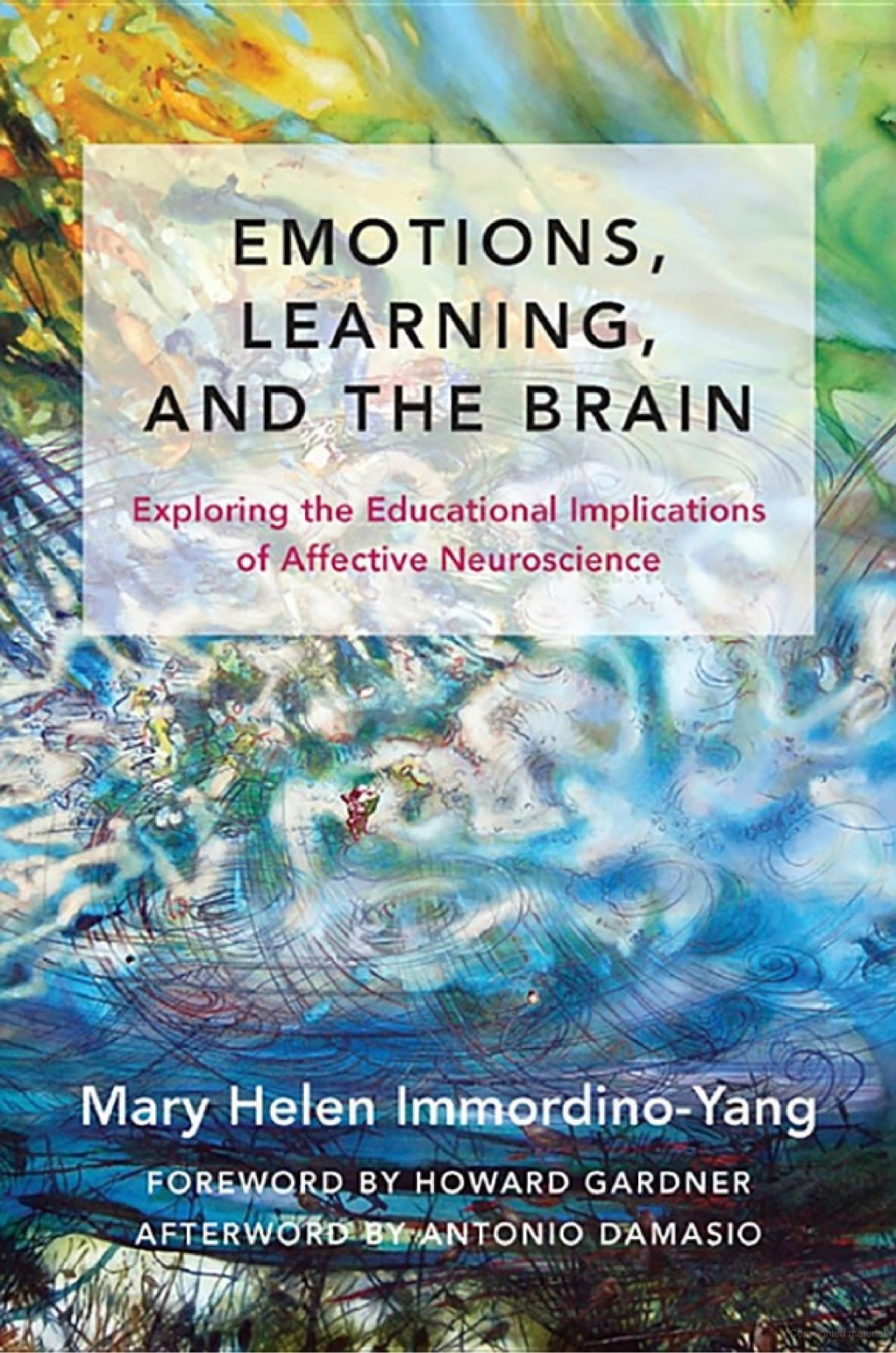
EMOTIONS, LEARNING, AND THE BRAIN
Exploring the Educational Implications of Affective Neuroscience
Mary Helen Immordino-Yang
FOREWORD BY HOWARD GARDNER
AFTERWORD BY ANTONIO DAMASIO

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Foreword

by Howard Gardner

In 1985, I published an introduction to the newly emerging interdisciplinary field called cognitive science. In *The Mind's New Science*, I documented the power as well as the limitations of the computer as a model for human cognition and showed how computational models and analyses were affecting fields such as psychology, linguistics, philosophy, and neuroscience. One limitation of the computational approach of the era was that it favored analyses that treated human cognition as being rational—a stance epitomized by the "general problem solving" computers of the era. Accordingly, while cognitive science provided insights into problem solving in mathematics, logic, and across the basic sciences, as well as in games like chess, certain aspects of the human psyche were ignored or minimized. Another limitation of cognitive science circa 1985 is that it assumed that all problems were akin to one another and that the approaches optimal in one domain (e.g. positing a possible solution and working backwards) were equally applicable in other domains.

Overall, in describing the lacuna of the cognitive approach of the nineteen eighties, I lamented the fact that the approach had little to say about the arts, creativity, the emotions, complex social interactions, or the importance of context in understanding human thought and behavior. One reason for these laments: these were areas of human life that I myself wanted to understand.

While reading Mary Helen Immordino-Yang's impressive collection of papers, I often thought back to the research panorama thirty years ago. As I write, in the second decade of the 21st century, we have a much broader and much deeper picture of the range of human thought and behavior. This progress is due to many scholars across several fields, among whom are Mary Helen's own teachers, such as Antonio Battro, Antonio Damasio, Hanna Damasio, Kurt Fischer, David Rose, and other important contributors, like George Lakoff. That said, Mary Helen stands out for the way in which she has drawn on the findings and perspectives of such scholars, initiated important lines of research in these areas, brought together her work with those of other innovative scholars into original powerful syntheses, and articulated the educational implications of cutting edge work in psychology, neurology, and other strands of the cognitive sciences.

Of the many significant findings and insights in this volume, let me mention ones that especially struck this chronicler of thirty years ago. At the time,

*We had no idea that one could study human emotions that emerge slowly over time—such as admiration or awe—and compare them psychologically

and neurologically with emotions that emerge more quickly, such as surprise or fear. Nor did we suspect that such slow-emerging emotions drew on basic non-conscious forms of regulation of bodily processes.

*We were not cognizant of the importance and the neural substrate of unfilled time—time to step back, reflect, evaluate, even daydream.

*We assumed that surgery as drastic as the removal of an entire cerebral hemisphere would result in debilitating cognitive limitations; we could not envision individuals whose behavioral repertoire was normal or close to normal in many respects.

*We had little idea of similarities and contrasts in brain processing of individuals from different cultural groups, let alone of the advantages and disadvantages of various modes of processing.

*We had no idea that certain networks of neurons (now called mirror neurons) fire when others are carrying out actions, but only when the goals of those actions are understood.

Whether or not we are scientists ourselves, most literate individuals are intrigued to learn of new scientific findings. And findings involving the human brain seem to be especially riveting; I can well remember the excitement a half century ago when the different functions and capacities of the left cerebral hemisphere and the right cerebral hemisphere first became widely known. (The specializations of each hemisphere were actually first described in the latter half of the 19th century, but achieved notoriety only after it became possible, due to radical surgery that separates the two hemispheres, to study the capacities and functions of each hemisphere separately.) Indeed, so powerful are findings from neuroscience that individuals find the *same* results more compelling if they are simply accompanied by a photograph of a brain, even when the two accounts are otherwise identical!

Mary Helen Immordino-Yang is one of the pioneers in the interdisciplinary field of Mind-Brain-Education, launched around the turn of the millennium at the Harvard Graduate School of Education and at several other campuses around the world. Given the widespread fascination with brain findings and her path-breaking studies, there has been enormous interest in her work and its possible implications for the classroom. It would be all too easy to pander to this interest, over-interpreting findings, embracing seductive “neuro-myths,” or using brain evidence simply to endorse practices that one would favor anyway. Indeed, such tendencies are widespread nowadays, even among researchers who should know better.

Just how to summarize often complex scientific findings and relate them to education is a tremendous challenge. Indeed, the challenge is sufficiently great that many scholars refuse to make the leap at all. While this caution is perhaps understandable, it leaves the field wide open to opportunists and even charlatans who say, “The Brain works like X; therefore, you should teach like Y, “ or, “The brain works like A, and so students should learn in manner B.”

In discussing the educational implications of her own research and that of

other leading scholars, Mary Helen is admirably restrained. She acknowledges the considerable distance between a finding obtained in the laboratory and a practice executed in a classroom. She appreciates that education is suffused with values; one cannot simply stipulate that because the mind (or the brain) works in a certain way, that mode of functioning dictates how one *should* teach or how one *should* learn. Indeed, education is about choices, and many of those choices reflect one's values and/or the constraints of a given context—be it the youngsters in a given classroom, the predilections of a teacher or a parent, or the dictates of national policy.

Without wanting to put words into Mary Helen's artful vocabulary, I believe that she endorses the following perspective. A range of sciences (and other disciplines) provide suggestions about how best to educate. None of them is definitive, but it would be foolish to ignore any of them, and we are best off if we try to draw on the range of perspectives, paying particular attention when the various indices point in the same direction. Time and again, in her essays, she combines findings about psychological development, neural development, and cultural contexts in order to make suggestions about how educators might proceed. Sometimes, her recommendations are quite general: emotions are powerful motivators and teachers ignore them at their peril. At other times, the recommendations are more targeted: children can construe mathematical problems in quite specific ways, and the mode of pedagogy that will work best becomes clear when teachers understand the particular assumptions and predilections that students bring to the solution of a given math problem. Some of the recommendations apply generally across human beings—e.g., we work more effectively with digital devices when they are designed to give us a sense of agency. Others are targeted to teaching individuals with atypical brain organization: individuals with a given neurological profile tackle problems most effectively when they can re-construe the problems so that they can draw on spared cognitive capacities.

Science proceeds brick by brick, building gradually on earlier findings, making adjustments as necessary, always mindful of limitations in method and inference. Education, on the other hand, unfolds in real time, and parents, teachers, and learners have to make the best use of time, techniques, texts, and tools. As a teacher of science herself, both to middle school children and to university students, Mary Helen is keenly aware of the pressures and constraints under which educators work. At the same time, she knows that teachers are learners (that is a major reason that individuals choose to enter the profession) and that they are eager to pick up ideas and practices that can enhance their effectiveness. And so, throughout this collection, Mary Helen reports findings, weighs their significance, and makes useful suggestions without stating or implying an exalted status for any of them. Perhaps even more important, she provides a way of thinking about scientific discoveries that is at once exciting and prudent—precisely the frame of mind that we hope to inculcate in teachers and learners everywhere.

As I read through these essays, I had an uplifting feeling: readers of this

book will be present at the birth and early stages of a new and vital field of knowledge. Building both on the initial vision of cognitive science, and on the important modifications and improvement introduced by her teachers, by other leading scholars, and as well by her own research, Mary Helen Immordino-Yang presents a panoply of important findings—fascinating in their own right and pregnant with implications for anyone who is interested in teaching and learning. And since we now know that these processes begin at birth—if not in utero!—and continue as long as one's mind is active, one can readily envision how a full-blown panorama of mind, brain, and education throughout the life cycle may emerge in the decades ahead. I can state with confidence that the work in these pages will be fundamental to this crucial field and I have every confidence that Mary Helen Immordino-Yang will continue her singular contributions to its vitality.

Emotions, Learning, and the Brain

Introduction: Why Emotions Are Integral to Learning

Teachers intuitively know that neither their nor their students' learning is steady and constant, the same day in and day out and moment to moment, consistent from topic to topic. Rather, we all have good and bad days; moments of excitement, engagement, and inspiration and moments of disappointment, disengagement, and frustration; afternoons just before vacation and mornings just after; some skills and topics that we find interesting and some that we don't. These differences influence how children learn and how teachers teach; they even affect what students know at a given time. In short, learning is dynamic, social, and context dependent because *emotions* are, and emotions form a critical piece of how, what, when, and why people think, remember, and learn.

The fundamental role of emotions in learning first became apparent to me during my first professional position after college, as a junior high school science teacher in a highly diverse, urban public school near Boston. The community I lived and worked in had many first-generation Americans, 81 languages total spoken in our school of 1,800, and many students living in underprivileged circumstances. Although I was teaching integrated science, a technical academic subject, I was intrigued that my students' questions and explanations seemed connected to their friendships, home situations, aesthetic tastes, and cultural values. I was fascinated but unprepared, for example, when the race relations among my seventh graders changed (and improved) dramatically after I taught a unit on hominid evolution that I designed with my former undergraduate professor. The students' new scientific understanding of natural selection for adaptive traits like dark or light skin seemed to powerfully influence their peer relationships and their own ethnic identities. Why had the students interpreted the science in such a personal, emotional way? And why, after the classroom turbulence had settled, did so many of my students suddenly seem to take a new interest in science? I brought these questions with me to graduate school, and through my research I still seek satisfying and complete answers to them.

Scientific understanding of the influence of emotions on thinking and learning has undergone a major transformation in recent years. In particular, a revolution in neuroscience over the past two decades has overturned early notions that emotions interfere with learning, revealing instead that emotion and cognition are supported by interdependent neural processes. It is literally

neurobiologically impossible to build memories, engage complex thoughts, or make meaningful decisions without emotion. And after all, this makes sense: the brain is highly metabolically expensive tissue, and evolution would not support wasting energy and oxygen thinking about things that don't matter to us. Put succinctly, we only think about things we care about. No wonder my seventh graders had taken that science lesson so personally and so seriously. They had found that science could help them make personally relevant meaning of the racial and ethnic diversity and identity issues they encountered in their daily lives.

This insight—that we only think deeply about things we care about—has important implications for education and pedagogy. It opens questions about how, when, and why students learn meaningfully (or just regurgitate facts and deploy procedures and algorithms, or possibly don't manage even those). It also raises issues about how technology, culture, and social relationships shape learning and how teachers can understand and leverage emotions more productively in the classroom. It suggests that, for school-based learning to have a hope of motivating students, of producing deep understanding, or of transferring into real-world skills—all hallmarks of meaningful learning, and all essential to producing informed, skilled, ethical, and reflective adults—we need to find ways to leverage the emotional aspects of learning in education.

To leverage emotions, it helps to understand what emotions are. Emotions, and the more biologically primitive drives that undergird them, such as hunger and sex, are action programs that have evolved as extensions of survival mechanisms. Put simply, emotions have evolved to keep us alive. Human beings have basic emotions, such as fear and disgust, to keep us off the edges of cliffs and to make us avoid spoiled food. We have social emotions such as love to make us affiliate, procreate, and care for our children. Thanks to our intelligent, plastic brain, we can also develop emotions that color and steer our intellectual and social endeavors, such as curiosity to make us explore and discover, admiration to make us emulate the virtue of others, and compassion, indignation, interest, and "flow" (Csíkszentmihályi, 1990).

These complex intellectual and social emotions are the subjective behavioral and mental reactions we have to situations and concepts of all sorts—reactions that play out in the body (e.g., through a racing heart) and in the mind through characteristic ways of thinking (e.g., searching for an escape route during fear, moving to help another person during compassion, or narrowing our attentional focus when we find something interesting). The feeling of these emotions organizes our sociality and morality, making us emulate role models, help those in need, or punish those who warrant it. It forms the basis for creativity and invention and for the decisions we make for now and for the future, even in academic contexts. For example, the act of dedicating one's professional life to teaching is possible only because of our ability to feel these emotions.

So, emotions evolved and are present in all complex creatures because they are essential to managing life. In humans, efficient life management means managing not just our physical survival but our social life and intellectual life. (These ideas derive from my work with Antonio Damasio; for seminal reading, see Damasio [1999] and Damasio and Carvalho [2013].) But where does the neurobiology come in? Among the most poignant and basic insights from affective neuroscience, the neuroscience of emotion, is that the emotions that regulate our sociocultural and intellectual lives appear to have co-opted the same neural systems that manage our survival in the basic biological sense. Just as poets and artists have suspected for millennia, we feel social relationships and appreciate intellectual achievements using the same brain systems that sense and regulate our guts and viscera, adjust our blood chemistry and hormones, and conjure our awareness and consciousness. No wonder our creations, reputations, cultural ideals, and personal relationships, including those in educational contexts, have such amazing psychological power.

But emotions have another dimension that is critically relevant to education. Complex emotional feelings, such as interest, inspiration, indignation, and compassion, are active mental constructions—they pertain not to the real physical context (the immediate context that we can see) but to abstract inferences, interpretations, and ideas. They pertain, in other words, to what we think we know about the world at the current time, interpreted in light of our past experiences and our imagined possible futures, using our available skills. When I say that many emotions are "complex," what I really mean is that they rely on subjective, cognitive interpretations of situations and their accompanying embodied reactions.

Even in academic subjects that are traditionally considered unemotional, such as physics, engineering, or math, deep understanding depends on making emotional connections between concepts. For example, one study using functional magnetic resonance imaging found that when mathematicians see equations that they judge to be "beautiful" and elegantly formulated instead of "ugly" and awkwardly formulated, they activate the same sensory, emotional brain region that activates during experiences of perceptual beauty, such as when admiring a painting (Zeki, Romaya, Benincasa, & Atiyah, 2014). In the Brain and Creativity Institute at the University of Southern California, we have found that this region also activates during experiences of moral beauty, such as those associated with feelings of admiration and compassion (Immordino-Yang, McColl, Damasio, & Damasio, 2009; see Chapter 9 for a description of this experiment). This and other evidence suggests that meaningful learning is actually about helping students to connect their isolated algorithmic skills to abstract, intrinsically emotional, subjective and meaningful experiences. Though supporting students in building these connections is a very hard job, it appears to be essential for the development of truly useful, transferable, intrinsically motivated learning.

In addition, emotions, like cognition, develop with maturity and experience. In this sense, emotions are skills—organized patterns of thoughts and behaviors that we actively construct in the moment and across our life spans to adaptively accommodate to various kinds of circumstances, including academic demands. (These ideas derive from my work with Kurt Fischer; for seminal reading, see Fischer and Bidell [2006].) The emotions of a preschooler are not the same as those of a fifth grader, a teenager, or a young or an older adult. The emotions of a brand new teacher are not the same as those of a veteran teacher. And even two people in the same developmental stage could construct different reactions to the same situation, sometimes substantially so. Why?

The reasons follow from emotion's survival-related roots and tie to emotion's centrality in learning. First, emotions involve automatic mental and bodily reactions to situations, and some people, cultural groups, and age groups are more reactive, or differently reactive, than others. For example, some individuals jump when startled, while others remain much calmer. These tendencies can also be influenced by culture; for instance, in many Asian cultures individuals strive to suppress their outward emotional displays, whereas in many Latino and Mediterranean cultures emotional expressiveness is valued. These differing ideals for emotion influence individuals' emotional behavior, including expression or suppression. In turn, our work suggests that by changing the magnitude of bodily reactions, cultural and individual differences in emotional expressiveness may affect what emotions "feel like"—how individuals know how they feel, or the subjective embodied quality of their feelings (Immordino-Yang, Yang, & Damasio, 2014).

Second, people learn through experience how to interpret situations, as well as how to make sense of their emotional reactions. Students' and teachers' emotion-laden interpretations and inferences, though often implicit or subconscious, form a central dimension of how they learn. The subjective inferences that individuals make, and their experiences of problem solving within an academic domain, imbue their memories and knowledge with emotional relevance. In the case described above, it was the mathematicians' subjective experience of thinking and solving problems within the mathematical domain that enabled them to appreciate certain equations as "beautiful." Their emotional reactions were possible only with an advanced level of technical expertise.

As we can see, understanding the role of emotions in learning goes far beyond recognizing the emotion a student is having *about* a situation in order to design learning environments that strategically manipulate students' reactions. For instance, giving candy to make children want to come to math class will not make students feel the joy of mathematical thinking. Instead, understanding emotions is also (and perhaps even more critically) about the *meaning* that students are making—that is, the ways in which students and teachers are *experiencing* or *feeling* their emotional reactions and how their feelings steer their thoughts and behavior, consciously or not. Emotions are

not add-ons that are distinct from cognitive skills. Instead emotions, such as interest, anxiety, frustration, excitement, or a sense of awe in beholding beauty, become a dimension of the skill itself. This is one reason that anxiety can be so debilitating to students' performance, that interest can precipitate a lifetime commitment to studying a topic, that kids have such trouble applying themselves when they don't know why they would ever use a skill outside of class, and that offering kids candy will make them like coming to class but will not help them learn to appreciate mathematical thinking.

Given the central role of emotion in learning, this book is about the early stage of my intellectual journey to explore the educational implications of my and others' research in affective and social neuroscience. I begin the book with three chapters that together sketch an account of how people feel in educational and other learning contexts—that is, of how the brain constructs conscious experiences with emotional meaning. These experiences can be memories for past events or information, the subjective feeling of what is happening now, or plans and imaginings for the future. Educators have long known that personal relevance is important for learning and that the ability to hold goals and dreams is critical to motivation and persistence. Likewise, the ability to consolidate memories for facts, procedures, and events into conceptual wholes—in short, to understand what one has learned—is critical for long-term retention and application of the knowledge in new contexts. But why, and how does this happen? In Part I of the book, I attempt to give insights into these issues.

In Part II, I present a collection of chapters that move toward implications for learning and teaching, including the network-based, dynamic nature of skill development (Chapter 4) and pedagogical strategies to support the development of experience-based intuitions (Chapter 5). Chapter 6 is a short essay meant to demonstrate the interdependence of emotion and cognition in one girl's poetry writing development. Chapters 7 and 8 take us to the story of two high-functioning young men, each of whom suffered the removal of an entire brain hemisphere to control severe seizures. These remarkable students' learning affords interesting insights into the role of emotions in organizing the recruitment of neuropsychological compensatory strengths. Chapter 9 discusses the importance of considering nonconscious emotional processing and the hooking of the conscious mind into nonconscious biological regulatory systems. Chapter 10 offers insights into the design of digital learning technologies by proposing that designers conceptualize our digitized devices as social partners with whom we must empathize to learn effectively.

A MESSAGE FOR TEACHERS: WHY I WROTE THIS BOOK, AND HOW TO READ IT

Though I was a teacher before I became a researcher, it is important to

recognize that this book does not presume to provide answers to specific educational dilemmas—recipes for teaching or the proverbial "what to do on Monday morning." Instead, my hope is that you will let the ideas in the book inform and enrich your reflections and discussions about learning and teaching. As an affective neuroscientist, my aim is to start a conversation in which together we create new knowledge about what learning in the real-world actually entails and how curricula can be designed to better honor your and your students' subjective experiences of learning. To this end, I have tried to present the scientific evidence in the most straightforward, accurate, and complete way that I can and to usefully and creatively synthesize and interpret the findings.

However, I also recognize that I am taking a risk in publishing this volume. The practical applications that derive from the science will never be completely straightforward because the real world is highly complicated, with many moving parts and hidden complexities. Nonetheless, I am emboldened to publish this collection for one main reason: scientific discovery is a process, and your voice is needed to shape that process. Many practicing teachers have told me that they are hungry for scientific insight into the role of emotion in learning. These teachers seek the background knowledge to engage parents, colleagues, administrators, policy makers, and scientists in critical exchanges. Many feel intuitively that emotions and social contexts are central to learning and believe that the neuroscientific evidence could catalyze, clarify, validate, or possibly falsify their intuitions. Throughout the book, via framing comments and other means, I have tried to provide handles for you to grab hold of. In the end, I have aimed to contribute a new perspective to the conversations around your worktables, that of affective social neuroscience. I ask you to think critically not just about my work but about your own and, indeed, about any evidence or policies used to justify educational strategies and designs. I hope that through your debates we will collaboratively create new understanding and better practice in education.

Finally, though my research is in affective social neuroscience, I remain, at heart, a human development psychologist. This basically means that I come from a tradition of scholars who work to understand human behavior "in the midst of things," with all of the real-world messiness that this entails. The ultimate aim is to understand how human behavior and thinking result from a dynamic integration of component processes in context. Good scientific research isolates processes for study. But it is equally important to bring the pieces back together to understand how the isolated processes contribute to little skills, ideas, and interactions between people and, in turn, to understand how those sum to describe whole, thinking, and acting people in a social, cultural world. To do this means striving to understand how both neurobiological and psychological functioning dynamically change, or "develop," in organized, adaptive patterns that reflect features of the social, physical, and cognitive contexts and characteristics and preferences of the individual. Ecological validity and individual variability, that is, understanding

what the scientific findings mean in the real world for real people, are of central interest. In essence, the work included in this book represents my attempt to bring ecological validity to the neuroscientific findings—to synthesize and interpret bodies of findings so that they may be useful in educational contexts.

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PART I

WHAT ARE EMOTIONAL FEELINGS, AND HOW ARE THEY SUPPORTED BY THE BRAIN?

CHAPTER 1

We Feel, Therefore We Learn: The Relevance of Affective and Social Neuroscience to Education

Mary Helen Immordino-Yang & Antonio R. Damasio

Chapter description: This chapter is the first paper I published with Antonio Damasio and my first attempt to reconcile what was known about learning in educational contexts with what his laboratory had shown from twenty years of research with patients with stroke and other kinds of acquired brain damage. In essence, this research with patients had uncovered a very interesting and unexpected finding: patients with certain types of brain damage could have preserved cognitive abilities (intelligence in the traditional sense of IQ) but be utterly unable to manage their lives on a day-to-day basis. Why? Because they could not adequately incorporate emotion into their thinking. Instead of becoming more rational and logical when their decisions were free from emotion, these patients did not care what other people thought of their behavior, were unable to learn from their past mistakes, and did not stop and change course when it became clear that their current actions were leading them astray. Critically, these patients had intact knowledge but had no sense of risk or morality and so would plow ahead into decisions that any "rational" person would find, at best, short-sighted or a waste of time and, at worst, dangerous, stupid, or immoral. Building from these patients and from classical insights about the fundamental role of emotions in readying the body for survival-relevant actions like fight, flight, or reproduction, Antonio Damasio and his team led the field into a new view of intelligence in which emotion and feelings of emotion-related bodily reactions are critical to steering thinking and decision making. They conceptualized emotions as a repertoire of know-how and actions that allows people to respond appropriately in different situations. They argued that, without emotion, all decisions and outcomes are equal—people can have no preferences, no interests, no motivation, no morality, and no sense of creativity, beauty, or purpose.

Here, we laid out the consequences of this insight for education. The basic premise is that when learning and knowledge are relatively devoid of emotion, when people learn things by "rote" without internally driven motivation and without a sense of interest or real-world relevance, then it is likely that they won't be able to use what they learn efficiently in the real world. Patients with lesions teach us that it is the emotional dimensions of knowledge that allow people to call up memories and skills that are relevant to whatever task is at hand. Without the appropriate emotions, individuals may have knowledge but they likely won't be able to use it effectively when

the situation requires. Emotions are, in essence, the rudder that steers thinking.

Recent advances in the neuroscience of emotions are highlighting connections between cognitive and emotional functions that have the potential to revolutionize our understanding of learning in the context of schools. In particular, connections between decision making, social functioning, and moral reasoning hold new promise for breakthroughs in understanding the role of emotion in decision making, the relationship between learning and emotion, how culture shapes learning, and ultimately the development of morality and human ethics. These are all topics of eminent importance to educators as they work to prepare skilled, informed, and ethical students who can navigate the world's social, moral, and cognitive challenges as citizens. In this article, we sketch a biological and evolutionary account of the relationship between emotion and rational thought, with the purpose of highlighting new connections between emotional, cognitive, and social functioning and presenting a framework that we hope will inspire further work on the critical role of emotion in education.

Modern biology reveals humans to be fundamentally emotional and social creatures. And yet, those in the field of education often fail to consider that the high-level cognitive skills taught in schools, including reasoning, decision making, and processes related to language, reading, and mathematics, do not function as rational, disembodied systems, somehow influenced by but detached from emotion and the body. Instead, these crowning evolutionary achievements are grounded in a long history of emotional functions, themselves deeply grounded in humble homeostatic beginnings. Any competent teacher recognizes that emotions and feelings affect students' performance and learning, as does the state of the body, such as how well students have slept and eaten, or whether they are feeling sick or well. We contend, however, that the relationship between learning, emotion, and body state runs much deeper than many educators realize and is interwoven with the notion of learning itself. It is not that emotions rule our cognition, or that rational thought does not exist. It is, rather, that the original purpose for which our brains evolved was to manage our physiology, to optimize our survival, and to allow us to flourish. When one considers that this purpose inherently involves monitoring and altering the state of the body and mind in increasingly complex ways, one can appreciate that emotions, which play out in the body and mind, are profoundly intertwined with thought. And after all, this should not be surprising. Complex brains could not have evolved separately from the organisms they were meant to regulate.

But there is another layer to the problem of surviving and flourishing, which probably evolved as a specialized aspect of the relationship between emotion and learning. As brains and the minds they support became more complex, the problem became not only that of dealing with one's own self but also that of managing social interactions and relationships. The evolution of human societies has produced an amazingly complex social and cultural context, and flourishing within this context means that only our most trivial, routine decisions and actions, and perhaps not even these, occur outside of our socially and culturally constructed reality. Why does a high school student solve a math problem, for

example? The reasons range from the intrinsic reward of having found the solution, to getting a good grade, to avoiding punishment, to helping tutor a friend, to getting into a good college, to pleasing her parents or the teacher. All of these reasons have a powerful emotional component and relate both to pleasurable sensations and to survival within our culture. Although the notion of surviving and flourishing is interpreted in a cultural and social framework at this late stage in evolution, our brains still bear evidence of their original purpose: to manage our bodies and minds in the service of living, and living happily, in the world with other people.

This realization has several important implications for research at the nexus of education and neuroscience. It points to new directions for understanding the interface of biology, learning, and culture, a critical topic in education that has proven difficult to investigate systematically (Davis, 2003; Rueda, 2006; Rueda, August, & Goldenberg, 2006). It promises to shed light on the elusive link between body and mind, for it describes how the health and sickness of the brain and body can influence each other. And, importantly, it underscores our fundamentally social nature, making clear that the very neurobiological systems that support our social interactions and relationships are recruited for the often covert and private decision making that underlies much of our thought. In brief, learning, in the complex sense in which it happens in schools or the real world, is not a rational or disembodied process; neither is it a lonely one.

REASONING, DECISION MAKING, AND EMOTION: EVIDENCE FROM PATIENTS WITH BRAIN DAMAGE

To understand why this is so, we begin with some history, and a problem. Well into the 1980s, the study of brain systems underlying behavior and cognition was heavily dominated by a top-down approach in which the processes of learning, language, and reasoning were understood as high-order systems that imposed themselves upon an obedient body. It is not that emotions were completely ignored, or that they were not viewed by some as having a brain basis. Rather, their critical role in governing behavior, and in particular rational thought, was overlooked (Damasio, 1994). Emotions were like a toddler in a china shop, interfering with the orderly rows of stemware on the shelves.

And then an interesting problem emerged. In a research atmosphere in which cognition ruled supreme, it became apparent that the irrational behavior of neurological patients who had sustained lesions to a particular sector of the frontal lobe could not be adequately accounted for by invoking cognitive mechanisms alone. After sustaining damage to the ventromedial prefrontal cortex (VMPF), these patients' social behavior was compromised, making them oblivious to the consequences of their actions, insensitive to others' emotions, and unable to learn from their mistakes. In some instances, these patients violated social convention and even ethical rules, failing to show embarrassment when it was due and failing to provide appropriate sympathetic support to those who expected it and had received it in the past.

These patients' ability to make advantageous decisions became compromised in ways that it had not been before. In fact, there was a complete separation

between the period that anteceded the onset of the lesion, when these patients had been upstanding, reliable, and foresightful citizens, and the period thereafter, when they would make decisions that were often disadvantageous to themselves and their families. They would not perform adequately in their jobs, in spite of having the required skills; they would make poor business deals in spite of knowing the risks involved; they would lose their savings and choose the wrong partners in all sorts of relationships. Why would patients suffering from compromised social conduct also make poor decisions about apparently rational matters, such as business investments?

The traditional way to explain these patients' symptoms had been that something had gone wrong with their logical abilities or their knowledge base, such that they could no longer make decisions in a rational way. But, in fact, with further testing, it became apparent that these patients did not have a primary problem with knowledge, knowledge access, or logical reasoning, as had previously been assumed. To the contrary, they could explain cogently the conventional social and logical rules that ought to guide one's behavior and future planning. They had no loss of knowledge or lowering of IQ in the traditional sense. Instead, it gradually became clear that disturbances in the realm of emotion, which had been viewed as a secondary consequence of their brain damage, could provide a better account of their poor decision making. Those emotional aspects included a diminished resonance of emotional reactions generally, as well as a specific compromise of social emotions, such as compassion, embarrassment, and guilt. By compromising the possibility of evoking emotions associated with certain past situations, decision options, and outcomes, the patients became unable to select the most appropriate response based on their past experience. Their logic and knowledge could be intact, but they failed to use past emotional knowledge to guide the reasoning process. Furthermore, they could no longer learn from the emotional repercussions of their decisions or respond emotionally to the reactions of their social partners. Their reasoning was flawed because the emotions and social considerations that underlie good reasoning were compromised (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; Damasio, Tranel, & Damasio, 1990, 1991).

In retrospect, these patients provided a first glimpse into the fundamental role of emotion in reasoning and decision making. They were missing a brain region that is now understood as needed to trigger a cascade of neurological and somatic events that together comprise a social emotion, such as embarrassment, compassion, envy, or admiration, and their social behavior suffered. This is significant in itself, but even more intriguing was the realization that without the ability to adequately access the guiding intuitions that accrue through emotional learning and social feedback, decision making and rational thought became compromised, as did learning from their mistakes and successes. While these patients can reason logically and ethically about standard cognitive and social problems in a laboratory setting (Saver & Damasio, 1991), out in the real world and in real time they cannot use emotional information to decide between alternative courses of action. They can no longer adequately consider previous rewards and punishments, successes and failures, nor do they notice others' praise or disapproval. These patients have lost their ability to analyze events for their emotional consequences and to tag memories of these events accordingly.

Their emotions are dissociated from their rational thought, resulting in compromised reason, decision making, and learning.

What does this mean for our argument about relevance to education? In addition to data from these patients, further evidence from psychophysiological and other studies of brain-damaged and normal people has allowed us to propose specific neural mechanisms underlying the role and operation of emotional signaling in normal and abnormal decision making (Bechara, 2005; Bechara & Damasio, 1997; Damasio, 1996). While the details of these neural mechanisms and evidence are beyond the scope of this article, taken as a whole they show that emotions are not just messy toddlers in a china shop, running around breaking and obscuring delicate cognitive glassware. Instead, they are more like the shelves underlying the glassware; without them cognition has less support.

To recap, the patients with prefrontal lesions we have described have social deficits. We have argued that these are fundamentally problems of emotion and therefore manifest as well in the realm of decision making. The relationship between these symptoms is very informative, in that it suggests that hidden emotional processes underlie our apparently rational real-world decision making and learning. Furthermore, this relationship underscores the importance of the ability to perceive and incorporate social feedback in learning.

While the relevance of these insights to educational contexts has not yet been empirically tested, they lead us to formulate two important hypotheses. First, because these findings underscore the critical role of emotion in bringing previously acquired knowledge to inform real-world decision making in social contexts, they suggest the intriguing possibility that emotional processes are required for the skills and knowledge acquired in school to transfer to novel situations and to real life. That is, emotion may play a vital role in helping children decide when and how to apply what they have learned in school to the rest of their lives. Second, the close ties between these patients' decision making, emotion, and social functioning may provide a new take on the relationship between biology and culture. Specifically, it may be via an emotional route that the social influences of culture come to shape learning, thought, and behavior.

While more work on the educational and cultural implications of these findings is warranted, interestingly, and sadly, some further insights into the biological connections between learning, emotion, and social functioning, especially as they relate to our hypothesis about culture, can be gleaned from another group of patients that has been discovered over the past few years. In this group, patients sustained comparable prefrontal damage in early childhood, rather than as adults. As they developed, these children were cognitively normal in the traditional IQ sense, able to use logical reasoning and factual knowledge to solve the kinds of academic problems expected of students. However, while smart in the everyday sense of the word, these children slowly revealed themselves to have varying degrees of psychopathic and antisocial tendencies. They were insensitive to punishment and reward and did not seek approval or social acceptance as typical children do. As adults, they are unable to competently manage their lives, wasting time, squandering resources, and engaging in dangerous, antisocial, and aggressive behaviors. By outward appearances, these patients behave in most ways similarly to the patients described above, who sustained prefrontal damage as adults (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; H. Damasio,

2005).

Additional investigation of adult patients with childhood-onset brain damage, though, revealed an intriguing difference between childhood- and adult-onset prefrontal brain damage. While both groups can reason about traditional cognitive problems in the structure of the laboratory setting, and both have normal IQs in the traditional sense, unlike patients with adult-onset prefrontal damage, childhood-onset patients appear never to have learned the rules that govern social and moral behavior. While adult-onset patients know right from wrong in the lab but are unable to use this information to guide their behavior, childhood-onset patients have apparently not learned right from wrong or the proper rules of social conduct. They do not know the social and ethical rules that they are breaking.

What is happening with these patients, and how is it relevant to the argument at hand? Unlike the often remarkable compensation for linguistic and other capacities after early childhood brain damage, so far the system for social conduct and ethical behavior does not show this kind of compensation. It is not that access in an abstract sense to the rules of social conduct requires intact frontal cortices, as the adult-onset patients show, and it is not that a social or moral conduct center in the brain has been irreparably damaged, because this scenario would not explain changes in general decision-making. Instead, the situation is both simpler and more grave. These early-onset prefrontal patients may be suffering from the loss of what we might term the “emotional rudder.” Without the ability to manipulate situations and to mark those situations as positive or negative from an affective point of view, these children fail to learn normal social behavior. In turn, they lose the commensurate decision-making abilities described earlier. Insensitive to others’ responses to their actions, these children fail to respond to educators’ and others’ attempts to teach them normal behavior.

But there is another intriguing piece to be learned from these children regarding the relationship between cognition and emotion, and the role of the “emotional rudder” in learning. As in the adult-onset patients, it is still possible for these patients to have an operating cognitive system that allows them to be smart on certain measures and in certain contexts, solving standard cognitive tasks in a laboratory or structured educational setting without difficulty. In these contexts, their lack of knowledge is confined to the social and moral domains.

And yet, once outside of the structured school setting, their social deficits manifest as a much broader problem. They have the nonsocial knowledge they need, but without the guiding effects of the emotional rudder they cannot use this information to guide their everyday living, even in nonsocial contexts. What these patients confirm is that the very neurobiological systems that support emotional functioning in social interactions also support decision making generally. Without adequate access to social and cultural knowledge, these children cannot use their knowledge efficaciously. As the psychologist Lev Vygotsky posited more than three quarters of a century ago, social and cultural functioning actually does underlie much of our nonsocial decision making and reasoning. Or, more precisely, social behavior turns out to be a special case of decision making, and morality to be a special case of social behavior (see A. R. Damasio, 2005, for a more complete treatment of this argument). The neurological systems that support decision making generally are the same systems that support social and moral behavior. Without adequate access to emotional, social, and moral feedback, in

effect the important elements of culture, learning cannot inform real-world functioning as effectively.

A PHYSIOLOGICAL AND EVOLUTIONARY ACCOUNT OF EMOTION AND COGNITION: FROM AUTOMATIC RESPONSES TO MORALITY, CREATIVITY, HIGH REASON, AND CULTURE

In the perspective of the insights described earlier, and of much research in neurobiology and general biology in the two intervening decades, the connection between emotion and cognition is being seen in a very different light. To outline the current position, we shall present a simple scenario. Think of an ant crawling along a sidewalk, carrying a piece of food back to its nest. The ant scurries into a sidewalk crack to avoid being stepped on and then continues industriously on its way. What motivates this ant to preserve its own life? How did it decide, albeit nonconsciously and automatically, to carry the piece of food and to turn toward its nest? Clearly, the decisions to hide to avoid being crushed, to carry the food, and to continue in the direction of the nest are primitive instances of cognition, composed of complex packages of innate responses that enable the ant to react advantageously to particular classes of situations. But what is essential to understand is that these and myriads of other primitive examples of cognition, even in the lowly ant, act together in the service of an emotional goal: to maintain and promote homeostasis and thus fitness. In short, the ant behaves the way it does because those behaviors promote its survival and efficiency. (Humans, as conscious beings, perceive that efficiency as well-being and pleasure.) Every action the ant takes is inherently biased toward helping the ant, or its group, do well.

Taking an evolutionary perspective, even the simplest unicellular organism has within the nucleus of its cell a master controller that permits that living organism to maintain itself for a certain span of life and to seek during that period the conditions that will allow it to thrive. Emotions and the mechanisms that constitute them as behaviors, which humans experience as resulting in punishment or reward, pain or pleasure, are, in essence, nature's answer to one central problem, that of surviving and flourishing in an ambivalent world. Put simply, the brain has evolved under numerous pressures and oppressions precisely to cope with the problem of reading the body's condition and responding accordingly, and it begins doing so via the machinery of emotion. This coping shows up in simple ways in simple organisms and in remarkably rich ways as brains get more complex. In the brains of higher animals and in people, the richness is such that they can perceive the world through sensory processing and control their behavior in a way that includes what is traditionally called the mind. Out of the basic need to survive and flourish derives a way of dealing with thoughts, with ideas, and eventually with making plans, using imagination, and creating. At their core, all of these complex and artful human behaviors, the sorts of behaviors fostered in education, are carried out in the service of managing life within a culture and, as such, employ emotional strategies (Damasio, 1999).

Emotion, then, is a basic form of decision making, a repertoire of know-how and actions that allows people to respond appropriately in different situations. The

more advanced cognition becomes, the more high-level reasoning supports the customization of these responses, both in thought and in action. With evolution and development, the specifications of conditions to which people respond, and the modes of response at their disposal, become increasingly nuanced. The more people develop and educate themselves, the more they refine their behavioral and cognitive options. In fact, one could argue that the chief purpose of education is to cultivate children's building repertoires of cognitive and behavioral strategies and options, helping them to recognize the complexity of situations and to respond in increasingly flexible, sophisticated, and creative ways. In our view, out of these processes of recognizing and responding, the very processes that form the interface between cognition and emotion, emerge the origins of creativity—the artistic, scientific, and technological innovations that are unique to our species. Further, out of these same kinds of processing emerges a special kind of human innovation: the social creativity that we call morality and ethical thought.

As the childhood-onset prefrontal patients show, morality and ethical decision making are special cases of social and emotional functioning. While the beginnings of altruism, compassion, and other notions of social equity exist in simpler forms in the nonhuman primates (Damasio, 2003; Hauser, 2006), human cognitive and emotional abilities far outpace those of the other animals. Our collective accomplishments range from the elevating and awe-inspiring to the evil and grotesque. Human ethics and morality are direct evidence that we are able to move beyond the opportunistic ambivalence of nature; indeed, the hallmark of ethical action is the inhibition of immediately advantageous or profitable solutions in the favor of what is good or right within our cultural frame of reference. In this way, ethical decision making represents a pinnacle cognitive and emotional achievement of humans. At its best, ethical decision making weaves together emotion, high reasoning, creativity, and social functioning, all in a cultural context (Gardner, Csikszentmihaly, & Damon, 2001).

Returning to the example of the ant: Our purpose in including this example was not to suggest that human emotions are equivalent to those of the ant, or that human behavior can be reduced to simple, nonspecific packages that unfold purely nonconsciously in response to particular situations. Although some aspects of human behavior and emotion could be characterized in this way, such reductionism would be grossly misplaced, especially in an essay about connections to education. Instead we aimed to illustrate that most, if not all, human decisions, behaviors, thoughts, and creations, no matter how far removed from survival in the homeostatic sense, bear the shadow of their emotive start.

In addition, as the prefrontal patients show, the processes of recognizing and responding to complex situations, which we suggest hold the origins of creativity, are fundamentally emotional and social. As such, they are shaped by and evaluated within a cultural context and, as we described in the previous section, are based upon emotional processing. No matter how complex and esoteric they become, our repertoire of behavioral and cognitive options continues to exist in the service of emotional goals. Neurobiologically and evolutionarily speaking, creativity is a means to survive and flourish in a social and cultural context, a statement that appears to apply from the relatively banal circumstances of daily living to the complex arena of ethical thought and behavior. In beginning to elucidate the neurobiological interdependencies between high reasoning, ethics, and creativity,

all of which are fundamentally tied to emotion and critically relevant to education, we hope to provide a new vantage point from which to investigate the development and nurturance of these processes in schools.

EMOTIONAL THOUGHT: TOWARD AN EVIDENCE-BASED FRAMEWORK

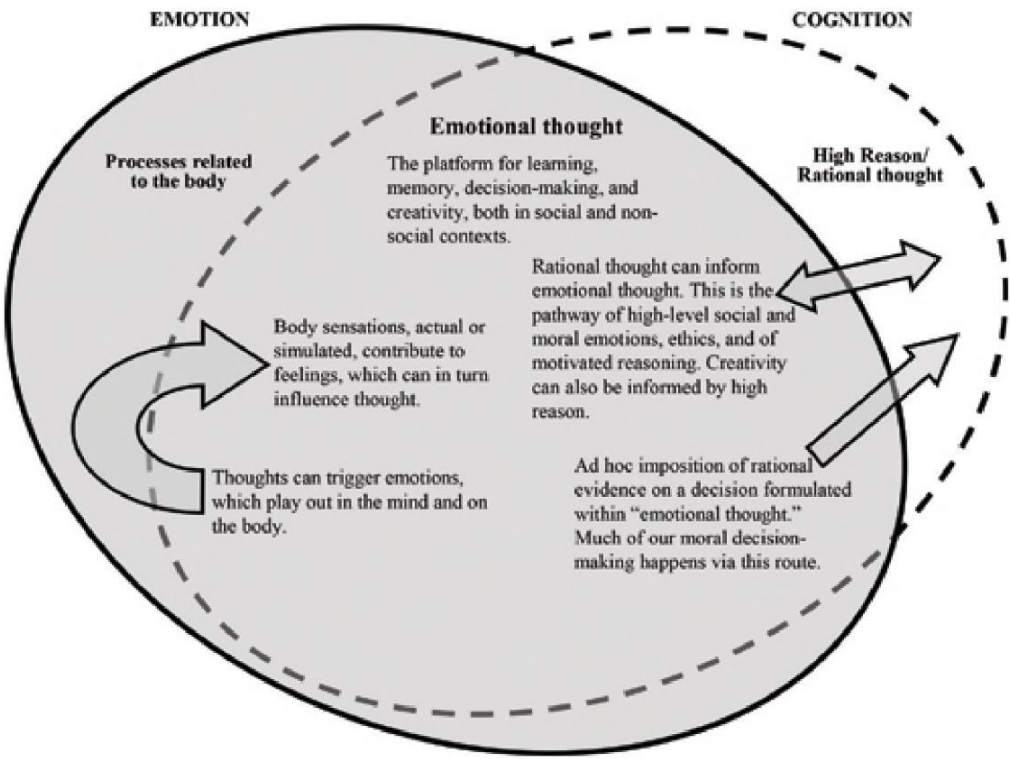
In general, cognition and emotion are regarded as two interrelated aspects of human functioning. However, while it is perfectly reasonable and in fact necessary to distinguish between these two aspects in studying learning and development (Fischer & Bidell, 1998), the overly stringent preservation of this dichotomy may actually obscure the fact that emotions comprise cognitive as well as sensory processes. Furthermore, the aspects of cognition that are recruited most heavily in education, including learning, attention, memory, decision making, motivation, and social functioning, are both profoundly affected by emotion and in fact subsumed within the processes of emotion. Emotions entail the perception of an emotionally competent trigger, a situation either real or imagined that has the power to induce an emotion, as well as a chain of physiological events that will enable changes in both the body and mind (Damasio, 1994). These changes in the mind—involving focusing of attention, calling up of relevant memories, and learning the associations between events and their outcomes, among other things—are the processes with which education is most concerned. Yes, rational thought and logical reasoning do exist, although hardly ever truly devoid of emotion, but they cannot be recruited appropriately and usefully in the real world without emotion. Emotions help to direct our reasoning into the sector of knowledge that is relevant to the current situation or problem.

In Figure 1.1 we provide a graphical depiction of the neurological relationship between cognition and emotion. In the diagram, we have used the term *emotional thought* to refer to the large overlap between cognition and emotion. Emotional thought encompasses processes of learning, memory, and decision making, in both social and nonsocial contexts. It is within the domain of emotional thought that creativity plays out, through increasingly nuanced recognition of complex dilemmas and situations and through the invention of correspondingly flexible and innovative responses. Both the recognition and response aspects of creativity can be informed by rational thought and high reason. In our model, recognition and response processes are much like the concepts of assimilation and accommodation proposed by Piaget (1936/1952, 1937/1954). However, Piaget focused almost exclusively on cognition and the development of logic, and although he recognized a role for emotion in child development (Piaget, 1953–1954/1981), he did not fully appreciate the fundamentally emotional nature of the processes he described.

In the diagram, high reason and rational thought also contribute to high-level social and moral emotions, to form the specialized branch of decision making that is ethics. Motivated reasoning works in a similar manner and refers to the process by which emotional thoughts gain additional significance through the application of rational evidence and knowledge. In the other direction, rational evidence can be imposed upon certain kinds of emotional thought to produce the sort of automatic moral decision making that underlies intuitive notions of good and evil (Greene,

Nystrom, Engell, Darley, & Cohen, 2004; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001; Haidt, 2001). For example, in evaluating the morality of incest, experimental evidence suggests that people decide quickly at the subconscious and intuitive level and later impose ad hoc rational evidence on their decision (Haidt, 2001). Conversely, complex moral dilemmas such as whether to send a nation to war are (one hopes) informed by an abundance of rational evidence.

FIGURE 1.1. The evolutionary shadow cast by emotion over cognition influences the modern mind. In the diagram, the solid ellipse represents emotion; the dashed ellipse represents cognition. The extensive overlap between the two ellipses represents the domain of "emotional thought," in which emotion and cognition come together to produce the thought processes that educators care about, among them learning and memory. Emotional thought can be conscious or non-conscious, and is the means by which emotion-related bodily sensations come into our conscious awareness. High reason is a small section of the diagram, and requires consciousness. Reprinted with permission from Immordino-Yang and Damasio (2007).



On the left side of the diagram, the bodily aspects of emotion are represented as a loop from emotional thought to the body and back. Here, emotional thoughts, either conscious or nonconscious, can alter the state of the body in characteristic ways, such as by tensing or relaxing the skeletal muscles or by changing the heart rate. In turn, the bodily sensations of these changes, either actual or simulated, contribute either consciously or nonconsciously to feelings, which can then influence thought. (*Simulated body sensation* refers to the fact that sometimes

imagining bodily changes is sufficient; actually tensing the fists, for example, is not necessary.) This is the route by which rational deliberations over, say, a nation's wartime decisions can produce high-level social emotions such as indignation, as well as the bodily manifestations of these emotions, such as tensed fists, increased heart rate, or loss of appetite. The feeling of these bodily sensations, either consciously or not, can then bias cognitive processes such as attention and memory toward, in this case, aggression. The end result may be an unprovoked argument with one's friend over a topic totally unrelated to the war, the creation of a bleak and angry abstract painting, or a generally tense mood.

In addition to the evidence discussed above, support for these relationships between the body, emotion, and cognition comes mainly from neurobiological and psychophysiological research, in which the induction of emotion, either directly by a stimulus in the environment or indirectly via thoughts or memories, causes mental changes as well as physiological effects on the body. In turn, feelings of emotion rely on the somatosensory systems of the brain. That is, the brain areas associated with interoception (the sensing of body states) are particularly active as people feel emotions such as happiness, fear, anger, or sadness (Damasio et al., 2000).

To conclude, in presenting this model, our goal is not to devalue established notions of cognition and emotion but to provide a biologically based account of this relationship and to begin to specify the nature of the overlap between cognition and emotion in a way that highlights processes relevant to education. These processes include learning, memory, decision making, and creativity, as well as high reason and rational thinking. They also include the influence of the mind on the body and of the body on the mind.

EDUCATIONAL IMPLICATIONS: A CALL FOR FURTHER RESEARCH

In teaching children, the focus is often on the logical reasoning skills and factual knowledge that are the most direct indicators of educational success. But there are two problems with this approach. First, neither learning nor recall happens in a purely rational domain, divorced from emotion, even though some of our knowledge will eventually distill into a moderately rational, unemotional form. Second, in teaching students to minimize the emotional aspects of their academic curriculum and function as much as possible in the rational domain, educators may be encouraging students to develop the sorts of knowledge that inherently do not transfer well to real-world situations. As both the early- and late-acquired prefrontal damage patients show, knowledge and reasoning divorced from emotional implications and learning lack meaning and motivation and are of little use in the real world. Simply having the knowledge does not imply that a student will be able to use it advantageously outside of school.

As recent advances in the neurobiology of emotions reveal, in the real world cognition functions in the service of life-regulating goals, implemented by emotional machinery. Moreover, people's thoughts and feelings are evaluated within a sociocultural context and serve to help them survive and flourish in a social, rather than simply opportunistic, world. While the idea that learning happens in a cultural context is far from new (Tomasello, Carpenter, Call, Behne,

& Moll, 2005), we hope that these new insights from neurobiology, which shed light on the nested relationships between emotion, cognition, decision making, and social functioning, will provide a jumping off point for new thinking on the role of emotion in education. As educators have long known, it is simply not enough for students to master knowledge and logical reasoning skills in the traditional academic sense. They must be able to choose among and recruit these skills and knowledge usefully outside of the structured context of a school or laboratory. Because these choices are grounded in emotion and emotional thought, the physiology of emotion and its consequent process of feeling have enormous repercussions for the way we learn and for the way we consolidate and access knowledge. The better educators come to understand the nature of the relationship between emotion and cognition, the better they may be able to leverage this relationship in the design of learning environments.

In conclusion, new neurobiological evidence regarding the fundamental role of emotion in cognition holds the potential for important innovations in the science of learning and the practice of teaching. As researchers struggle with new directions and techniques for learning about these connections, a biological framework may help to constrain possibilities and generate new hypotheses and research directions. Just as neuroscience is coming to inform other education-related topics and problems (Goswami, 2006), the study of emotions, creativity, and culture is ripe for interdisciplinary collaborations among neuroscientists, psychologists, and educators. After all, we humans cannot divorce ourselves from our biology, nor can we ignore the high-level sociocultural and cognitive forces that make us special within the animal kingdom. When educators fail to appreciate the importance of students' emotions, they fail to appreciate a critical force in students' learning. One could argue, in fact, that they fail to appreciate the very reason that students learn at all.

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