The Temporal Dynamics of Learning Center

Purpose

To achieve an integrated understanding of the role of time and timing in learning, across multiple scales, brain systems, and social systems, to 1) create a new science of the temporal dynamics of learning; 2) to use this understanding to inform educational practice; and 3) to create a new collaborative research structure, the network of networks, to transform the practice of science.

Mission statement

The Temporal Dynamics of Learning Center is a multi-institution group of scientists and educators focused on understanding the critical role of time and timing in learning. The Center investigators comprise four interacting research networks, providing strong expertise in each of four fundamental areas of learning: sensorimotor learning, memory systems, learning of expertise, and social interactions related to learning. In addition, the Center has cross-cutting resources representing innovative technologies to support learning research and data sharing. The Center will recruit the most relevant investigators and technologies to each research network to form a diverse interdisciplinary group of scientists to address major, unanswered research questions central to the temporal dynamics of learning. Examples of research questions include: How is temporal information about the world learned? How do the intrinsic temporal dynamic properties of brain cells and circuits facilitate and/or constrain learning? How can the temporal features of learning be used to enhance education? What are the best theoretical ways to conceive the temporal dynamics of learning in the brain and between brains? Each research question will be selected to be highly interdisciplinary, to cross the boundaries of traditional fields of learning research, and will be informed by interactions with educators.

This will lead to development of novel, highly cross-disciplinary answers and theories for each question. As answers become well developed, ideas and technology will be translated via specific education and outreach efforts to a diverse set of K-12 students, educators, undergraduate and graduate students, and to other stakeholders with support from our corporate partners and The Science Network, a C-SPAN for science. While advancing our science, the Center will also promote a new type of collaborative scientific research paradigm in the form of a network of research networks structure.

Introduction

It is commonly accepted that there is a crisis in education in the US. We have too many struggling learners, too many students who drop out before finishing high school, too many students who cannot read, too many students who cannot do basic arithmetic, let alone advanced mathematics. What is not commonly accepted is what to do about this crisis. In spite of the No Child Left Behind Act, in spite of increasing funds being
allocated to improve reading, reading scores remain flat. We believe that part of the current crisis in education is the lack of scientific understanding of how the brain learns, and the lack of translation of this scientific understanding to the classroom. An essential, yet understudied, component of learning that could have a strong impact on education is the role of time and timing in learning.

Why timing? Because timing is critical for learning at every level, from learning the precise temporal patterns of speech sounds, to learning appropriate sequences of movements, to optimal training and instructional schedules for learning, to interpreting the streams of social signals that reinforce learning in the classroom. Moreover, a decade of neuroscience research demonstrates that the temporal dynamics of processes within the brain can predict learning and performance. For example, we have learned that low power in the gamma frequency band, measured over the frontal cortex of babies using electroencephalography (EEG), predicts poor reading ability later. This finding, coupled with cortical plasticity research, suggests that early intervention may ameliorate this problem. From this and other successful examples, we believe that by investigating the temporal dynamics of learning we can change the capacity of children to learn, as well as change the environment to aid in learning.

The scientific goal of the Center is therefore to understand the temporal dynamics of learning, and to apply this understanding to improve educational practice. This goal requires a broad, multi-disciplinary research approach, with strong integration of research findings across levels of analysis. A multi-disciplinary approach is required because learning occurs at many levels: at the level of synapses and neurons; at the level of brain systems involved in memory and reward; at the level of complex motor behaviors; at the level of expertise learning; and finally, at the level of learning via social interactions between teachers and students. Each level has its own temporal dynamics, and its own timing constraints that affect learning. Of course, these levels are not independent, but instead, timing constraints at one level affect learning at another level in a nested way. For example, the dynamics at the cellular level, which is often on the order of milliseconds, implement learning on the whole-brain and behavioral level on much longer time scales, including memories that last a lifetime. Our goal is to use a multidisciplinary approach incorporating cellular and systems neuroscience, cognitive science, brain imaging, the study of human social interactions during learning, and learning theory to study the temporal dynamics of learning over a broad range of levels, both temporal and spatial, from cells to social interactions, and from milliseconds to years. We believe that an enterprise of this scale requires the Center mode of organization.

In order to address questions of such broad scope, we have created four research networks, each of which focuses on a different, major aspect of learning: sensorimotor learning, memory, perceptual expertise, and social systems related to learning. These research networks were chosen as a starting point for developing a science of the temporal dynamics of learning that is ultimately relevant to education. In broadly defining these areas as relevant starting points, we are taking into account that we must understand the input and output of the system with respect to sensorimotor function, that
we must understand how individuals develop perceptual abilities and expertise, that we must understand how information is acquired and maintained over time, and finally, we must take into account that learning is embedded in a social world. Each network is composed of multiple principal investigators who bring complementary techniques, disciplinary perspectives, and expertise to the network. The Sensorimotor Network (led by Howard Poizner, UCSD) studies relatively simple forms of sensory learning (e.g., speech perception) and motor learning, focusing on brain mechanisms for learning at the single-neuron and circuit level, and computational strategies of learning. The Perceptual Expertise Network (led by Thomas Palmeri and Isabel Gauthier, Vanderbilt University) studies the dynamics by which people acquire expertise in identifying and interpreting objects in the world (e.g., the common expertise of recognizing faces or letters, and the specialized expertise for reading music or watching birds). The Interacting Memory Systems Network (led by Andrea Chiba and Robert Clark, UCSD) studies learning of complex associative and episodic memories, focusing on how different brain systems code these memories with different temporal requirements. The Social Interaction Network (led by Marian Stewart Bartlett, UCSD) explores the social interactions that provide the context for much of learning. This network studies how children develop social skills such as joint attention, and how understanding the timing of social interactions in learning can be implemented in socially intelligent tutoring systems. All networks incorporate both experimental researchers and computational modelers, who work within and across networks to develop integrated theoretical and conceptual understanding of learning processes. The science of the Center is conducted within the context of the research networks. The research networks have regular meetings to share ongoing research, coordinate collaborative projects, and plan new collaborations.

Research in the Center is organized around three specific Center Initiatives that define an emerging Science of the Temporal Dynamics of Learning. The scientific goals of each initiative are inherently cross-disciplinary, and require coordinated research by all four research networks. Thus, the members of the research networks associated with each initiative also meet together on a regular basis in Initiative meetings to synchronize their research around these Center Initiatives. This aggregate of Initiative meetings and Network meetings represents a combined vertical integration of science, where scientists build working relationships and share ideas related to the broad, conceptually-oriented Initiatives; and horizontal integration in which scientists develop deep technical expertise by working with other labs in Networks to examine the same fundamental aspects of learning using a diverse, yet synchronized, array of methods, techniques, and levels of analysis. In this way, we achieve an integration of our science that is not possible within one research initiative or one research network. It is through this mechanism that the whole produces more than the sum of its parts – the networks and the initiatives are interdigitated to create a seamless web of the new science of the temporal dynamics of learning.

Overview of the Center’s Initiatives

Our goal is to contribute to the science of learning by adding a strong science of the temporal dynamics of learning. We are beginning to develop a coherent view of the
temporal dynamics relating to learning. In addition, we intend to identify those aspects of learning dynamics that will prove the most relevant for improving education. Thus, we chose to identify as our Center Initiatives three broad but critical questions that logically parse the temporal dynamics of learning into its constituent components. The value of this approach is that answering the Initiative questions would, in itself, constitute a somewhat complete science of temporal dynamics of learning.

The selection of Initiatives is based on the idea that there are three sources of temporal dynamics for learning: (1) Dynamics in the external world (including sensory stimuli, interpersonal interactions, and rewards). Some of these dynamics are explicitly learned, for example sequence and order of speech sounds and other sensory inputs. Others influence learning, such as the relative timing between action and reward. (2) Dynamics intrinsic to the brain itself (e.g., cellular processes within neurons, or activity patterns in brain networks, such as oscillations) and dynamics that have been shaped by development and experience. These dynamics can influence how and what the brain learns. (3) Dynamics of the muscles and body. These are learned to enable appropriate movements, and also to allow active movement of sensors like eyes, fingertips, and the body, to sample the environment.

Thus, our three Center Research Initiatives are:

1. TEMPORAL DYNAMICS OF THE WORLD: How is temporal information about the world learned and how do the temporal dynamics of the world influence learning?

2. TEMPORAL DYNAMICS OF THE BRAIN: What are the temporal dynamics of brain cells, brain systems, and behavior? How do these dynamics change with learning, and how do they influence learning?

3. TEMPORAL DYNAMICS OF MOVEMENT AND EXPLORATION: What are the temporal structures for body movements and sampling the environment and how are they learned?

Each of these broad Center Research Initiatives will be addressed by formulating specific research strands that represent tractable subtopics within the Initiative. The Center will focus on one to a few strands at a time within each Initiative. By aggregating information over time, completion of multiple strands within each Initiative will provide meaningful answers to aspects of the Initiative questions. Strands prioritized for study in this phase of the Center will be detailed in the implementation section of this document. Progress towards addressing the Initiatives is detailed in the Annual Report.

In addition to these research initiatives, our fourth Initiative focuses on Education, Outreach, and Diversity. Here, our plans involve developing training programs for undergraduates, training programs for our graduate and postdoctoral students, methods for reaching out and “in” to educational practitioners, policy makers, and the public, and implementing programs to increase diversity in the Center.