Learning-to-Learn from Novice to Expertise: New Challenges and Approaches for One of the Oldest Topics of Cognitive Science

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We start with the following questions: (1) What can Cognitive Neuroscience tell us about the oldest of modern theories of skill acquisition? [Posner] (2) How does the latest neurocognitive research tie in with reinforcement learning models and theories to shed new light on remediation of effects due to schizophrenia or aging? [Vinogradov] (3) Are there overlooked but important phenomenon in learning or transfer? [Gray & Berry] (4) How do we instruct students on complex *emergent processes* as opposed to simpler *sequential* ones? [Chi] Each of our panelists brings us a snapshot of questions and issues on one or more of these questions for what we hope is an interesting and informative ramble through contemporary issues in learning.

Michael Posner – Skill Learning in the Light of Developments in Cognitive Neuroscience

In 1967, Fitts and Posner proposed that skill acquisition consists of three serial stages (the cognitive, associative, and automatic) and that a power function related response time to practice. In this talk, we update this view of skill acquisition by (1) relating cognitive operations to brain areas, (2) emphasizing parallel operations of different brain networks, and (3) relating genetic polymorphisms to individual differences in behavior.

The three part approach remains. However, the *cognitive stage* is now represented by a network of brain areas which allows complex cognitive goals to access the motor output. The hippocampus is crucial to the *associative stage* by developing links between past and present learning. In the *automatic stage* practice influences the connectivity between brain areas by changing the brain's white matter.

By deactivating the key nodes in mouse model networks by laser light, we found that deactivating the Executive Network disrupts performance at all levels of skill. Disrupting the hippocampus interferes with learned behavior and results in reinstating habits prior to new learning. These findings suggest a parallel model of the stages of skill.

For humans, we found that 2-4 wk of meditation practice improved connectivity in pathways surrounding the anterior cingulate. This increased connectivity may provide a mechanism for producing the automatic stage of processing. This hypothesis was tested and supported by mouse models suggesting that changes in connectivity begin at the start of practice.

Practice generally leads to faster reaction time; however, this is not always true for children or those with low levels of motivation. We have found a polymorphism in a gene related to sustained attention that is associated with increases in reaction time after high levels of practice. We now believe that practice, as suggested long ago by Clark Hull, has both facilitatory and inhibitory effects on the speed of responding, the balance between these tendencies yields the function relating reaction time to practice.

These findings suggest important modifications in our view of skill learning to account for both the behavioral outcomes and the brain mechanisms that underlie improvements in skill.

Sophia Vinogradov – Basic Cognitive Operations, Goal-Directed Learning, and Plasticity

In this talk, we (1) review key studies that use computational models to demonstrate the relationship between performance on measures of basic cognitive operations and successful engagement in goal-directed reinforcement learning, (2) present new and old data demonstrating that these operations can be enhanced by cognitive training, and (3) discuss new methods to measure these operations in an efficient, scalable, interpretable, and actionable manner.

Goal-directed learning and decision-making engage a set of neural substrates which show the computational characteristics of model-based reinforcement learning. Such model-based systems rely on constructing and searching a range of possible future states and outcomes and selecting the one that is most adaptive (i.e., allows for achievement of the current goal). These processes have been matched to aspects of intelligence and learning ability.

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Our work and others has shown that performance in basic cognitive operations such as attention, processing speed, and cognitive control can be improved and that this improvement has meaningful implications for both learning and real-world functioning. For example, in older adults, attention training significantly enhances performance in several measures of executive function, and significantly improves skill acquisition in a speed of processing learning task, with the largest benefits shown in the most challenging components of the learning task (Van Vleet et al., 2016). In a longitudinal study of older adults, training *processing speed* resulted in a 70% reduction of driving cessation over a 10-year period (Ross, Freed, Edwards, Phillips, & Ball, 2017). In people with schizophrenia, impaired performance on auditory processing speed correlated with lower cognitive function; whereas auditory processing speed was significantly improved with targeted cognitive training, and the degree of improvement predicted gains in verbal learning and general cognition (Biagianti, Fisher, Neilands, Loewy, & Vinogradov, 2016).

Unfortunately, at there is no reliable instrument that can be used to assess these operations in real-world settings in a manner that delivers a report that is both meaningful and actionable to the measured individual.

Wayne Gray & Jacquelyn Berry – Limits to Training and Expertise in Helicopter Pilots and Tetris Players

We describe two phenomena, one old and one new. Both seem as if they should be surmountable but both give every indication of being irritatingly persistent. Neither seems like it should be an *individual difference* factor but both, apparently, are. The old one is *stable suboptimal performance* which refers to the paradox that besets people who perform the same task daily, weekly, or monthly and somehow puts a cap, for some people, on human performance. The new phenomenon is *TetLag* – a name given by the Tetris Community to refer to the period of time a player should wait in switching between two versions of Tetris so that one's fingers "do not become confused."

TetLag would be a small, but intriguing, problem if limited to the Tetris but it seems to include helicopter pilots, firemen, and riders of backwards bicycles. It applies to situations in which two or more similar but not identical tasks are well-learned – such a flying similar models of helicopters or steering your family car and then steering the "tiller" of a fire company's ladder truck.

Stable suboptimal performance is well-named as it can be annoyingly stable. As one informant says, "there are people who will never be full pilots, they are only going to be first officers. It's frustrating for me as an instructor because I want to get them to the next level but I can't and I don't know why." It is easy to attribute these limits, as Thorndike did back in 1913, to situations in which a reasonable person would not be bothered enough to put in the effort to perform better. However, it seems odd that, rather than being "exceptions" that there should be an entire category of people who are motivated and smart enough to become first officers but are not motivated or smart enough to become full pilots! That this population of expert performers (i.e., helicopter pilots), also suffers from TetLag suggests the wide-spread but largely hidden prevalence of both phenomena.

Michelene T. H. Chi – Learning the Underlying Structures of Causal and Acausal Processes

For decades, research has shown that students across all grades have difficulty learning science *processes* such as *diffusion* and *natural selection*. Such difficulties are revealed by misconceptions that persist even with the best instruction. However, in learning other processes such as the circulatory system or the ecosystem of an aquarium, students generally excel. This is the conundrum that we seek to understand.

Our new framework analyzes all processes taught in classroom learning into four components; the pattern, the agents, the agents' interactions, and the causal mechanisms relating the agents' interactions to the patterns.

Applying this framework to the processes that students easily understand and to those they have difficulty making sense of, suggests that prior work has missed an *inter-level causal mechanism* that distinguishes between two types of process models and predicts that students will have problems acquiring one type of model but not the other. We characterize this distinction and name these processes as *Sequential* or *Emergent* processes and identify the students' problem as one of understanding Emergent processes.

Students face three challenges to understanding Emergent processes: (1) they are ignorant of Emergent kinds of processes and their causal mechanisms; (2) due to this lack of knowledge, they attribute explanations appropriate for Sequential processes to Emergent ones; (3) they cannot discriminate the two kinds of processes, since the perceptual patterns of the two kinds of processes are often similar (e.g., the V-pattern manifested by geese and pilots as opposed to the linear pattern manifested by wolves chasing a prey and ants marching toward a food source).

In essence, we find that many of the processes students have to learn in their science curricula are of the Emergent kind. However, classroom instruction does not distinguish between the easy to understand Sequential processes and the hard to understand Emergent ones. We are testing our framework by developing an online instructional module intended to teach students to distinguish the two types of processes and, thereby, acquire understanding of the Emergent ones.