MIND, BRAIN, AND EDUCATION

The Potential of Systems Thinking in Teacher Reform as Theorized for the Teaching Brain Framework

Vanessa Rodriguez[1]

ABSTRACT— The teaching brain is a dynamic system that is in constant interaction with the learning brain. If we fail to explore the teaching brain we will continue to design educational reform policies that ignore the most important lens in the classroom: the teachers'. Master teachers recognize their perspective and leverage their teaching brains to embody a systems thinking view of their practice. If all teachers were taught how to recognize themselves as self-created, organized systems existing within the larger teaching–learning interaction, they would understand how their context and intentions affect the teacher–student interaction. Education reform must acknowledge and understand more about the teaching brain, how master teachers practice systems thinking and the mutually interacting brains of teacher and student if we hope to truly improve how we educate children.

Teaching and learning are too often viewed as simple, linear systems. In this commonly held perspective, the teacher gives the student knowledge. In turn the student absorbs that knowledge and standardized assessments are then used to determine the level of achievement for both the teacher and student. Since its creation the field of Mind, Brain and Education (MBE) has argued against this linear framework by contributing research supporting the idea that students are not receptacles of knowledge, but rather dynamic systems who have complex learning brains. Students interact with the knowledge and demonstrate dynamic patterns of learning that are contingent on their unique characteristics and environment. However, even this more progressive view does not provide a holistic approach to our educational dilemmas as it does not account for the teacher as an independent dynamic system which interacts with learners. More importantly, we have not considered that perhaps the reason that master teachers are able to understand and positively affect the student as a dynamic system is because they are systems thinkers.

Teaching is an interactive, reciprocal system in constant connection with two other systems: namely the teacher system and the learner system (Rodriguez, 2013). Without a systems-based view of teaching which acknowledges all three systems, educational interventions are limited in their ability to effect change. Their linear focus is too narrow and ignores the mutual effect within and between these systems. While education reform efforts in research and practice have focused on a linear view of teaching and learning, I argue that master teachers[1] have been more successful with learners because they utilize a systems thinking approach. Master teachers are able to recognize and manage the mutuality of the teacher, the student, and the larger interactive system (inclusive of the classroom and multiple learners). It is this systems thinking perspective that supports master teachers in constantly adapting to the changing environment of their classroom.

In this article, I extend the teaching brain framework and discuss how master teachers practice systems thinking by leveraging their teaching brain. I argue that all teachers can become successful chief interventionists by developing this skill to recognize and understand the interacting system of the teaching and learning brain. Researchers should include teachers in our exploration to further understand complex

[1]Harvard University

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

dynamic systems. Throughout the article I will refer to the learner system as the learning brain and the teacher system as the teaching brain. In previous work (Rodriguez, 2012, 2013) I have advocated for a focus on the teaching brain so that we may understand the multifaceted interaction that occurs between learner and teacher. The purpose of this article is to move forward and delve deeper into the framework of the teaching brain to reimagine teaching and teachers from a systems thinking perspective. I first discuss how thinking linearly limits our ability to understand teaching and improve teachers. I then briefly explain the teaching brain as a dynamic system. Next I suggest systems thinking as an alternative approach for teacher reform which is mindful of learning and teaching brain methodology. I describe which attributes of master teachers suggest that they employ systems thinking in their teaching methods. Lastly, I consider how this approach could be used to guide the development of novel solutions to education challenges.

THE LIMITATIONS OF LINEAR THINKING IN TEACHING

A linear interpretation of teaching creates inherent limitations in our ability to understand and manipulate teaching and learning in the classroom. In the linear perspective, we might assume, as has been done traditionally, that knowledge is a quantifiable entity that can be passed from teacher to student in a unidirectional flow. This perspective also suggests that summative testing of the student should be able to clearly identify the successful transmission of this knowledge received from the teacher. Similarly, a linear view of teaching suggests that information about the learner can be simply poured into the teacher's brain at the start of the linear process and then transmitted to the learner and assessed at the end to determine effective teaching (Rodriguez, 2012). This linear input/output model ignores the interactive nature of teaching and the fact that the human mind is forever changing based on the person's context (Strauss & Ziv, 2012). A teacher who thinks linearly takes in student-centered information and acts reflexively based on instinct rather than as a result of the complex cognitive processing of this student-centered information. I refer to this method common in "cookie-cutter" classroom teaching as *spinal cord teaching* (see Figure 2 in Rodriguez, 2013), where a priori student types are presented and matched to a set list of teaching actions. Even with an understanding of dynamic development, teaching approaches which are linear treat the teaching interaction as if the only system involved is the student's learning brain.

This linear view is the basis of many educational reform policies with its reliance on standardized testing as the preferred method for assessing student learning, achievement, and development. More importantly, these assessments are used to determine both student learning and teacher effectiveness—a logic model based on the rationale that if students score high on these exams there is a direct causal pathway from the teacher's effectiveness. This philosophy was paramount in the Race to the Top initiative that embedded education policy with massive incentives to implement test-based performance metrics for teachers and principals. States were asked to comply with core standards and accelerated computerization and privatization of education. However, these initiatives and the linear logic model they were founded upon contravene the very nature of a systems-based approach to teaching and learning. They are in direct contrast to an understanding of the dynamic, interactive system of teaching and learning brain. Instead, the assessment emphasis is put on the most downstream event, tangible student output (e.g., test scores), and not the interactive nature of teacher and learner.

THE DYNAMIC SYSTEMS OF TEACHING

In earlier pieces I have written about how the use of a dynamic systems framework has helped to better understand that learning is a dynamic rather than a linear process (Rodriguez, 2012). By using guiding principles of dynamic systems theory (DST), researchers have designed tools and methods which can map the growth and change of a child's learning development (Fischer & Bidell, 2006; Thelen & Smith, 1998; Thomas et al., 2009; Thomson & Fischer, 2007; van Geert & Fischer, 2009). One of the goals of the "Teaching Brain" series in the MBE journal has been to highlight that teaching, like learning, is also a dynamic system. Learning is dynamic because the learner makes the choice to accept the information; they are not passive receptacles. While grounded within their context they then process this information and in turn reach a deeper level of understanding. Similarly I have argued that teachers engage in the same process when teaching their students (Rodriguez, 2013).

Teachers steeped within their context choose to accept feedback from the learner (also referred to as student-centered information) and process it. In turn, their teaching develops. Inevitably, the student (or learning brain) is one dynamic system and the teacher (or teaching brain) is another. However, because teaching is not independent and must involve a learner there is also the larger system of the teacher–learner (T–L) interaction. By focusing on the teaching brain I believe we can gain an understanding of the multidimensional interaction occurring between the teacher and learner. We must first have a deep understanding of teaching as a core human skill (Strauss & Ziv, 2012) or we will not go far in designing interventions for teachers engaged in the interaction. The teaching brain framework advances our understanding of this skill, allowing us to reimagine teaching and teachers from a systems thinking perspective.

SYSTEMS THINKING: A BRIEF REVIEW

Systems thinking developed in response to the need for models of the practical application of DST. Built upon the theoretical foundation of dynamic systems, systems thinking provides a set of tools that helps us understand the relationship between the parts within a system (Bertalanffy, 1968). It is a way to understand the whole and the interconnectedness of the parts within it. In essence the whole has emergent properties that exist only in relation to the complete whole (Checkland, 2012; Córdoba-Pachón, 2011). Therefore the parts are context-dependent and have mutual responsiveness. A systems thinking approach considers the feedback loops within a system in lieu of a linear reductionist perspective of input and output driven information transfer. The emphasis on mutually responsive feedback loops acknowledges that information is given and received with behaviors contingent upon that interaction.

While there are several approaches to systems thinking I would like to highlight two that help to frame this article. The first is one in which there are clearly defined systems that can be observed, predicted, and engineered to produce reliable changes. This clearly defined process, often called "hard" systems thinking, has been popular in fields such as healthcare, industrial management, and information systems (Ackoff, 1981; Clarke, 2007; Córdoba, 2009; Seddon, 2008). However, this well-liked management science does little to help us understand systems which are highly dependent on the perception of the humans within it. Humans observe the world using their own lens which is rooted in their context. Because of this there are infinite ways in which we may identify an existing system, its parts, function, objective and ultimately its desired outcome. In contrast, the soft systems methodology (SSM) takes into account the human experience (Checkland, 1981; Wilson, 1990). SSM attempts to create models of purposeful action that are cognizant of defined worldviews. In this model real-world situations could be studied with an eye towards actionable improvement. While these are not meant to be holistic real-world models, they are intellectual devices useful in exploring practical everyday situations from a particular viewpoint. Most importantly, SSM differentiates itself from applied hard systems thinking by acknowledging the importance of human purpose and intent when trying to model a system. SSM models therefore explicitly attempt to center themselves on the human understanding of the "perceived world" (Checkland, 2012). Soft systems thinking provides for a richer understanding of the teacher and therefore of T–L interactions (Checkland & Holwell, 1998). It is an ideal tool for exploring the teaching brain and its implications for educational reform.

SYSTEMS THINKING IN EDUCATION REFORM

Systems thinking is not new to the field of education. In the mid-1960s the U.S. Department of Education contracted the School of Education at the University of Southern California to create a research report on how to apply systems thinking to instruction. Their findings were later developed into a book (Heinich, 1968). Decades later this quest continued to be of interest to education reform. Checkland adapted his methodology for teachers so that they could teach SSM effectively to students (Checkland & Poulter, 2006). Shortly thereafter an impressive field guide for change leadership was published by noted systems thinkers in education (Després, 2008). The guide covered the breadth of education from 21st century skills to systemic leadership, self-organized schools, and even learning and teaching as dynamic processes. However, missing from work on dynamic systems, systems thinking and even the learning brain is the concept that *master classroom teachers are themselves systems thinkers*. Even if we were to understand learning and teaching as a recursive process, if we fail to explore the teaching brain we will continue to design educational reform policies that ignore the most important lens in the classroom: the teachers'.

THE POTENTIAL OF SYSTEMS THINKING IN TEACHER REFORM

The teachers' lens is particularly important when considering how to create sustainable long term solutions to the complex problems of education. Our understanding of learning was revolutionized by the application of DST to the learning brain. This revolution has recently been applied to teaching in the new framework of the teaching brain (Rodriguez, 2013). However, the teaching and learning brains are only parts of a larger interactive teacher–learner (T–L) system, and as such a systems thinking approach is needed to fully comprehend and intervene in that system. A systems thinking approach has been advocated as a 21st-century skill for students and, following an empty vessel theory of teaching, it has been injected into teacher training as a critical skill for students. Yet this is an insufficient response to the potential of systems thinking. We need to fully understand the teaching brain to leverage its parts and create more effective interventions. To do this, we first need to acknowledge the teaching brain and develop conceptual and experimental frameworks for exploring its characteristics (Hari, Himberg, Nummenmaa, Hämäläinen, & Parkkonen, 2013).

Accordingly, I believe we must then encourage teachers to recognize themselves as self-created organized systems (in line with the theory of autopoiesis[2]) within the larger T–L system (Maturana & Varela, 1987; Varela, Thompson, & Rosch, 1993). Only by recognizing themselves as an independent part within the larger T–L system will they understand how their lens and intentions affect that system (Córdoba-Pachón, 2011). Using an SSM approach, we can harness the systems thinking teacher to serve as *dynamic interventionists*—constantly adapting their

interactions on a micro level in a purposeful human effort to maximize the impact on the learner. If not, we will continue to promote linear education reform approaches limited by their misguided reliance on applied hard systems thinking in which each part of the system is defined, stable, and predictable.

Characteristics of a Systems Thinker

Below I outline and contextualize the characteristics of a systems thinker and follow each characteristic with an example of how a master teacher might exhibit each feature (Checkland, 1981).

1. *Recognizes the existing parts within a system and multiple systems within a larger system interacting and affecting each other*—Classroom teachers would include themselves, each individual learner, the students as a whole, the physical environment, the classroom culture, and many other interacting parts when describing their classroom as a dynamic system. They acknowledge that they are an autopoietic system requiring self-regulation and self-reference. At the same time, the teacher also recognizes the individual learner as a complex system flowing in and out of their context therefore affecting the complete system's purpose.
2. *Recognizes all parts must exist in order for the system to run effectively*—Systems-thinking teachers would tailor their lessons to include the learner. A teacher might build a series of lessons around skateboarding because that is of particular interest to her students. However, recognizing all of the parts of her class system, the teacher might tailor the lessons to leverage her own abilities by constructing the skateboarding project within a theatrical setting in consideration of her strengths as a former theatre major.
3. *Parts within the system are arranged specifically to carry out their purpose*—A systems-thinking teacher might map out her yearlong curriculum to follow assumed patterns of child development based on her experience. Early in the year she focuses on setting structures and routines to establish the class culture. This allows for the development of trust between the students and the teacher which is critical for tackling more cognitively demanding topics that often expose learner weaknesses (Kent, 2013). This explicit arrangement of the system parts is also mindful of the teacher's system in which she may believe strongly that only in a trusting relationship will students feel comfortable failing and later learning from those failures (D'Andrea, 2013).
4. *Recognizes that feedback is the driving factor affecting the system*—Systems-thinking teachers understand that while they are responsible for leading where the students go, they need to constantly adapt their teaching based on the feedback they receive from students. Systems-thinking teachers often shift a lesson or a whole unit midstream upon receiving explicit or implicit student feedback. They also adapt their teaching based on how they process student feedback. This processing is grounded in their context and viewed through their own lens. Therefore the teacher's shift in the lesson is a result of her internal feedback mechanism relaying information on how the project and student are developing. Feedback affects the lesson design, implementation, and learning impact. For example, after recognizing the students' acute awareness of a national tragedy of a mass school shooting, the teacher may decide to refocus the upcoming WWII project—shifting from military tactics and armaments to the non-violent home front strategy.
5. *Recognizing the system to predict how events will play out and to inform one's opportunity to manipulate and intentionally manage the system's outcomes*—Systems-thinking teachers utilize this lens to help them predict how the T–L system will develop and move towards its long term goals. They can use this insight to consciously interact with and manipulate its parts in an attempt to ensure goal completion. Systems thinkers may choose to ignore certain feedback while reinforcing other feedback in order to strike that critical balance in the system. For example, in a school where the administration has just recently decided that student cell phone use is prohibited, a systems thinking teacher predicts the potential for student unrest. Anticipating the negative affect this will have on student engagement and classroom climate, this teacher creates a timely project focused on writing petitions and designing community organizing campaigns in support of cell phone use in schools. This manipulation of the curriculum helps her to reengage the students while achieving the larger content and skill goals of thematic writing and problem solving. This teacher has recognized various sources of feedback from the systems parts, understood their reciprocal effects, and used this to manipulate the system and achieve its goal.

THE SYSTEMS WITHIN TEACHING

Overview

As introduced above, there are three systems within teaching: the learning brain which is the system of the learner, the teaching brain which is the system of the teacher, and the system of the teaching–learning (T–L) interaction. A teacher who has mastered systems thinking holds both the learner's and teacher's brain in mind when considering how to enact the teaching response. Such a teacher understands that both the teaching and learning brain exist within the larger T–L interaction that is the overarching system.

Learning Brain

The learning brain is a complex system composed of many variables. One way to attempt to categorize the nearly infinite variables is to group them into internal and external (or adoptive) factors. Internal (biologic) factors include variables such as a learner's natural cognitive[3] strengths and weaknesses, memory, and emotional responses, as well as their personality traits. Each learner has a unique mix of these internal strengths and weaknesses and applies them in a unique pattern to their learning system (Fischer & Paré-Blagoev, 2000; Karcher & Fischer, 2004; Levine, 2002). Similarly, the learner is also defined by external influences affecting learning, such as friends, family, culture, and society. Together, these internal and external characteristics interact to form the learning brain. Dynamic skills theory organizes these factors into progressive systems or representations that develop in the learner—moving from understanding single representations, to single abstractions, to abstract systems and principles (Fischer & Lazerson, 1984). The learning brain is in constant communication, giving feedback to and receiving feedback from other systems (e.g., other students, teachers). With respect to teaching, the learning brain is constantly interacting with the teaching brain and this interaction creates the feedback loop which is essential to successful T–L interactions (Watanabe, 2013).

Teaching Brain

Just as the learning brain is a complex system composed of many interacting variables, so too is the teaching brain. The teacher's personal context represents a fundamental component of the teaching brain (see Figure 4 in Rodriguez, 2013). This personal context is influenced by internal factors such as biological phenotypes[3] as well as external (adoptive) factors such as training, family, beliefs, and experience. Those influences which are most significant to teaching become part of each teacher's context. In this model of the teaching brain teachers recognize the difference between teacher-centered information and student-centered information. To do so they generate *theories* of the student's mind, cognition, emotion, and memory to formulate a complete theory of the student's learning brain (ToLB). They then evaluate their lens or "perceived view" of the students' learning brain (ToLB) by generating a meta-level understanding of their own cognition, emotion, and memory. Together, this multifaceted, dynamic system comprises the teaching brain. This system is constantly interacting with the learning brain through reciprocal feedback loops which support successful teaching (see Figure 5 in Rodriguez, 2013).

Teacher–Learner System

To understand successful teaching, the teaching and learning brain need to be viewed as components of a larger interactive system in which information flows and feeds back between the systems in a dynamic process. Student-centered information is fed to the teacher, processed and then a teacher-centered response is fed back to the student for student processing (see Figure 5 in Rodriguez, 2013). While this may seem abstract, it is in fact a very tangible experience in teaching. For example: A student answers a teacher's question with an angry "I don't know." On one level the teacher processes the information as a lack of knowledge. However, the teacher also considers a series of interactions occurring since the beginning of the year with this child and the child's personal context. The student has a history of struggling with this subject and a fear of embarrassment that precludes answering whenever they are unsure. On the basis of this context, and the student's answer and tone, the teacher might choose to push the student to give an answer and contextualize it by saying, "I know this is a difficult question but we can work through it together." The student then accepts this revised situation and, based on existing trust and experience with the teacher, takes a risk and engages in a discussion of his or her thinking with the teacher. It is important to note that these interactions between teacher and student are not all explicit. They may not always occur through talking or writing. Much of the interaction is implicit—nonverbal communication that is as important to teaching as it is more generally in human behavior (Watanabe, 2013; Yano, 2013; Yun, Watanabe, & Shimojo, 2012). Thus, the teaching and learning brains are components of a larger interactive T–L system predicated on constant communication (explicit and implicit) between teacher and student.

If we accept the dynamic interactivity of the T–L system, then taking a systems thinking approach to teaching becomes critical. Only by viewing the act of teaching through a systems thinking lens will practitioners, researchers, and policymakers be able to recognize and understand the dynamic and complex nature of teachers, students, and their interactions. Such an understanding would enable us to develop more effective interventions that account for the multiple interactive systems. To begin to develop this understanding we need to examine the master teachers who use this systems thinking approach every day. This next section moves from theoretical frameworks to empirical data that sheds light on how master teachers employ systems thinking in their teaching methods.

SYSTEMS THINKING AS APPLIED BY MASTER TEACHERS

While much of educational reform policy is dependent on a linear view of teaching and learning, many master practitioners understand the insufficiency of the linear view and eschew this perspective. Master teachers inherently adopt a systems thinking approach to their practice. Through experience and careful honing they learn to see the wider view and

understand how their own context and the student's learning brain interact in their classrooms to define the educational experience. They embody the systems thinking perspective and leverage it to create more complex and dynamic learning experiences that engage students and are more effective.

While systems thinking has been recognized as one of the necessary 21st-century skills for learners, we have not yet come to recognize it as a skill that is already possessed by master teachers. I hypothesize that at the core of a master teacher is their ability to be a systems thinker. This skill goes beyond the awareness of the academic capacity or social emotional needs of a learner. It allows teachers to tap into cognitive skills that recognize the different parts of the learner's system, what I refer to as a theory of the learner's brain (ToLB) (Rodriguez, 2013). Master teachers keep this ToLB in mind so they can make decisions and adjust their interactions in a way that helps their student's learn more effectively. It allows them to be open to the possibility that suboptimal T–L interactions may be a reflection of their view of the student's learning brain. This recognition of the reciprocal parts within the T–L system helps master teachers to design appropriate interventions (targeting themselves and the learner) to meet the needs of the learner. In addition, master teachers are able to do this at both micro and macro levels, constructing ToLB for individual students and for the class as a whole. This supports them in interacting with students independently while being mindful of the collective learning of their class.

To examine the nature and extent of the systems thinking approach of master teachers, I recently interviewed over 20 master teachers about their process of teaching. This section uses excerpts from several of these interviews to highlight the early insights about the systems thinking perspective of master teachers.

In a description of her teaching process Leah describes that she "spends a lot of time tailoring [her teaching] to the body [and] with the bodies." She describes the "bodies" as "the constellation of the bodies of the class." Her description of the bodies in the class as a constellation highlights her perspective that students are all part of the system and that they affect each other in creating the atmosphere of the class.

In another example Leah explains that she is constantly making rapid, real-time decisions in her classroom. She describes these decisions as going on all of the time, "just zapping away." In an effort to demonstrate the unexpected events that affect the context of the T–L interaction Leah describes, "all of a sudden somebody's nose is bleeding, or a spider is in the room and the girls are freaking out, or somebody just broke down in tears." Leah explains that she's aware of these different events occurring in her classroom and therefore adjusts her lessons accordingly to still tend to the student's overall needs. She shares that she "[takes] the temperature of the room" and "changes [her] lesson plan."

The external factors that a master teacher balances within their understanding of the larger T–L system are not always as explicit as a spider or a nosebleed. Often influences on the learning brain happen internally and require a teacher to recognize them on an implicit level. Leah also describes how students "may be intuitively learning things and then, [she] can watch how they're intuitively learning and then that can help [her] in the lesson." She explains how she uses unintentional student feedback to teach more effectively.

Another master teacher, Caitlin, describes being "worried that [she has] preconceived notions about kids" because she can "decide [their] fate." She is concerned that these less obvious student characteristics might drive her decision making. At the same time Caitlin explains that "sometimes [her] gut feeling about students is very correct," suggesting that master teachers don't avoid incorporating this implicit information into the T–L system. Master teachers are able to see how the teaching and learning brain have a purpose in the larger T–L system that they are within. They not only understand each system but they often are the force arranging the parts of these systems in a specific way so that learners can reach their goals.

Another teacher, Bob, describes such an occurrence when explaining his approach to "pressing students to generate something with more emotional content or belief." He declares that sometimes he pushes a student until they cry, "knowing that that could be an outcome." However, he admits that it is never easy nor does he use this approach early in the relationship. He describes the outcome as always being positive. In a situation like this, what could the teacher possibly be thinking? For the outside observer this would surely look like a failure on the teacher's part. It would seem as if the teacher lacked sensitivity and was unable to be empathic to his learners. However, Bob explains it quite differently. His understanding of this student's learning brain is that "they are not giving [their all] because they are afraid of something, they're thinking, What do the other kids wanna hear? What does the teacher wanna hear? Everything but what they wanna say, because their opinions have never been valued." In this interaction Bob explains that he needs the student to break down and cry because that's when he knows that the wall holding them back has been broken down and now they are free. He explains that he "needs that to happen, if it doesn't happen [he's] failing. [He doesn't] care if it takes six months." Bob explains that he has to be cautious not to overstep his professional boundaries. In a situation like this it is dangerous but he assesses the needs of the learner and plans whether this type of interaction has to happen in order for students to get at the "truth from their own perspective."

Clearly this strategy would not work for everyone. I would not suggest that we label it as a best practice for teaching and promote it in teacher training programs. However, it is clear that Bob recognizes this strategy as something that works for

him in very particular situations. In developing this technique, this master teacher incorporates an understanding of himself and the learner (ToLB) and then uses the dynamic feedback between these systems to constantly manipulate the variables involved.

Similarly, Caitlin holds individual student information in her mind until she needs to use it to manipulate the interaction to benefit the student. She does this to help her build the appropriate culture in her classroom. In one example Caitlin explains that she keeps in mind information about individual students when considering the group seating in her classroom. She explains that she needs to store somewhere in her mind that "student x and student y should never sit together again [because] those two did not work well together, but these two students x and z work really well together." While it may seem like a small task, Caitlin explains that "gather[ing] the information about kids" and holding it at hand is quite complex. It requires a micro-level understanding of how the student's learning brain interacts with all of the other students in the classroom and how her teaching brain can interact with the learners' in order to manipulate the situation to support student scholarship.

Most significant to Caitlin's work is the culture of her classroom. In her words culture is "the nature of her day." Each day she is building upon her classroom environment where students are "kind to one another and respected but also held accountable . . . for their actions and for their work and for how much effort they put in." She finds it important to "walk into a classroom where [she] want[s] to spend [her] day" and where the students also want to spend their day. As Caitlin shares, "a lot of energy as a teacher" is spent doing this "because it's in these very small events that you build the culture of your classroom." In Caitlin's view, the constant interaction of implicit and explicit feedback defines the classroom atmosphere and promotes a higher-order educational experience characterized by synchrony (flow) between teacher and student (Kent, 2013; Rodriguez, 2012; Watanabe, 2013; Yano, 2013).

As noted above, it is the awareness of multiple systems and the complexity among them that highlight the master teacher as a systems thinker. Master teachers recognize the micro and macro systems that affect their teaching interaction with students. For example, Caitlin shares the daily struggle of managing the micro and macro systems within her classroom. She asks, "How do you respond when a kid says I need to go to the nurse but you feel like the kid might not be truthful? How do you deal with a kid who you know [is] completely disrupting the classroom and you know why the kid is [doing that], you know the kid has a terrible history with alcoholism in the family. So you understand that but you [want to] protect the other kids in the room. I think it is very hard to build that culture and it actually takes more energy and more thought than one realizes."

Teachers that have fully developed their ability as systems thinkers also understand the level to which their own personal contexts affect how they interact with individual students and the classroom culture as a whole. These master teachers are able to infuse their teaching with an awareness of personal context and its ability to affect the interactive T–L system. For Delia this means recognizing that her father's background has played a large part in developing her value of being a life long teacher. She describes that her father "ran away as a teen to England and didn't receive education after the age of 15, so education [has] always been a big part of [her] life." Choking back tears Delia explained that she reflects back on his experience and knows that what she does in the class each day can "influence the students." She "keeps that in [her] mind as [she] goes through the [teaching] process" each day. Delia also shares that she "struggled as a reader," as did "one of her sisters." This experience directly shapes her interactions with students in the classroom. She has empathy and "know[s] the process and keep[s] that . . . in the forefront of [her] mind and appl[ies] any strategies or techniques and share[s] [her] knowledge."

Lastly, systems thinking also involves finding stability in one system by making adjustments in connected systems based on feedback. These adjustments help the individual system which affects the larger system that it sits within. As an example, Caitlin shares how her current class experiences affect her family life. Though she explains that her family, husband, and young daughter are hugely important to her, she confesses that she has argued with her husband about how much she works. She admits that "it's been a source of distress; not so much how much [she] works but how much [she] lets [her] emotional well-being become tied to the school." She shares that after arguments like this she becomes more aware of the impact that her work as a teacher has on her life as a wife and mother. Following these times Caitlin finds herself changing how she teaches, seeking to be more efficient at her school work so that she has more time for her family. She describes these instances as "waves" where she balances the multiple worlds with each other. In this example, Caitlin is consistently engaging in a balancing process in order to maintain the stability of the larger T–L system.

As we read these examples it may seem rather typical that a teacher would consider the complex system of the individual learner, the full class body, and herself (both as a teacher and an individual) when engaged in teaching. However, this description of teaching is in direct contrast to how we train and evaluate teachers. We do not speak of teaching as a web of dynamic complex systems. We do not talk about evaluating teachers outside of a linear model for evaluating students. Instead we train teachers by demanding that they follow learner-based best practice strategies. Even in our most progressive programs, teacher training is focused on filling teacher's brains with knowledge of how students learn.

We then expect that if we evaluate student learning we can attribute a certain amount of the child's knowledge to that which the teacher has contributed. The master teacher excerpts above depict events that are easily overlooked as ordinary, but in fact they highlight a sophisticated systems-thinking paradigm towards educating. While we may have been nodding our heads in agreement as we read through the teacher expositions of their cognitive processes, what we may have failed to recognize is that we do not currently have a way of training or measuring what those master teachers were describing. I believe this is because we do not fully understand the unique cognitive, psychological, and biological processes occurring in our brains when we teach.

CONCLUSION

Systems thinking is a practical application of the principles within systems dynamics. A systems thinker recognizes the existing parts within a system, how the parts interact, and how they affect one another. Systems thinking provides insights into how a system and its parts will react to changing inputs and allows for interventions that can guide changes and improve outcomes. Within the classroom there are three core systems: the teaching brain, the learning brain, and the overarching T–L system. At the core of each of these are multiple domains that are both implicit and explicit. The manipulation of these domains allows for enormous variation in teaching practices and outcomes. Despite this complexity, a linear view of teaching dominates education policy and pedagogy. This narrow scope substantially limits the ability to understand the fundamental mechanics of teaching and the T–L interaction. However, by examining the characteristics of master teachers and their teaching brain we can see how skillful practitioners leverage a systems-thinking approach to guide their classroom interactions. Education reformers should use this insight to develop enlightened interventions that empower all teachers to grow their systems thinking abilities to deliver dynamic interventions on a micro and macro level.

Understanding the interacting systems of a classroom and the systems-thinking view of master teachers provides clear implications for educational research. It offers a real-life example of how human systems interact, through explicit and implicit feedback and response (Rodriguez, 2013; Watanabe, 2013). Watanabe's (2013) study in this issue describes the power of this implicit feedback by observing behavioral synchronization between two people even with simple motor tasks. This study is on the vanguard of exciting new research studying the between-brain activity during human interaction using functional magnetic resonance imaging (fMRI), electroencephalography (EEG) and near-infrared spectroscopy (NIRS) (Konvalinka & Roepstorff, 2012). More research like this is needed to substantiate the observations we see in the classroom. The T–L system (Rodriguez, 2013) could also be used to develop the conceptual and experimental frameworks needed to guide "two-person neuroscience" (2PN) (Hari, Himberg, Nummenmaa, Hämäläinen, & Parkkonen, 2013). These behavioral and neurobehavioral studies are necessary for discovering the variables and networks underlying these complex systems. Perhaps this cycle of research from classroom observation to experimental and then neuro-behavioral studies (and back) can serve as its own system, where each field provides insights and feedback that drives discovery within the system as a whole. After all I believe that is the ultimate vision of MBE.

Acknowledgments—Thank you to Kurt Fischer for his help and guidance during the preparation of this special section. The author is also grateful for thoughtful discussions and fruitful comments offered by Courtney Pollack. Vanessa Rodriguez's research on the teaching brain is supported, in part, by a grant from the Harvard Initiative for Learning and Teaching.

.

ENDNOTES

1 The definition of master teacher varies from state to state. However, in general a master teacher has vast experience teaching and has been recognized for distinguished ability to master content, deliver instruction, and assess for student understanding and learning development. Master teachers have proven their ability to create effective learning environments which promote success for all students. Master teachers have also committed to their continued professional growth, leadership and collaboration within education at large.

2 Translated literally from Greek, *autopoiesis* means self-creation. In the early 1970s Humberto Maturana and Francisco Varela introduced a theory of autopoiesis where living systems are self-created, self-governed, and independent. Though the system gives and receives feedback from other systems, it maintains its own identity and form through self-regulation.

3 This is not to suggest that biological factors are deterministic or that they are not affected and altered by external factors.

REFERENCES

Ackoff, R. L. (1981). *Creating the corporate future: Plan or be planned for*. New York, NY: Wiley.

Bertalanffy, L. V. (1968). *General system theory: Foundations, development, applications*. New York, NY: George Braziller.

Checkland, P. (1981). *Systems thinking, systems practice*. New York, NY: Wiley.

Checkland, P. (2012). Four conditions for serious systems thinking and action. *Systems Research and Behavioral Science*, *29*, 465–469. doi:10.1002/sres.2158

Checkland, P., & Holwell, S. (1998). *Information, systems, and information systems: Making sense of the field*. New York, NY: Wiley.

Checkland, P., & Poulter, J. (2006). *Learning for action: A short definitive account of soft systems methodology and its use for practitioners, teachers and students*. Chichester, England: Wiley.

Clarke, S. (2007). *Information systems strategic management: An integrated approach*. London, UK: Routledge.

Córdoba, J. R. (2009). Critical reflection in planning information systems: A contribution from critical systems thinking. *Information Systems Journal*, *19*, 123–147. doi:10.1111/j.1365-2575.2007.00284.x

Córdoba-Pachón, J. R. (2011). Embracing human experience in applied systems thinking. *Systems Research and Behavioral Science*, *28*, 680–688. doi:10.1002/sres.1117

D'Andrea, K. C. (2013). Trust: A master teacher's perspective on why it's important: How to build it and its implications for MBE research. *Mind, Brain, and Education*, *7*(2), 86–91.

Després, B. (2008). *Systems thinkers in action: A field guide for effective change leadership in education*. Lanham, MD: Rowman & Littlefield.

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., & Lazerson, A. (1984). *Human development: From conception through adolescence*. New York, NY: W.H. Freeman.

Fischer, K. W., & Paré-Blagoev, J. (2000). From individual differences to dynamic pathways of development. *Child Development*, *71*, 850–853.

Hari, R., Himberg, T., Nummenmaa, L., Hämäläinen, M., & Parkkonen, L. (2013). Synchrony of brains and bodies during implicit interpersonal interaction. *Trends in Cognitive Sciences*, *17*, 105–106. doi:10.1016/j.tics.2013.01.003

Heinich, R. (1968). *Application of systems thinking to instruction*. Los Angeles, CA: Education and Training Consultants.

Karcher, M. J., & Fischer, K. W. (2004). A developmental sequence of skills in adolescents' intergroup understanding. *Journal of Applied Developmental Psychology*, *25*, 259–282. doi:10.1016/j.appdev.2004.04.001

Kent, A. (2013). Synchronization as a classroom dynamic: A practitioner's perspective. *Mind, Brain, and Education*, *7*, 13–18. doi:10.1111/mbe.12002

Konvalinka, I., & Roepstorff, A. (2012). The two-brain approach: How can mutually interacting brains teach us something about social interaction? *Frontiers in Human Neuroscience*, *6*(215), 1–9. doi:10.3389/fnhum.2012.00215

Levine, M. D. (2002). *A mind at a time*. New York, NY: Simon & Schuster.

Maturana, H., & Varela, F. (1987). *The tree of knowledge: The biological roots of human understanding*. Boston, MA: Shambala.

Rodriguez, V. (2012). The teaching brain and the end of the empty vessel. *Mind, Brain, and Education*, *6*, 177–185. doi:10.1111/j.1751-228X.2012.01155.x

Rodriguez, V. (2013). The human nervous system: A framework for teaching and the teaching brain. *Mind, Brain, and Education*, *7*, 2–12.

Seddon, J. (2008). *Systems thinking in the public sector: The failure to reform regime—and a manifesto for a better way*. Axminster, England: Triarchy Press.

Strauss, S., & Ziv, M. (2012). Teaching is a natural cognitive ability for humans. *Mind, Brain, and Education*, *6*, 186–196. doi:10.1111/j.1751-228X.2012.01156.x

Thelen, E., & Smith, L. B. (1998). Dynamic systems theories. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (5th ed., pp. 563–634). New York, NY: Wiley.

Thomas, M. S. C., Annaz, D., Ansari, D., Scerif, G., Jarrold, C., & Karmiloff-Smith, A. (2009). Using developmental trajectories to understand developmental disorders. *Journal of Speech, Language, and Hearing Research*, *52*, 336–358. doi:10.1044/1092-4388(2009/07-0144)

Thomson, J. M., & Fischer, K. W. (2007). Dynamic development and dynamic education. *Monographs of the Society for Research in Child Development*, *72*(3), 150–156. doi:10.1111/j.1540-5834.2007.00450.x

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* (p. 313–336). New York, NY: Oxford University Press.

Varela, F., Thompson, E., & Rosch, E. (1993). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Watanabe, K. (2013). Teaching as a dynamic phenomenon with interpresonal interactions. *Mind, Brain, and Education*, *7*(2), 92–101.

Wilson, B. (1990). *Systems: Concepts, methodologies and applications*. (2nd ed.). New York, NY: Wiley.

Yano, K. (2013). The science of human interaction and teaching. *Mind, Brain, and Education*, *7*, 19–29. doi:10.1111/mbe.12003

Yun, K., Watanabe, K., & Shimojo, S. (2012). Interpersonal body and neural synchronization as a marker of implicit social interaction. *Scientific Reports*, *2*(959). doi:10.1038/srep00959