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NEUROSCIENTIFIC CONTRIBUTIONS TO MOTIVATION IN EDUCATION

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Neuroscientists and motivation specialists in education are two very different groups of scholars. Their subject matter overlaps in many ways (e.g., students' learning, motivation), but rather striking differences exist in terms of their training, journals, research methodology, dependent measures, unit of analysis, and what they accept as convincing evidence about how motivation works. Because this is so, it is reasonable to ask whether a chapter on neuroscience can contribute meaningfully to this *Handbook on Motivation at School*. We think that it can, but we also think that educators need a guide to clarify its potential value. The purpose of this chapter is to offer such a guide.

We organize the chapter into three sections. The first section speaks to the potential future partnership between motivation specialists in education on the one hand and cognitive and affective neuroscientists on the other hand. This partnership may or may not take root and thrive, so we identify and explain the key differences between the two fields, differences that may prove to be barriers ("we are so different") yet may also prove to be opportunities ("we have so much to learn from each other"). The second section explains what educators can gain from neuroscientific data. We argue that educators may have much to gain from neuroscience, because it has been our experience that motivation specialists who take the time to listen to, understand, and benefit from neuroscientists tend to deepen and sharpen their understanding of motivational processes. The third section is the largest and potentially most interesting section. Here, we show how neuroscientific data can enhance (and already has enhanced) our understanding of education-related motivational phenomena. We take 10 motivational constructs that are featured in other chapters of this Handbook (e.g., goal, value, intrinsic motivation, self-regulation) and look at each one through the unique lens of cognitive neuroscience. Overall, the purpose of the chapter is to act as a potential catalyst to ready motivation specialists in education to benefit from neuroscientific data.

DIFFERENCES BETWEEN NEUROSCIENCE AND MOTIVATION IN EDUCATION

Imagine how a conversation about student motivation might go between a motivational specialist in education and a cognitive neuroscientist. The two meet to discuss

ways to understand and to help a struggling student. The motivational specialist will have observed the student in and out of the classroom, and her data will show the student's experience (questionnaire data) and behavior (observational data) during learning activities and during social interaction with teachers and peers. These are the kinds of data that the reader will encounter in practically every chapter in this Handbook. The cognitive neuroscientist, on the other hand, will have observed the student in a laboratory setting, such as a research laboratory in which the student wears an electroencephalographic (EEG) cap or lays on a bed inside a functional magnetic resonance imaging (fMRI) scanner. Her data will show changes in cerebral blood flow, event-related potential (ERP) waveforms, and reaction times while the student is exposed to briefly presented stimuli, such as images and incentives. These are not the kinds of data the reader will encounter in the other chapters in this Handbook.

The motivation specialist and the cognitive neuroscientist collect, think about, and interpret different types of data, so the key question becomes how they might communicate well, learn from each other, and help and benefit each other. These are critical questions, because if the answers are unclear, then the two will likely go their separate ways. Worse, the two may contradict, oppose, frustrate, and even outright reject and dismiss each other. So, we begin this chapter by highlighting three key differences between motivational specialists in education and cognitive neuroscientists.

Levels of Description

The primary reason that communication sometimes breaks down between motivation specialists in education and cognitive neuroscientists is because the two generally utilize different levels of description, including different levels of analysis and explanation (Willingham & Lloyd, 2007). Both study, describe, analyze, and seek to explain behavior—effort, persistence, avoidance, learning, performance, and so on. And both likely agree on the underlying psychological cause of that behavior—a goal, reward, outcome expectation, and so on. Where the two fundamentally differ is in their description of the underlying cause of the behavior, as illustrated in Figure 21.1.

For the motivation specialist, the level of description revolves around the psychological construct. As per Figure 21.1, the motivational specialist explains behavior by asking to what extent the student has set a goal, has a plan or strategy to accomplish it (i.e., implementation intention), and can resist attractive distracters (i.e., self-control). In contrast, for the cognitive neuroscientist, the level of description revolves around the brain-based mechanisms that underlie the psychological construct. The neuroscientist explains behavior by asking about the neural bases of these psychological constructs and hence the activity of the person's prefrontal cortex (goal origin), anterior cingulate cortex (selection and coordination of a sequence of options in the face of conflicting information), striatum (reward), and amygdala (aversion).

Notice that the two have the basis for a wonderful partnership: the cognitive neuroscientist can explain the mechanisms underlying the psychological construct while the motivational specialist can link the psychological construct to important schooling outcomes. But, to form this partnership, the two need to know that they tend to speak different languages.
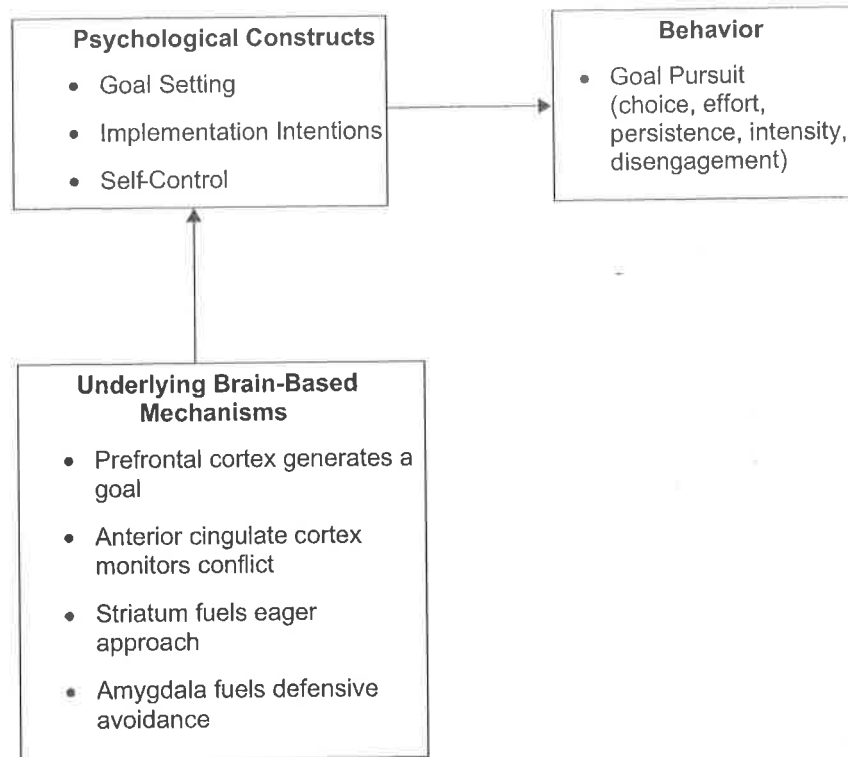
Figure 21.1 Different Levels of Analysis for Motivation Specialists in Education and for Cognitive Neuroscientists

Momentum

In terms of momentum, the last three decades of the 20th century represented the golden age of motivation study. Consider the birth and flourishing of all these motivation theories just from the mid-1970s: learned helplessness (Seligman, 1975), reactance theory (Wortman & Brehm, 1975), flow (Csikszentmihalyi, 1975), self-determination theory (Deci, 1975), self-schemas (Markus, 1977), self-efficacy theory (Bandura, 1977), and attribution theory (Weiner, 1979). Today, the pace of new discoveries and the birth of new theories is not quite the same as it once was. The rate of growth seems linear. But the pace of new discoveries in the neuroscientific study of motivational processes does show signs of such vibrancy and momentum. The rate of growth seems exponential. This momentum can be seen in the identification of new processes, the offering of new explanations, the start of new journals, the proliferation of handbooks, the creation of neuroscience laboratories and research teams around the world, new conferences, and the sheer number of professors, graduate students, and post-doctoral fellows who have decided to self-identify as cognitive or affective neuroscientists. This is not to say that one field is better than the other, but their growth rates and their pace of novel discoveries are different.

Timescales

Motivational specialists in education and cognitive neuroscientists typically have in mind different timescales when they think about and study motivational processes. Typically (but not always) motivation specialists in education tend to investigate how motivational processes arise, change, and affect behavior from one day, one week, one semester, or even one developmental period to the next, whereas cognitive neuroscientists tend to

investigate these same motivational processes on a timescale of seconds or milliseconds (msec).

One group of motivational specialists, for instance, developed and implemented a two-month intervention to help preadolescents endorse a growth mindset (Blackwell, Trzesniewski, & Dweck, 2007). Once a week for eight consecutive weeks, preadolescents learned that neural pathways in the brain can grow, that the brain changes by forming new connections, and that students are in charge of this learning process. Before and after the classroom-based intervention, students completed a questionnaire assessing the growth mindset. Compared to students who did not participate in the intervention, students who completed the intervention endorsed a greater growth mindset (and showed post-intervention gains in their grades as well).

The neuroscientific study of the growth mindset looks quite different. One group of cognitive neuroscientists, for instance, first assessed participants' growth mindset with the same aforementioned questionnaire but then asked participants to put on an EEG cap to assess their cortical brain activity as they were tested on moderately difficult questions (e.g., What is the capital of Australia?) and as they typed in their one-word answers (Mangels et al., 2006). Five seconds after typing each answer, participants received correct (green asterisk) or incorrect (red asterisk) feedback for one second. Correct answers to any missed questions were provided for 2 seconds. After all the questions were presented, the experimenters administered a surprise test to see how much participants were able to learn the answers to the questions they had earlier missed. Participants with a fixed mindset exhibited a pattern of neural activity 300 msec after the red light that suggested that they found the incorrect feedback to be salient and threatening, while participants with a growth mindset did not show this same pattern of cortical reactivity at 300 msec but, instead, engaged in sustained semantic processing (anterior cingulate cortex, frontal-parietal regions) of the learning-relevant feedback for the 2 seconds. As a result of their openness to the post-feedback learning-relevant information, participants with a growth mindset scored significantly higher on the surprise post-experimental test.

The difference in timescales is one that currently keeps motivational specialists and cognitive neuroscientists apart, but there are timescale exceptions. Some motivational specialists do study participants' immediate reactions to environmental stimulation and opportunities (e.g., reaction times in msec), and some cognitive neuroscientists study how the brain changes and develops in response to various types of stimulation (or deprivation) over a period of years. These exceptions are important because they suggest a possible future pathway for convergence between the two fields as they merge not only their subject matters but also their timescales.

WHAT CAN MOTIVATION SPECIALISTS IN EDUCATION GAIN FROM NEUROSCIENTIFIC DATA?

Motivation specialists in education have multiple opportunities to gain from neuroscientific data, but we emphasize three in particular: (1) new objective measures of motivation, (2) a new data source to mine for new perspective and knowledge, and (3) new criteria to constrain the proliferation of motivation theories.

Potential Gain #1: New Objective Measures

Many believe that neuroscientific data (brain scans) are more real than are other types of data. The attraction is that neuroscientific data are objective, rather than subjective and
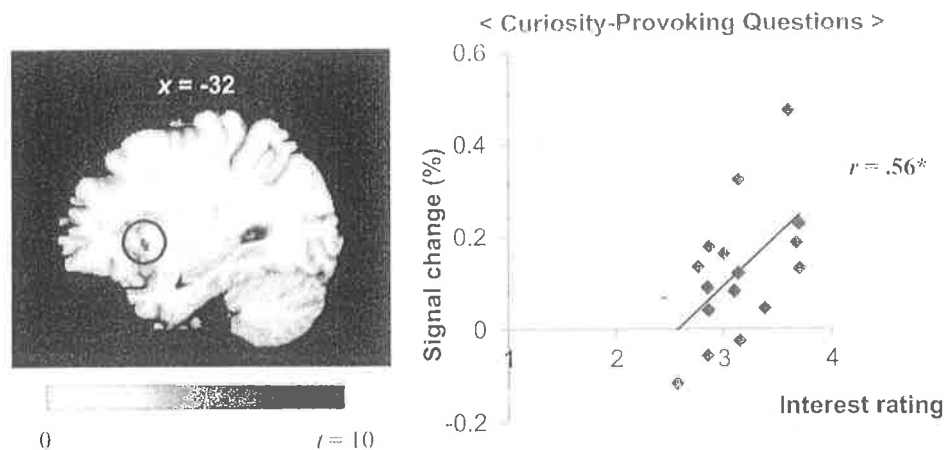
Figure 21.2 Scatterplot of the Association between Self-Reported Interest Ratings and BOLD Signal Changes in the Anterior Insula During Exposure to Curiosity-Provoking Questions

self-reported. It is a problem, for instance, when the student reports high interest in math on a questionnaire, yet his behavior during math class suggests otherwise.

A science needs objective measures. Those who study motivation in education certainly have objective (usually behavioral) measures at their disposal, but they nevertheless tend to rely rather heavily on self-report ratings (e.g., "I am highly interested in this art class."). A cognitive neuroscientist might alternatively assess the status of students' task-related interest by recording their anterior insula brain activity. To illustrate this point, Figure 21.2 displays the scatterplot (the zero-order correlation) of the relation between participants' neural activity in the anterior insula and their self-reported interest in the task (from Lee & Reeve, 2013). The correlation between the self-report and the objective measure is quite high, but the important point is that one measure has greater scientific credibility than does the other.

The general suspicion of self-report ratings can be easily demonstrated by asking people how happy they are on sunny versus rainy days: "on a scale of 1 to 10, with 10 being the happiest, how happy do you feel about your life as a whole?" (Schwarz & Clore, 1983, p. 519). Self-reported happiness depended on whether it was sunny ($M = 7.5$) or rainy ($M = 5.4$). When data depend on something as fickle as the weather, one needs to question how trustworthy they are. One also needs to look for new opportunities to incorporate a greater reliance on objective measures.

Potential Gain #2: New Perspective and New Knowledge
about Motivational Phenomena

Most motivational constructs are understood in an incomplete way. Much is known about the various motivational constructs highlighted throughout this Handbook, but much is also unknown. Neuroscientific data offers the opportunity to add new perspective and new knowledge about literally any motivational construct, even those that are currently rather well understood.

As one illustration, the undermining effect is a well-established and education-related motivational phenomenon (Deci, Koestner, & Ryan, 1999). Self-determination theory proposes that the pursuit of tangible extrinsic rewards during an inherently interesting activity will undermine students' future intrinsic motivation for that activity. Consider what happens

in the brain under these conditions (Murayama, Matsumoto, Izuma, & Matsumoto, 2010). In one condition, participants engage in an interesting activity on two successive occasions. Interesting activities are inherently rewarding experiences, as confirmed by the presence of activations in the brain's subcortical reward center, the striatum, at both Time 1 (T1) and Time 2 (T2). In the second condition, participants engage in the same interesting activity but with the promise of an attractive reward (money) at T1. At T2, however, the participant engages in the interesting activity without the promised extrinsic reward. The pursuit of the attractive reward produces activations in the striatum at T1, but those previously present striatal activations disappear at T2. That is, after the previously offered monetary reward was removed, the task-generated intrinsic motivation was undermined—even evaporated.

The new perspective is that what motivational specialists see in their self-report and behavioral data can also been seen in a new way in the neuroscientific data. The opportunity for new knowledge is to understand how interesting activities generate striatal activity to produce intrinsic motivation. It is well-known that attractive rewards can generate striatal-based extrinsic motivation, but the neural basis of intrinsic motivation is not well-known. It seems to us that understanding the neural basis of intrinsic motivation represents untapped potential to gain new insights.

Potential Gain #3: New Opportunities to Constrain Motivation Theories

The number of motivation theories in education tends to proliferate without any built-in constraints (Hulleman, Schrager, Bodmann, & Harackiewicz, 2010). Contradictory data can, of course, constrain new theories, but not many published studies report and interpret null findings. Neuroscientific data offers one opportunity to hold motivation theories more accountable than they currently are. That is, successfully localizing the brain activity associated with a hypothesized motivational construct provides compelling evidence for the reality and importance of that construct, just as the absence of such underlying brain activity casts suspicion about the reality and importance of that construct (Willingham & Lloyd, 2007). To the extent that a theory of motivation can be explicit about its underlying psychological processes and the conditions under which those processes do and do not occur, then neuroscientific data can provide an objective test as to whether those hypothesized processes are neurally viable.

For instance, it seems fair and necessary to ask for evidence about the substantive nature of the following popular motivational constructs in education: intrinsic motivation, fear of failure, mastery-avoidance goals, cognitive dissonance, implicit power motivation, self-regulatory strength, need for cognition, interdependent self-construals, self-handicapping, and four different types of value (within Expectancy x Value theory). It is interesting and informative, for instance, to ask if the brain actually processes the four different types of value proposed by Expectancy x Value theory—namely, intrinsic value, utility value, attainment value, and cost (Eccles & Wigfield, 2002). It is a new question for motivational specialists in education to ask how value is represented in the brain.

Cognitive neuroscientists see value as the reward- or punishment-based association one has with various environmental objects and events; these associations can be automatic and unlearned ("Pavlovian") or cognitively complex and learned (Dickinson & Balleine, 2002). But value itself exists on a common scale in the brain in which all environmental objects and events can be compared on an apples-to-apples unidimensional common scale (Montague & Berns, 2002). This contrast between a quantitative understanding of value (value exists on a unidimensional common scale) versus a qualitative understanding (four different types of value) brings the discussion back to the chapter's

opening section to ask if the motivational specialist and the cognitive neuroscientist might be able to learn from each other, or whether the two will go their separate ways.

Potential Misuses of Neuroscientific Data

Most teachers rate neuroscientific knowledge as important. How to translate this knowledge into improved instruction, however, is not yet clear. The essential question is whether or not neuroscience can offer anything helpful-that is above and beyond what teachers already know and do (Della Sala, 2009), and the essential problem is that neuroscientific findings are not prescriptive—these data do not tell teachers how to use them (Chrisodoulou & Gaab, 2009; Willingham, 2009). Hence, when teachers look at a computer screen showing a student's brain scan while reading, their first reaction is one of interest. The teacher's conversation with the neuroscientist turns flat, however, with the teacher's second reaction, which is to ask how this information on the computer screen might be applied to the classroom. While the "how to" is not yet clear, it is rather clear that classroom applications to date have been prone to wishful thinking, overinterpretation, or oversimplification.

Some examples of the overenthusiastic misuse of neuroscientific data to improve learning and instruction include the classic "students use only 10% of their brain" (Goswami, 2006), the recommendation that students engage in coordination exercises (e.g., bounce a basketball with both hands) to enhance executive functioning (Chang, Tsai, Chen, & Jung, 2013), the recommendation that teachers personalize instruction to fit students' individual learning styles (Rohrer & Pashler, 2012), and the recommendation that teachers personalize instruction to fit students' right versus left brain lateralization (i.e., left-brain thinkers are logical, whereas right-brain thinkers are creative; Nielsen et al., 2013). Educational misuses tend to gain popularity from websites, blogs, testimonials, and sales pitches and from the unpopularity of peer-reviewed research published in scientific journals. What appears to be helpful in preventing these potential misuses are books written to help educators discern uses from misuses, such as those offered by Della Sala and Anderson (2012), Geake (2009), and Willingham (2012). In the end, whether education trends toward uses, rather than misuses, will likely depend on the emergence, participation, and communicative prowess of mediators and translators who are as comfortably at home in the classroom as they are in the neuroscience lab.

HOW NEUROSCIENCE DATA CAN ENHANCE (AND ALREADY HAS ENHANCED) OUR UNDERSTANDING OF MOTIVATIONAL PHENOMENA

Neuroscientists and motivation specialists in education look at motivation very differently. As the authors have listened to (and participated in a few of) these back-and-forth conversations, two old phrases of wisdom come to mind. The first is, "You say toe-may-toes, I say ta-mott-toes, so let's call the whole thing off." The second is, "Why do you see the speck that is in your brother's eye, but do not notice the log that is in your own eye?" Both sayings cast a rather pessimistic light on a potential education–neuroscience partnership, but both also underscore the need for greater mutual understanding. So, in that spirit, we present the Top 10 widely studied motivational constructs in educational psychology that have also been studied from a neuroscientific perspective: reward, goal, value, intrinsic motivation, agency, self-efficacy, self-regulation, risk taking, emotion

regulation, and implicit motives. We hope this review will offer motivational specialists a fresh way of thinking about the motivational constructs they study and, in doing so, allow cognitive and affective neuroscientists to become more like kindred spirits and colleagues and less like competitors and rivals.

Reward

The most important motivational construct in contemporary neuroscience is reward. This is because reward is fundamental to goal-directed effort, learning, and well-being, not to mention survival itself (Schultz, 2000). For the cognitive neuroscientist, goal-directed effort follows from and is dependent on extracting reward-related information from environmental objects, events, and circumstances (Berridge & Kringelbach, 2008). The reward-related information that people extract out of their surroundings includes the presence and availability of reward, the value of that available reward, the predictability of that reward, and the costs associated with trying to obtain it.

The striatum functions as the brain's reward center, and it consists of the nucleus accumbens, caudate nucleus, and putamen (Liljeholm & O'Doherty, 2012). It is actually the amygdala that detects, learns about, and responds to the rewarding properties of objects and events (Baxter & Murray, 2002), but this information is passed along to the striatum. What activates the striatum is reward-related information and, in the brain, that means dopamine release. Once activated, the striatum translates the experience of reward into motivational force, approach behavior, and the exertion of effort (Pessiglione et al., 2007).

The starting point for the brain's reward center is the manufacturing site for brain dopamine—the ventral tegmental area. The ventral tegmental area projects fibers into the striatum and into the nucleus accumbens in particular. The ventral tegmental area–to–nucleus accumbens pathway extends further upstream (up-brain) into the cortical brain, including into the orbitofrontal cortex, where the learned reward value of environmental objects is stored. The ventral tegmental area also sends reward-related excitatory signals into brain structures responsible for behavior preparation and execution (e.g., the supplemental and presupplemental motor areas). Overall, the more dopamine that is released upon encountering environmental objects and events, the greater will be the approach motivation and learning. The neural substrates of the brain's reward center appear in Figure 21.3.

Neuroscientific data on the brain's reward center reveals two interesting findings about reward dynamics. First, because some level of dopamine is always present in the brain, what really matters in the neural processing of reward is the extent of change in dopamine release. When events unfold as better than expected, the ventral tegmental area releases increased dopamine; in contrast, when events unfold as worse than expected, the ventral tegmental area decreases dopamine release (Montague, Dayan, & Sejnowski, 1996). Thus, the extent of dopamine release (not the physical characteristics of the stimulus itself) contributes to motivated behavior and learning.

Second, what causes the ventral tegmental area to release dopamine is the anticipation—and not the actual receipt—of a rewarding event. That is, we experience greater approach motivation and learning when we first hear that something good is going to happen, not when we actually encounter that good event. Unpredicted or underpredicted reward-related events produce the greatest dopamine release. For this reason, students typically experience more pleasure in thinking about recess or the school prom than they
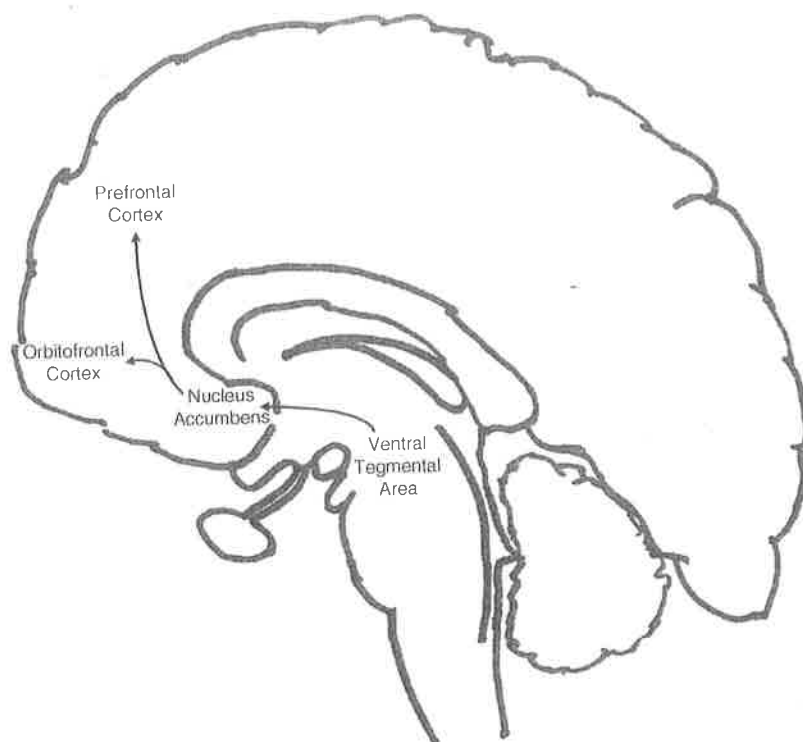
Figure 21.3 Reward Circuit in the Subcortical Brain

do during the actual experiences of recess or attending the prom. Of course, if things go better than expected at recess or at the prom, then the dopamine release will continue in kind.

Goal

In motivation study, goals are future-focused cognitive representations that guide behavior to an end state that the individual is committed to either approach or avoid (Hulleman et al., 2010). In a cognitive neuroscience analysis of goals, these future-focused goals have their origin in past reward-related information stored in the prefrontal cortex (Miller & Cohen, 2001). Past reward-related information therefore comes to serve as the anticipatory motivational basis of future goals. In addition, when the reward information associated with multiple environmental events is compared, people show preferences (in terms of choice and effort expenditures) for those goal-related objects and events that have the highest reward signal. Hence, biologically experienced reward serves as the basis not only for reward and goals but also for the additional motivational constructs of preference and value.

Value

A value is the worth of something. When people have a choice among objects or events, they determine the worth of those various options and generally pursue the one with the greatest value. The orbitofrontal-striatal circuit (see Figure 21.3) is a valuation system that continuously recalculates valuation in terms of how rewarding and how punishing

a broad range of objects and events are (Montague & Berns, 2002). It does so by valuing all of these potential stimuli and events on a common dopamine-based scale, which is the neural equivalent of a monetary currency (i.e., just as all economic goods can be converted into money, the value of all environmental objects and events can be converted into dopamine). Once the value of an object has been learned, activity in the orbitofrontal cortex helps people consider their options, remember the incentive value associated with each of those options, and make their selection among the differently valued objects to pursue. Hence, from a cognitive neuroscientific perspective, little distinction is made between reward and value.

Intrinsic (and Extrinsic) Motivation

In the cognitive neuroscience literature, extrinsic motivation is synonymous with incentive motivation. As people experience extrinsic motivation, they show greater orbitofrontal cortex activity as they weigh the value of the incentive being offered and greater anterior cingulate cortex activity as they go through a decision-making process as to whether engagement in the activity will bring enough reward to justify the effort (Plassmann, O'Doherty, & Rangel, 2010). The whole process is very much a "means to an end" cost-benefit analysis.

According to motivational specialists in education, intrinsic motivation is different. When students are intrinsically motivated, they engage in activities because they find it inherently interesting and enjoyable to do so (Deci & Ryan, 1985). Intrinsic motivation is a concept that cognitive neuroscientists have not attempted to explain or understand. Recognizing this, the two authors of this chapter, two educational psychologists, have investigated the neural bases of intrinsic motivation themselves (Lee & Reeve, 2013, 2015; Lee, Reeve, Xue, & Xiong, 2012). Our initial studies compared neural activity when participants imagined intrinsically motivating situations (e.g., writing an enjoyable paper) versus when they imagined extrinsically motivating situations (e.g., writing an extra-credit paper). Results showed that the anterior insular cortex was uniquely activated during intrinsically rather than during extrinsically motivating activities. The close correlation between anterior insular cortex activity and subjective experiences of interest was illustrated earlier in Figure 21.2.

Other intrinsic motivation researchers have investigated curiosity (Kang et al., 2009) and challenge (Murayama et al., 2010). Participants in these studies showed neural activity related to reward processing (striatum activity) when they experienced spontaneous satisfactions from feeling suspense over what comes next (curiosity satisfaction) and from feeling mastery from making progress on optimal challenges (competence satisfaction). These findings suggest that intrinsic motivation involves both anterior insula–based "intrinsic reward processing" and striatum-related "extrinsic reward processing." For this reason, we recently examined participants' neural activity while they engaged in two different versions of the same task representing high versus low intrinsic motivation. Results based on fMRI showed that the intrinsic motivation neural system revolved around (1) anterior insula activity, (2) striatum activity, and (3) anterior insula–striatum interactions (Lee & Reeve, 2015). Overall, anterior insula activity is associated with intrinsic satisfactions (e.g., interest, curiosity, enjoyment), striatum activity is associated with reward processing that includes both extrinsic and intrinsic motivation, and these two brain areas bilaterally communicate and are functionally interconnected to constitute the neural bases of the intrinsic motivation system.

Agency

Agency is the sense of "I did that," and it lies at the center of intentional, voluntary, purpose-driven action. Motivation researchers in education generally study agency as self-generated motivation to act on and transform the environment in an intentional and desired way (Bandura, 2006). Cognitive neuroscientists study agency more narrowly, as they contrast self-as-cause versus other-as-cause (Engbert, Wohlschlager, & Haggard, 2008; Farrer & Frith, 2002; Miele, Wager, Mitchell, & Metcalfe, 2011; Spengler, von Cramon, & Brass, 2009). A subjective experience of agency arises only when the activities of the motor-related brain regions (i.e., supplemental motor area, presupplemental motor area) are closely linked to a self-instruction to act (i.e., "self-initiated action"; Miele et al., 2011). Self-as-cause agency is associated with activation in the anterior insula and anterior prefrontal cortex, whereas other-as-cause nonagency is associated with activation in the inferior parietal cortex (Farrer et al., 2003; Farrer & Frith, 2002; Lee & Reeve, 2013; Miele et al., 2011). Whether agency is studied at the metacognitive or at the neural level of description, both research literatures reach the same conclusion that "unless people believe they can produce desired effects by their actions, they have little incentive to act" (Bandura, 2006, p. 170).

Self-Efficacy

Self-efficacy is the generative capacity in which the individual orchestrates his or her skills in the pursuit of goal-directed action while coping with environmental and intrapsychic demands and circumstances (Bandura, 1977). The precuneus (embedded within the parietal lobe) is involved in many of the judgment processes the individual engages in to assess how well (or poorly) he or she will cope with a demanding task or situation, including self-related imagery, episodic memory retrieval, and the experience of agency (Cavanna & Trimble, 2006; den Ouden, Frith, Frith, & Blakemore, 2005). The more practiced and automated one's coping skills are, the more able the individual is to focus attention on retrieving relevant episodic memories and on predicting and planning effective future courses of action. The hippocampus is important to automation of procedural knowledge, and the downregulation of competent self-representations from the precuneus has been shown to lessen negative affect (confusion and anxiety; Bandura, 1988) and cortisol reactivity (the stress hormone) during coping (Sapolsky, 1992).

Self-Regulation

Self-regulation is an ongoing, cyclical process that involves forethought, action, and reflection (Zimmerman, 2000). Forethought involves goal setting and strategic planning, while reflection involves assessment and making adjustments to produce more informed forethought. What the self regulates during self-regulation are the pursuit of one's goals, including the means of goal pursuit, such as plans, strategies, emotions, and environmental affordances.

Several brain structures exercise executive control and inhibition over action. The prefrontal cortex contributes top-down control that guides behavior by activating internal representations of action, such as goals and intentions. Executive control over action is carried out in the ventral medial prefrontal cortex, the anterior cingulate cortex, and the dorsolateral prefrontal cortex, as each is involved in high-level regulatory behaviors such

as planning, organizing, and changing action (Damasio, 1994, 2003; Ochsner & Gross, 2005). The anterior cingulate cortex, for instance, regulates goals and goal-directed action by monitoring conflict, integrating emotional information, and updating new information about previously encountered events (Behrens, Woolrich, Walton, & Rushworth, 2007; Botvinick, Cohen, & Carter, 2004; Craig, 2009). These brain processes are fundamental in explaining the neural bases of forethought, decision making, and reflective action.

Risk Taking

A neuroscientific perspective on self-regulation is essential to understanding risk taking and impulsivity in children and adolescents. This is because self-regulation is largely a top-down phenomenon in which cortical brain regions regulate, manage, and control subcortical brain regions. Subcortical brain regions are involved in basic motivational and emotional processes (e.g., "Ice cream—I want it!"), whereas cortical brain regions are involved in self-control, resisting temptation, decision making, assessing risk, and self-regulation (e.g., "Okay, but wait until after dinner.").

During childhood, subcortical brain processes and reward-driven affect tend to dominate the cortical brain and its reflective capacities, because childhood is an age in which cortical structures are still maturing (Best, Miller, & Jones, 2009; Cragg & Nation, 2008). Although adolescents become increasingly able to control strong motivations and emotional processes (e.g., urges) and to delay immediate gratification for the benefit of long-term goals, they nevertheless tend to take more risks than adults do (e.g., dangerous driving; Arnett, 1991). The basic neurological problem underlying adolescent risk taking is that the hot subcortical brain structures are already mature and actively involved in decision making, whereas the cold cortical brain structures are still immature and less actively involved in decision making (Galvan, 2010; Galvan et al., 2006; Somerville, Hare, & Casey, 2010).

Emotion Regulation

Emotion regulation involves the calming down (modulation) of emotional reactions and responses through top-down cortical control processes (Gross, 2002). The five most studied top-down emotion regulatory strategies are situation selection, situation modification, attentional deployment, reappraisal (cognitive change), and suppression (response modulation), though the majority of neuroimaging studies of emotion regulation have focused on reappraisal (Gross, 2008).

Cognitive regulation of emotion is implemented by cortical regions that regulate attention, memory, and affect—namely the frontoparietal regions that include the dorsolateral prefrontal cortex, inferior parietal cortex, anterior cingulate cortex, and medial prefrontal cortex (Silvers, Buhle, & Ochsner, 2014). The dorsolateral prefrontal cortex maintains attention on one's goals, the inferior parietal cortex executes some control over working memory, the anterior cingulate cortex detects conflict and errors, while the medial prefrontal cortex inhibits goal-inappropriate diversions. The targets of all this cognitive control are the brain areas that are the source of strong goal-incongruent emotions, including the amygdala, striatum, and posterior insula. Executive control over the amygdala reduces negative affect; executive control over the striatum enhances positive affect; and executive control over the posterior insula reduces negative bodily based emotional states such as disgust and pain.

Implicit Motives

This distinction between cortical and subcortical processes is important to the understanding of many motivational constructs, but it is especially relevant to any distinction between implicit (unconscious) and explicit (conscious) processes, such as implicit and explicit social motives (Schultheiss & Brunstein, 2010). Research on social motives shows that (1) explicitly assessed (questionnaire) measures of achievement, affiliation, and power are not necessarily correlated with implicitly assessed (projective) measures of these constructs and that (2) the two types of social motives predict different types of dependent measures (Schultheiss, 2008; Schultheiss, Yankova, Dirlikov, & Schad, 2009).

A neuroscientific perspective on implicit motives has tended toward understanding the brain-based mechanisms behind individual differences in the need for achievement, affiliation, and power. Such person-level individual differences seem to develop from learning experiences in which need-relevant stimuli reliably activate the striatum, which is the brain's reward center. Individuals who are high in the need for power, for instance, show increased striatal activation when exposed to power-related incentives, such as winning or losing a contest or viewing dominant (angry) or submissive (surprise) facial expressions, while they do not show these same striatal activations in the presence of achievement- or affiliation-related stimuli (Rawolle, Schultheiss, & Schultheiss, 2013).

FUTURE CONVERGENCE?

Currently, not much overlap can be found between motivational specialists in education and cognitive neuroscientists, but we see the overlap in the subject matter of these two fields as a gravitational pull that can bring them closer together. Although we cannot yet predict what the future catalysts for future convergence might be, we can suggest that readers keep an eye out for two potential gravitational pulls.

First, new discoveries about the neuroscience of a motivational phenomenon will excite and interest motivational specialists in education, as their professional curiosity will pull them toward the effort to incorporate these new discoveries into their existing psychologically oriented explanations. The reverse is also likely to happen, as new discoveries at the psychological level will excite and pull at the curiosity of cognitive neuroscientists, as per the earlier discussions of the undermining effect, emotion regulation, and so forth.

Second, perhaps the single most exciting discovery in cognitive neuroscience is that of brain plasticity, which is the brain process whereby the internal structure of the brain reorganizes itself in response to its use (Kleim & Jones, 2008). Usage typically involves either sensory stimulation or repeated practice, as both types of experiences have been shown to be able to produce increased grey matter volume and reorganized synaptic and dendritic interconnectivity (Trachtenberg et al., 2002). For instance, a lifetime reliance on suppression as a preferred emotion regulation strategy has been shown to be related to greater anterior insula volume (Giuliani, Drabant, Bhatnager, & Gross, 2011). Trying to explain how the brain areas related to motivation and learning change, grow, and develop seems like a future research question to pull the two fields together.

CONCLUSION

East and West Germany were united in 1990, and that collaboration has worked out rather well. North and South Korea today remain divided as two distinct countries, and that separation has not worked out so well. Cooperation and integration seem to

outfunction competition and isolation, at least when it comes to nation-states. The same is likely true for motivation and neuroscience. Neuroscience needs the subject matter and well-understood motivational phenomena that education has to offer, and motivational specialists in education can benefit from neuroscience in the ways identified earlier in the chapter (i.e., objective measures, new knowledge opportunities, and theory constraint). But fields of study, like governments, do not just naturally come together and share. Rather, it takes diplomats—that is, graduate students, post-doctoral fellows, professors, and well-informed translators who are trained and experienced in both fields—to do so. We hope that the present chapter might act as a catalyst to populate the new frontier of motivational neuroscience. New discoveries and improved understanding await.

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