collaborated with public school teachers to produce research aimed at improving classroom teaching. Their findings were best summarized by Clark and Peterson in a review of research literature on teachers' thought processes (Clark & Peterson, 1986).

They found the complexity of classroom teaching to be reflected best in studies of teacher planning. These studies have suggested that classroom teacher planning is a cyclical and iterative process like any complex system of development. Teachers are required to adapt to multiple variables such as the learner, school environment, administrative mandates, outside forces, and teacher ability (Lortie, 1975; Yinger, 1979). Rather than static linear curricula, teachers often design dynamic systems and learning tools (Clark & Lampert, 1986). Yinger's (1979) research was an in-depth case study of one teacher's planning decisions over five months. The study had two components: (1) an ethnographic study based on twelve weeks of teacher observations and think-alouds during planning and teaching; and (2) observations of the teacher during simulation and judgment tasks, used to elicit the teacher's perceptions of her students in class. The study highlighted the use of executive planning (e.g., meta-routines), internal constructs that teachers use to organize and sequence all other routines (Yinger, 1979). A detailed description of the teacher's cognitive processes revealed that teacher planning was used intentionally to control the classroom environment which in turn aided the teacher in influencing student behavior.

This technique is often observed and described as preparing the learning environment for optimal support. Evidence of this has been identified in animal populations as well as in humans (Thornton & Raihani, 2008). However, as Strauss (1993) indicated, the teacher's purpose—and as a result teaching—is mostly invisible to the naked eye. Let's again go back to David and his friend. It is quite likely that as David teaches his friend to play the game he will try many forms of instruction such as preparing the environment. One can imagine David saying, "OK now you try it" while placing game pieces on the board to offer an example of what to do and what not to do in a given situation. It would be narrow-minded to believe that David's goal is to merely create an optimal learning environment. Let us remember that David is teaching his friend to play the game so that they can play together. We teach in order to gain a common understanding and therefore a unified context (also described as synchrony)

This process is extremely complex and requires that a teacher's knowledge be meta-cognitive: thoughtful of both the mind of the learner as well as his/her own mind-brain. This contextual knowledge is situation-specific (Bolster, 1983; Elbaz, 1983; Smith & Geoffrey, 1968), constructed by experimenting with actions and observing their outcome (Clandinin & Connelly, 1984; Lampert, 1985). The situation, or context, shapes all aspects of teacher thought regarding pedagogy, student interaction, adaptation, and implementation of research. Teachers are constantly experimenting, inventing their actions in regard to their environment, which includes the learner. A teacher's context can be seen as the tight connection between environment, teacher planning, routines, and methods. The importance of the teacher's context including self-image as well as perceptions of the classroom was highlighted in several in-depth case studies which argued for the central importance of the unique characteristics of each teacher and their effects on the educational experience (Clandinin, 1985; Lampert, 1985).

Clark and Lampert's (1986) review of this era of research on teaching concluded that "the teacher's job is to produce intellectual and behavioral changes in people who bring their whole selves to the learning situation and are constantly changing those selves in interaction with one another." Therefore, teacher knowledge, similar to a learners' knowledge, or the learning mind-brain, is dynamic, variable, and context-dependent (Clandinin, 1985). However, with recent developments in archeology and the brain sciences we must push further to explore the origin, evolution, biological, and psychological aspects of teaching. Granted, more research needs to be performed to specify the definitions and characteristics of these general domains of teaching.

WE TEACH TO CREATE SYNCHRONY

Many researchers have focused their efforts on improving structures and tools that support learners in achieving optimal levels of understanding. Often this research is identified as work toward improving teaching. However, this practice follows an empty vessel theory of both learning and teaching wherein knowledge is an object to be transmitted from one empty vessel to another. This is in direct contrast with our understanding of brain development. Fundamental to constructive dynamics is the understanding that individuals construct skills in order to participate in specific tasks within their context (Fischer & Bidell, 2006). Consider again teaching as an evolved skill: Why do humans teach? Teaching is an adaptive skill that we have continued to develop over thousands of years (Csibra & Gergely, 2011). Like any skill it was constructed so that we could participate in a specific task within our context. It is unlikely that the task was a state exam, algebra, or diagramming a sentence. When did this skill of teaching appear? Is teaching a core skill that existed with the very first humans similar to learning? (For insight on this, see Chazan, this issue.)

The instinctual skill of teaching, as described with David above, exists to create synchrony among two or more humans interacting. A parent teaches a child how to walk because it is necessary to become part of our society, not because we must walk upright to survive. We teach reading and writing not because we cannot communicate without it but because it allows us to become part of one another's context. This definition of teaching follows core principles of dynamic systems by respecting how both the learner's and teacher's brains develop.

Before we can begin to effectively consider the role of the classroom teacher, it is necessary to truly understand the complex skill of teaching. We must redefine our classification of this skill; we must build a theory and method that capture the origin and purpose of teaching specific to humans.

Reclassifying Teaching: Viewing Teaching Through a New Lens

As described above, several disciplines have studied elements believed to define the skill of teaching. Biologists have studied the cooperative behavior and coordinated interaction of observable teaching. Developmental and cognitive psychologists have identified the human-specific ability to adapt teaching in response to various contexts. Teacher education researchers have worked with classroom teachers to uncover some of the cognitive processes of classroom teaching. These studies can be used as stepping stones toward documenting teaching characteristics specific to humans.

With this foundation we begin to understand that teaching is more than a set of skills learned by adults in service of educating children in a classroom. Teaching must be studied as a distinct, human-specific, cognitive, and biologic process which includes ontogenetic and phylogenetic origins. There are a few studies which have begun to document such distinctions. A study of a group of children between the ages of 2–4 supports the intrinsic development of teaching skills at early ages. Ashley and Tomasello (1998) studied teaching between pairs of children and found that 2-year-olds were unable to teach skills to one another, whereas 3.5-year-olds were able to teach their untrained peers a task that they had mastered. Adding to this developmental finding, Astington and Pelletier (1996) discovered that the quality and nature of teaching also change with time. They found evidence that older children maintained more sophisticated teaching techniques through the use of description and collaboration while younger children taught only by showing. Wood, Wood, Ainsworth, and O'Malley (1995) reported that older children were more effective peer instructors when asked to perform teaching tasks requiring ToM. Due to its sophisticated meta-cognitive prerequisites (such as adaptation and intention), teaching becomes easily observable in the toddler years, growing more complex as one's need to socially synchronize expands to include more people (Strauss et al., 2002).

Strauss and colleagues further highlight the unique nature of teaching in an experiment where children were asked to play a board game together. Children in the experiment demonstrated different behaviors when teaching one another to play the game as compared to playing the game in competition with one another (Strauss et al., 2002). While the game was the same in both conditions, the study team observed that cheating occurred only during competitive play and never during the teaching phase (Strauss et al., 2002); this finding reinforces the importance of intention and goals when considering the definition of teaching.

These studies highlight the phylogenetic and ontogenetic origins of teaching that mature within us. Teaching is an internal function which evolves and develops over time, not in service or as a byproduct of learning but as what Csibra and Gergely (2011) would call an "independently selected adaptive cognitive system" (Ashley & Tomasello, 1998; Astington & Pelletier, 1996; Wood et al., 1995). These studies help to debunk the belief that teaching is a selfless act existing for the sole purpose of learning where any learning tool (i.e., computer, iphone, textbook) is considered a teacher. Shifting from our current thinking we need to conceptualize teaching as a skill that is distinct from learning although it too develops dynamically and within context.

The Fallacy of Teacher as Transmitter: Recognizing Teaching as a Dynamic System

The empty vessel theory of learning is founded on the notion of transmission, such that the teacher transmits information to the student (Lakoff & Johnson, 1980; van Geert & Fischer, 2009). The word *transmission* indicates that the object for transmission already exists and the "teacher" is exporting the information from one place to be imported in another, or by the learner. In this scenario the teacher can be any type of information transmitter (i.e., person, television, computer). Therefore it is no surprise that this logic model moves further to include an empty vessel theory of teaching wherein the teacher is merely a learning tool. In this model the teacher as exporter (i.e., person, television, computer) is a learning tool that can be filled with any information necessary for the learner's knowledge acquisition.

Challenging this "empty vessel" theory was one which attributed learning to stages of cognitive development such that a student would become competent in one area and then move up the ladder to the next level of difficulty (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956; Freire, 1970; Piaget, 1950; Piaget & Inhelder, 1973). However, the most successful theory to debunk the notion that knowledge could exist as an object for transmission has been dynamic systems theory (DST). DST utilizes concepts of chaos and emergence to design mathematical models to represent the growth and change of developing systems. For over a decade the field of MBE has utilized the framework of DST to model learning development as a dynamic complex system (Abraham & Shaw, 1992; Dawson-Tunik, Fischer, & Stein, 2004; Fischer & Bidell, 2006; Fischer & Rose, 2001; Fischer & Silvern, 1985).

Research supports that learning is not a physical transmission but one where the accepter of information begins to form an internal structure that replicates properties of the information imported in relation to his or her environment (van Geert & Fischer, 2009). As the accepter, or learner, processes this new information he or she may exhibit stage-like or dynamic (non-stage-like) development. Using dynamic skill analysis, researchers can design tools to identify this development and the necessary conditions for these changes to take place (Fischer & Bidell, 2006). Understanding this type of human development as dynamic requires the acknowledgement of the individual's ecology: external factors such as the individual's circumstances, setting, goal, state, support, and other variables (Bronfenbrenner & Morris, 2006). The context both affects the individual and is affected by him or her. Therefore, "knowledge" is not something to be transmitted as an object that exists independently. Instead, "knowledge" emerges through the interactions between the learner and his or her context (Battro, Fischer, & Léna, 2008; Fischer & Rose, 2001; Fischer, Rose, & Rose, 2007; van Geert & Steenbeek, 2005). MBE researchers have grounded themselves in these core principles to describe the "learning brain" as dynamic, variable, and context dependent. An important consideration is that a learner's range between functional and optimal levels of understanding varies significantly depending on the level of support provided by teachers (Fischer & Bidell, 2006).

DST AS A FRAMEWORK FOR THE "TEACHING BRAIN"

Dynamic systems theory has already become a strong framework for understanding learning and should be used to address Battro's (2010) call to "invent new neurological models to describe and predict the unfolding of teaching processes" (p. 29). Teaching is not merely a tool for learning. Our categorization for it must shift so that we recognize it as part of our natural human development. The cyclical pattern of learning development detailed in dynamic skills theory is likely to parallel patterns of activity for the development of the teaching brain.

Because of the tight relationship between teaching and learning we can hypothesize that, like learning, development of the teaching brain occurs in spurts, with each cluster of spurts producing a new level of skill and understanding (Fischer & Rose, 2001; Fischer et al., 2007; Freire, 1970). Dynamic skills theory tools, such as developmental webs and learning pathways as well as statistical tools which describe the variability of development in longitudinal data, have given us empirical evidence to debunk the empty vessel theory of learning, providing support for the idea that there is no such thing as a perfect student who will learn by merely receiving information (Fischer et al., 2007; Freire, 1970; van Geert & Steenbeek, 2005; van Geert & van Dijk, 2002). Instead, a student's learning mind-brain develops uniquely, affected by his or her personal context.

Similarly we must end the practice of pouring knowledge of learning into the teacher's empty vessel with the expectation that they will then become master teachers. Teachers are not empty vessels who exist without context. Furthermore, it is incorrect to suggest that teachers are merely learning tools. Learning can happen without any teaching occurring. A baby learns how to nurse, read body language, and talk without direct instruction (for further insight on innate skills of evolutionary depth, see Chazan, this issue). Objects such as bottles, books, and walkers help a baby learn but they are not teaching the child. Teaching is an intentional human interaction which supports us in synchronizing as a species. The measure of effective teaching is not to assess whether an individual has learned but to evaluate whether the learner and teacher come closer together in thought and skill. In a sense they should flow together successfully within each other's context (Csikszentmihalyi, 1991; Rathunde & Csikszentmihalyi, 2006).

EDUCATION BASED ON ONLY ONE BRAIN

The most common education reform efforts continue to view classroom teachers as they would a learning tool. Within this empty vessel model teacher quality is only considered through the lens of learners via student assessments and evaluations (Braun, 2005; Carey, 2004; Gates, 2012; Johnson, 2009; Toch, Rothman, & Sector, 2008; Walsh, 2007; Weisberg, Sexton, Mulhern, & Keeling, 2009) or an understanding of the learning brain (Fischer & Rose, 2001; Fischer, 2009; Immordino-Yang & Damasio, 2007). Even books promoting brain-based education as the new paradigm for teaching, although based solely on the learning brain, have become extremely popular (International Mind, Brain and Education Society, 2007; Jensen, 2005; Jensen, 2008).

In one such *New York Times* best seller, John Medina (2008), a developmental molecular biologist, offers several examples of brain-based teaching. Medina calls for a method where we evaluate in-service and pre-service teachers for advanced ToM skills in order to determine how well they can customize instruction. He concluded that because our brains are all individually wired, students should have individualized instruction. Medina has also studied the brain's ability to pay attention. Because the brain cannot multitask, holds attention for about 10 min, and can recognize patterns better than details, Medina recommends that teachers teach in 10-min segments, beginning by explaining the entire topic in 1 min and connecting it to a core concept. Each 10-min interval should then end with a hook that gives the learner enough emotional arousal to interest them in the next 10 min. In the average K-12 teacher's day this would require five distinct topics to be taught in a 150-min period. Medina suggests that because repetition is helpful to our long-term memory, schools should actually divide the school day into 25-min periods in which students would cycle through the same 25-min lesson three times in one day for repeated exposure (Medina, 2008).

Medina should be commended for suggesting teaching methods based on how the brain learns, but all of these recommendations are ignorant of how the brain *teaches*. How much ToM is necessary for successful teacher–student interaction? Although ToM is a prerequisite to teaching, it is not the sole variable needed for a successful teacher–learner interaction. Do some successful teachers have less or more ToM than others? Most likely the variables that affect one's teaching brain all create individual recipes of which ToM is only one ingredient. Is it possible for a teacher to refocus their attention every 10 min so that they can change their teaching topic regularly? Is it sustainable for a teacher to teach the same lesson three times a day to the same group of students in the same way? Or eight times for four different groups over the course of one school day! Medina does not consider these issues that focus on the teaching brain. Instead his approach and that of much of the brain-based education literature utilizes an empty vessel theory of teaching which ignores the individual nature of the teaching brain much the same way it did for learning.

Brain-based education efforts have yet to consider a new paradigm for teaching. If we continue to study teaching only through the lens of student learning we will forever lack an understanding for the neuroscience of teaching, which will prevent us from comprehending the interaction (both successful and unsuccessful) between learner and teacher (Battro, 2010; Rose, Daley, & Rose, 2011; Strauss, 2005).

THE TEACHING BRAIN: DEVELOPING A COMPREHENSIVE MODEL

Adding to Fischer and Bidell's (2006) proposal, I believe we must "analyze a full range of variation in levels of skill and understanding" in teaching in order to capture all-inclusive "educational implications of growth cycles" (Fischer & Rose, 1998). Just as specific areas of the brain are activated when a student is learning, it is likely that there are other areas of the brain which activate when the educator is utilizing cognitive, psychological, and biological processes specific to the skill of teaching (i.e., ToM and intent to teach). Therefore, it should be possible to identify the neural network that is characteristic of the teaching brain as opposed to the default network characteristic of the brain at rest (Immordino-Yang, Christodoulou, & Singh, 2012). In doing so, research on teaching will begin to address the importance of observable networks in the teaching brain instead of focusing solely on learning and ignoring teaching (Aoki, Funane, & Koizumi, 2010; Thornton & Raihani, 2008).

It is likely that we can observe the brain activity underlying specific teaching interactions with new neuroimaging technology (Battro, 2010). Prior technology has restricted research from capturing the complexity of the social interaction of teaching. Researchers have sought to study the neural foundations underlying social interactions and have found that the interaction affects the brain activity of both individuals involved (Fliessbach et al., 2007; Frith, 2007; King-Casas et al., 2005). Studies have even reported the synchronization of brain activity between the two brains during communication (Schippers, Roebroeck, Renken, Nanetti, & Keysers, 2010; Stephens, Silbert, & Hasson, 2010). Wearable optical topography systems offer the potential to measure the brain activity of more than two individuals at the same time (Suda et al., 2010). New mathematical tools may also be used to explore information encoding in various regions of the brain and model how they function as an integrated system (Aoki et al., 2010). These tools represent exciting new methods for exploring the dynamic and complex interactions of the teaching brain and its relationship to the teaching mind and teaching behavior.

CONCLUSION

Importantly, past research has leveraged our rich understanding of learning to frame our exploration of teaching and basic understanding of its cognitive processes (Clark & Lampert, 1986; Strauss, 2005). However, in order to truly understand the interaction between a student and a teacher we must focus as much effort on understanding the teaching brain as an independent entity rather than solely as a subordinate tool for the learning brain. Researchers need to explore the ontogenic and phylogenetic origins of teaching from its early development in toddlers to the expert classroom teacher. We must stop believing that an ipad application, smart technology video game, or even an avatar can teach. *These objects are learning tools not teachers*. They do not teach because they have no goal of human interaction or synchrony; they merely exist to export information to the learner. That is not to question the usefulness of these tools for both learners and teachers, but by believing the tools are *teaching* learners we are contributing valuable time and effort toward research and interventions that will not yield a better understanding of teaching. Researchers and policy makers must shift their focus toward understanding the interactions across multiple brains in order to better comprehend the complex social system of educating (Aoki et al., 2010). Through the use of DST we can begin to connect the study of learning and teaching to form a better understanding of how to effectively practice comprehensive brain-based education and truly understand teaching and teacher quality.

Acknowledgments—Thank you to Kurt Fischer for his help and guidance during the preparation of this special section. Vanessa Rodriguez's research on the teaching brain is supported, in part, by a grant from the Harvard Initiative for Learning and Teaching.

REFERENCES

Abraham, R. H., & Shaw, C. D. (1992). *Dynamics: The geometry of behavior* (2nd ed.) Boston, MA: Addison Wesley Longman.

Aoki, R., Funane, T., & Koizumi, H. (2010). Brain science of ethics: Present status and the future. *Mind, Brain, and Education*, *4*, 188–195. doi: 10.1111/j.1751-228X.2010.01098.x

Ashley, J., & Tomasello, M. (1998). Cooperative problem-solving and teaching in preschoolers. *Social Development*, *7*, 143–163.

Astington, J. W., & Pelletier, J. (1996). The language of mind: Its role in teaching and learning. In D. R. Olson, & N. Torrance (Eds.), *The handbook of education and human development: New models of learning, teaching, and schooling* (pp. 593–620). Cambridge, MA: Blackwell.

Battro, A. M. (2010). The teaching brain. *Mind, Brain, and Education*, *4*, 28–33. doi: 10.1111/j.1751-228X.2009.01080.x

Battro, A. M., Fischer, K. W., & Léna, P. J. (2008). *The educated brain: Essays in neuroeducation*. New York, NY: Cambridge University Press.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). In B. S. Bloom (Ed.), *Taxonomy of educational objectives: The classification of educational goals, Handbook I: Cognitive domain*. New York, NY: Longmans.

Bolster, A. S. (1983). Toward a more effective model of research on teaching. *Harvard Educational Review*, *53*, 294–308.

Braun, H. I. (2005). *Using student progress to evaluate teachers: A primer on value-added models* (Policy Information PERSPECTIVE). Princeton, NJ: Educational Testing Service.

Bronfenbrenner, U., & Morris, P. A. (2006). The bioecological model of human development. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology* (6th ed., pp. 793–828). Hoboken, NJ: Wiley.

Carey, K. (2004). The real value of teachers: Using new information about teacher effectiveness to close the achievement gap. *The Education Trust*, *8*(1), 1–39.

Caro, T. M., & Hauser, M. (1992). Is there teaching in nonhuman animals? *The Quarterly Review of Biology*, *67*, 151–174.

Clandinin, J. (1985). Personal practical knowledge: A study of classroom images. *Curriculum Inquiry*, *15*, 361–386.

Clandinin, J., & Connelly, F. M. (1984). Personal practical knowledge at Bay Street School: Ritual, personal philosophy and image. In R. Halkes & J. Olson (Eds.), *Teacher thinking: A new perspective on (persistent problems in) education* (pp. 134–148). Heirewig, Holland: Swets Publishing Service.

Clark, C. M., & Lampert, M. (1986). The study of teacher thinking: Implications for teacher education. *Journal of Teacher Education*, *37*(5), 27–31. doi: 10.1177/002248718603700506

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M. C. Wittrock & American Educational Research Association (Eds.), *Handbook of research on teaching: A project of the American Educational Research Association* (3rd ed., pp. 255–314). New York, NY: Macmillan.

Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1567), 1149–1157. doi: 10.1098/rstb.2010.0319

Csikszentmihalyi, M. (1991). *Flow: The psychology of optimal experience*. New York, NY: Harper.

Dawson-Tunik, T., Fischer, K. W., & Stein, Z. (2004). *Do stages belong at the center of developmental theory? A commentary on Piaget's stages*. doi: 10.1016/j.newideapsych.2004.11.004

Elbaz, F. (1983). *Teacher thinking: A study of practical knowledge*. New York, NY: Nichols.

Fischer, K. W. (2009). Mind, brain, and education: Building a scientific groundwork for learning and Teaching. 1. *Mind, Brain, and Education*, *3*, 3–16. doi: 10.1111/j.1751-228X.2008.01048.x

Fischer, K. W., & Bidell, T. R. (2006). Dynamic development of action and thought. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology* (6th ed., pp. 313–399). Hoboken, NJ: Wiley.

Fischer, K. W., & Rose, S. P. (1998). Growth cycles of brain and mind. *Educational Leadership*, *56*(3), 56–60.

Fischer, K. W., & Rose, L. T. (2001). Webs of skill: How students learn. *Educational Leadership*, *59*(3), 6–12.

Fischer, K. W., Rose, L. T., & Rose, S. P. (2007). Growth cycles of mind and brain: Analyzing developmental pathways of learning disorders. In K. W. Fischer, J. H. Bernstein, & M. H. Immordino-Yang (Eds.), *Mind, brain, and education in reading disorders* (pp. 101–123). New York, NY: Cambridge University Press.

Fischer, K. W., & Silvern, L. (1985). Stages and individual differences in cognitive development. *Annual Review of Psychology*, *36*, 613.

Fliessbach, K., Weber, B., Trautner, P., Dohmen, T., Sunde, U., Elger, C. E., & Falk, A. (2007). Social comparison affects reward-related brain activity in the human ventral striatum. *Science*, *318*(5854), 1305–1308.

Franks, N. R., & Richardson, T. (2006). Teaching in tandem-running ants. *Nature*, *439*, 153.

Freire, P. (1970). *Pedagogy of the oppressed*. New York, NY: Continuum.

Frith, C. D. (2007). The social brain? *Philosophical Transactions of the Royal Society B-Biological Sciences*, *362*, 671–678.

Frye, D., & Ziv, M. (2005). Teaching and learning as intentional activities. In B. Homer & C. Tamis-LeMonda (Eds.), *The development of social cognition and communication* (pp. 231–258). Mahwah, NJ: Erlbaum.

Gates, B. (February 22, 2012). Shame is not the solution. *The New York Times*.

Hauser, M. (2000). *Wild minds: What animals really think*. New York, NY: Henry Holt.

Heyes, C. M. (1998). Theory of mind in nonhuman primates. *Behavioral and Brain Sciences*, *21*, 101–134.

Immordino-Yang, M. H., Christodoulou, J. A., & Singh, V. (2012). "Rest is not idleness": Implications of the brain's default mode for human development and education. *Perspectives on Psychological Science*, *7*, 352–365.

Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, *1*, 3–10. doi: 10.1111/j.1751-228X.2007.00004.x

International Mind, Brain and Education Society (2007). *Mind, brain and education: The official journal of the international mind, brain, and education society*. Malden, MA: Blackwell.

Jensen, E. (2005). *Teaching with the brain in mind* (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.

Jensen, E. (2008). *Brain-based learning : The new paradigm of teaching* (2nd ed.). Thousand Oaks, CA: Corwin Press.

Johnson, S. M. (2009). *How best to add value? Strike a balance between the individual and the organization in school reform* (Briefing Paper No. 249). Washington, DC: Economic Policy Institute.

King-Casas, B., Tomlin, D., Anen, C., Camerer, C. F., Quartz, S. R., & Montague, P. R. (2005). Getting to know you: Reputation and trust in a two-person economic exchange. *Science*, *308*(5718), 78–83.

Kruger, A. C., & Tomasello, M. (1996). Cultural learning and learning culture. In D. R. Olson & N. Torrance (Eds.), *The handbook of human development and education* (pp. 369–387). Oxford, UK: Blackwell.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: University of Chicago Press.

Lampert, M. (1985). How do teachers manage to teach? Perspectives on problems in practice. *Harvard Educational Review*, *55*, 178–194.

Lortie, D. C. (1975). *Schoolteacher: A sociological study*. Chicago, IL: University of Chicago Press.

Medina, J. (2008). *Brain rules: 12 principles for surviving and thriving at work, home and school*. Seattle, WA: Pear Press.

Pearson, A. T. (1989). *The teacher: Theory and practice in teacher education*, New York: Routledge.

Penn, D. C., & Povinelli, D. J. (2007). On the lack of evidence that non-human animals possess anything remotely resembling a 'theory of mind'. *Philosophical Transactions of the Royal Society of London, Series B*, *362*, 731–744.

Piaget, J. (1950). *The psychology of intelligence*. London, UK: Routledge and Kegan Paul.

Piaget, J., & Inhelder, B. (1973). *Memory and intelligence*. London, UK: Routledge and Kegan Paul.

Povinelli, D. J., & Eddy, T. J. (1997). Specificity of gaze-following in young chimpanzees. *British Journal of Developmental Psychology*, *15*, 213–222.

Premack, D. (1984). Pedagogy and aesthetics as sources of culture. In M. S. Gazzaniga (Ed.), *Handbook of cognitive neuroscience* (pp. 15–35). New York, NY: Plenum Press.

Premack, D. (1991). The aesthetic basis of pedagogy. In R. R. Hoffman & D. S. Palermo (Eds.), *Cognition and the symbolic processes : Applied and ecological perspectives* (pp. 303–326). Hillsdale, NJ: Erlbaum.

Premack, D. (n.d.). *Three factors that make the human the world's only teacher*. Unpublished manuscript.

Premack, D., & Premack, A. J. (1994). Why animals have neither culture nor history. In T. Ingold (Ed.), *Companion encyclopedia of anthropology: Humanity, culture and social life* (pp. 350–365). London, UK: Routledge.

Premack, D., & Premack, A. J. (1996). Why animals lack pedagogy and some cultures have more of it than others. In D. R. Olson & N. Torrance (Eds.), *The handbook of education and human development: New models of learning, teaching, and schooling* (pp. 302–344). Cambridge, MA: Blackwell.

Premack, D., & Premack, A. J. (2003). *Original intelligence: Unlocking the mystery of who we are.* New York, NY: McGraw-Hill.

Raihani, N. J., & Ridley, A. R. (2008). Experimental evidence for teaching in wild pied babblers. *Animal Behaviour*, *75*, 3–11. doi: 10.1016/j.anbehav.2007.07.024

Rathunde, K., & Csikszentmihalyi, M. (2006). The developing person: An experiential perspective. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology* (6th ed.). Hoboken, NJ: Wiley.

Rose, L. T., Daley, S. G., & Rose, D. H. (2011). Let the questions be your guide: MBE as interdisciplinary science. *Mind, Brain, and Education*, *5*, 153–162. doi: 10.1111/j.1751-228X.2011.01123.x

Schippers, M. B., Roebroeck, A., Renken, R., Nanetti, L., & Keysers, C. (2010). Mapping the information flow from one brain to another during gestural communication. *Proceedings of the National Academy of Sciences*, *107*(20), 9388–9393. doi: 10.1073/pnas.1001791107

Smith, L., & Geoffrey, W. (1968). *An analysis toward a general theory of teaching: Complexities of an urban classroom*. New York, NY: Holt, Rinehar, and Winston.

Stephens, G. J., Silbert, L. J., & Hasson, U. (2010). Speaker–listener neural coupling underlies successful communication. *Proceedings of the National Academy of Sciences*, *107*(32), 14425–14430. doi: 10.1073/pnas.1008662107

Strauss, S. (1993). Theories of learning and development for academics and educators. *Educational Psychologist*, *28*, 191–203.

Strauss, S. (2005). Teaching as a natural cognitive ability: Implications for classroom practice and teacher education. In D. B. Pillemer & S. H. White (Eds.), *Developmental psychology and social change: Research, history, and policy* (pp. 368–389). New York, NY: Cambridge University Press.

Strauss, S., Ziv, M., & Stein, A. (2002). Teaching as a natural cognition and its relations to preschoolers' developing theory of mind. *Cognitive Development*, *17*, 1473–1487.

Suda, M., Takei, Y., Aoyama, Y., Narita, K., Sato, T., Fukuda, M., & Mikuni, M. (2010). Frontopolar activation during face-to-face conversation: An in situ study using near-infrared spectroscopy. *Neuropsychologia*, *48*, 441–447. doi: 10.1016/j.neuropsychologia.2009.09.036

Thornton, A., & McAuliffe, K. (2006). Teaching in wild meerkats. *Science*, *313*, 227–229.

Thornton, A., & Raihani, N. J. (2008). The evolution of teaching. *Animal Behaviour*, *75*, 1823–1836. doi: 10.1016/j.anbehav.2007.12.014

Toch, T., Rothman, R., & Sector, E. (2008). *Rush to judgment: Teacher evaluation in public education*. Washington, DC: Education Sector.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.

Tomasello, M., & Call, J. (1997). *Primate cognition*. New York, NY: Oxford University Press.

Tomasello, M., Kruger, A. C., & Ratner, H. (1993). Cultural learning. *Behavioral and Brain Sciences*, *16*, 495–511.

van Geert, P., & Fischer, K. W. (2009). Dynamic systems and the quest for individual-based models of change and development. In J. P. Spencer, M. S. C. Thomas, & J. L. McClelland (Eds.), *Toward a unified theory of development: Connectionism and dynamic systems theory re-considered* (pp. 313–336). New York, NY: Oxford University Press.

van Geert, P., & Steenbeek, H. (2005). Explaining after by before: Basic aspects of a dynamic systems approach to the study of development. *Developmental Review*, *25*, 408–442. doi: 10.1016/j.dr.2005.10.003

van Geert, P., & van Dijk, M. (2002). Focus on variability: New tools to study intra-individual variability in developmental data. *Infant Behavior and Development*, *25*, 340–374. doi: 10.1016/S0163-6383(02)00140-6

Walsh, K. (2007). *If wishes were horses: The reality behind teacher quality findings*. Working paper, National Council on Teacher Quality, Washington, DC.

Weisberg, D., Sexton, S., Mulhern, J., & Keeling, D. (2009). *The widget effect: Our national failure to acknowledge and act on differences in teacher effectiveness*. Brooklyn, NY: The New Teacher Project.

West, S. A., Griffin, A. S., & Gardner, A. (2007). Social semantics: Altruism, cooperation, mutualism, strong reciprocity and group selection. *Journal of Evolutionary Biology*, *20*, 415–432.

Wood, D., Wood, H., Ainsworth, S., & O'Malley, C. (1995). On becoming a tutor: Toward an ontogenetic model. *Cognition and Instruction*, *13*, 565–581.

Yinger, R. J. (1979). Routines in teacher planning. *Theory into Practice*, *18*, 163–169.

Ziv, M., & Frye, D. (2004). Children's understanding of teaching: The role of knowledge and belief. *Cognitive Development*, *19*, 457–477.