"'The Art of Changing the Brain' *is* teaching. Zull argues that educators can use knowledge about the brain to enhance pedagogical techniques. He does an excellent job of demonstrating his thesis by describing good approaches: e.g., increasing reception of information by enhancing the sensory aspects of teaching materials; taking advantage of integrative mechanisms by allowing time for reflection; maximizing the adaptive functions of the brain by challenging students to be creative; using action areas of the brain by providing activities to confirm and extend learning. Teachers need to recognize that motivational-emotional systems of the brain modulate cognitive functions and that pedagogies [that] attempt to force students to learn in ways that violate brain mechanisms are likely to be counterproductive. Zull's years of experience as both professor of biology and director of a university teaching institute are apparent; the book is well written and appropriately technical for the audience interested in applying current knowledge about the brain to learning and instructing. Highly recommended."

—*Choice*

"Writing for all educators, [Zull's] theme is that a better understanding of brain function will promote a more flexible and varied approach to learning. The results offer a refreshing clarity. [In] his fine book . . . Zull has done a remarkable job of simplifying both brain function and learning processes. It is a synthesis of what we know about the brain and about learning, a synthesis that simplifies both fields to draw a usable map of the terrain of learning. I encourage educators at all levels to grapple with Zull's model . . . and integrate his insights with their own experience and understanding of the learning process. A work like *The Art of Changing the Brain* has long been needed."

—Pierce J. Howard,

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To my mother, Eileen Gates, who showed me the joy of learning—and living —throughout my life

Published in 2002 by

Stylus Publishing, LLC
22883 Quicksilver Drive
Sterling, Virginia 20166

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Library of Congress Cataloging-in-Publication Data

Zull, James E. (James Elwood), 1939–
The art of changing the brain : enriching teaching by exploring the biology of learning / James E. Zull—1st ed. p. cm.
Includes bibliographical references.
ISBN 1-57922-053-3 (hardcover : alk. paper)
—ISBN 1-57922-054-1 (pbk. : alk paper)
1. Learning, Psychology of. 2. Learning—Physiological aspects. 3. Brain. 4. Teaching—Psychological aspects. I. Title.

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ACKNOWLEDGMENTS

Some critics warned me that this book could not be written, or should not. And it didn't take long for me to discover good reasons for these warnings. The opportunities to make mistakes are unending. And I am sure I have taken advantage of a large number of them, despite striving to avoid doing so.

I apologize for these inevitable, but presently undetected, errors of content and interpretation. However, there would be many more were it not for the support of many dear and honest friends and critics.

Beginning with my colleagues at Case Western Reserve, I must first thank David and Alice Kolb. It was David's work and profound insights on human learning that triggered the very conception of the book. Once Alice showed up on the scene, she gave me such encouragement that my periodic instincts to abort were forgotten. I also thank Mano Singham, who is wiser about teaching than anyone I know and who cheerfully and analytically helped me keep my message on target for teachers. Lyn Turkstra read every chapter and covered the pages with comments as she gently but firmly guided me around the territory of the brain. In addition, Hillel Chiel, Alison Hall, David Katz, and Peter Whitehouse all added to my knowledge of the brain.

I am also indebted to my friends and colleagues in the Mind, Brain, and Education Program at the Harvard Graduate School of Education. Their support, insightful criticism, and personal engagement extended far beyond what I had any right to expect. I especially thank Kurt Fischer and Howard Gardner who both encouraged me at crucial times

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during my brief sabbatical at Harvard. I also got valuable insights from Marc Schwartz through his work on science education for middle school children. First among the students at Harvard is Juliana Paré-Bagolev, who read most chapters and gave many hours of her time, all the while continuing her own teaching and brain-imaging research on dyslexia and bringing a new child into the world. Other students who gave me valuable feedback are Mary Helen Immordino-Yang, whose comments prompted me to completely rewrite chapter 1, and Mike Connell, whose observations on certain chapters led to important changes and additions.

Kathy Schuh at the University of Iowa also critiqued parts of the book, and her comments deepened my understanding. I also am grateful to Neil Fleming, my New Zealand partner in thinking about teaching. His decades of accumulated wisdom proved invaluable in helping me clarify confusing places in the book, and the extensive and detailed critiques he produced represented an expenditure of time and effort that both surprised and humbled me.

My publisher, John von Knorring, first encouraged me to write a book on education and the brain and then stuck with me through several abortive efforts, in which I did not respect the task enough. When I finally began to make progress, he was first in line encouraging me and urging me on to publication. For all this and for his ability to distinguish good from bad, I am grateful. I also thank Larry Goldberg, my editor, and his team at Shepherd Incorporated, for their personal interest and careful work. It always seemed that this project was more than just a job to them.

I find myself groping for the right words to thank my family. I am amazed at their patience when I forgot important engagements and other responsibilities, while totally engrossed in writing or, worse, dreaming. I especially thank my wife, Susan, for the weekends sacrificed and the innumerable blank stares tolerated as I, lost in my theories, failed to hold up my end of the conversation. I never felt more support, and sometimes never more selfish, as she allowed me, indeed encouraged me, to pursue

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my ideas. This generosity and love continually reminded me that, no matter how it may have seemed at critical moments, in the end she is the best idea I ever pursued.

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INTRODUCTION

A NEW PERSPECTIVE, SOME STRUGGLES, AND A HOPE

Learning is about biology. Only living things learn.

This obvious fact has been lurking just beneath our consciousness for a long time. It is why teachers felt excited as neuroscience blossomed in the past few decades. And it is why some predicted a revolution in education, once we found out how the brain works.

But as science gave us more information, teachers began to realize that this did not automatically produce better education. Neuroscientists could not tell us how to teach. In fact, biologists still pay little attention to our concerns. They are excited about science, not about education.

This means that, to a great extent, educators have been left to interpret neuroscience on their own. There is virtually nothing on this topic written by scientists, which is one reason I decided to write this book. There was a gap waiting to be filled.

But revolution is not my goal. There is no reason to abandon the good practices that cognitive science and education research have given us. Rather, I hope to deepen and enrich our understanding of these practices. Biology can enrich what we already do.

This enrichment comes, to a great extent, from the perspective that biology provides for the teacher. Often, our perspective of teaching is from above. We view the learner as needing our help, which we hand down to him. From this perspective we can forget that the actual learning takes place down there in the brain and body of the learner. When we turn this around and begin to ask about the learning itself, we

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may see things differently. We may see both ourselves and our students as the biological creatures we are, and this more grounded perspective is what ultimately enriches us.

* * *

Let me briefly explain some challenges the book presented, and how I tried to deal with them.

When my friends first heard the title of my book, some of them reacted strongly. One remarked that her first thought was of “mind control.” Another said, “It sounds aggressive! Are we really going after their brains?”

Although these comments seemed a little extreme, they did give me pause. I even considered changing the title. But I couldn’t bear the thought that you might look at my book, there on the shelf, read the title, and completely miss the main message.

This main message is that *learning is change.* It is change in ourselves, because it is change in the brain. Thus the art of teaching must be the art of changing the brain. At least this much should be up front.

Another struggle was the question of defining learning. I was advised that I must tell the reader what I mean by learning. Someplace in the book I must give my definition. But I have not done so. Or, at least, you will not find a particular place in the book where I focus on a definition.

I had two reasons for this decision. First, I came to feel that inventing a definition would make more trouble than it was worth. Such definitions, in themselves, can need explaining, and the last thing I needed was to sow further confusion or add to the explaining.

Second, one of my goals is for you to find your own definition of learning. Learning is about change, and it is change. It is a living, growing thing that comes through different routes and leads to different ends as our lives evolve and grow. I cannot even say that I have yet defined it, but I am *developing* a definition. And I am content for you to feel the same. If you find your own definition changing as you read, you

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will understand the life in learning, and you may want to put off constructing your own definition, at least for a while.

When they looked at my manuscript, my friends in the learning and education field sometimes wanted to define me. This became another struggle. Am I a constructivist, an associationist, or a traditionalist? Where do my allies lie in the learning debates, if I have any?

If you are inclined to ask that question, let me suggest that you read more than one or two chapters before you decide. I am not sure where I fit, and it could be that I am simply a misfit. I say this because my starting point is always biology. I just go where biology leads me. Sometimes what I see is rather traditional, and sometimes it is far out on the wings of constructivism. Or it might be something quite different from either. But I don't care, as long as I believe I have been faithful to the biology. In the end, I am a biologist.

This question of defining things also is apparent in the way I speak of "brain science" or "brain research." You will find that I jump around a lot between cognitive science, cognitive neuroscience, and neuroscience without paying much attention to the terms at all. I have just been sloppy about this.

There is a reason for this sloppiness. I have come to distrust the definitions of disciplines that we invent as our knowledge grows. These definitions are useful for the experts but can be confusing to others. And they may imply divisions and differences that don't really exist. Even experts get caught up in this, sometimes arguing fiercely that something is really "cognitive" rather than "neuronal."

The teachers who read my manuscript sometimes wanted more specifics. Exactly what should teachers *do* in order to "change the brain"? My instinct was to shy away from making suggestions, but I didn't always follow that instinct. So you will find some specific ideas, especially in chapters 6 and 7, and I frequently mention things that I have tried or would like to try. But I still don't have a lot of faith in giving directions to teachers. In fact, I have often noticed that when

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teachers start telling other teachers how to solve their problems, things can quickly get tense. For the most part, we seem to want to solve our own problems, and I am happy to leave it that way.

I also struggled to keep the book at a reasonable length. This sometimes meant that I could only mention a topic or idea that really deserved much more attention. I often felt frustrated with what I wasn't saying! I tried to rectify this with endnotes, which occasionally became quite lengthy, or by referencing a specific article where the science details can be found. So if you find yourself frustrated or impatient with something, it is possible that you may find what you need, or part of what you need, in these notes.

Finally, I am particularly sensitive to the reactions of my biology and neuroscience colleagues. You may feel that my biological generalizations are inadequate or even misleading. I only touch the surface of our knowledge about nervous systems. This is necessary, and I have worked hard to be accurate, but if you still cannot forgive me, at least you should know that I am fully aware of this shortcoming.

* * *

Let me end this introduction by telling you about a hope. When I first started, I wanted the book to be brilliant. I was sure that my ideas were unique and important. But along the way, I have been rightly humbled. This subject is majestic and my brain isn't.

But it wasn't humility that led me to change my hopes: it was my recognition of a bigger goal. It came to me when, after one of my workshops, a teacher came up to me and said, "I am going to change how I teach. This was so useful!"

What a rush! Someone found my ideas useful. And I realized that, in the end, this is what matters the most. The greatest testament is to have my ideas applied: to have been *useful.*

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1

THE SWEET EDGE

LEARNING IS PHYSICAL—WE CAN UNDERSTAND!

> If you stand right fronting and face to face with a fact, you will see the sun glimmer on both its surfaces, as if it were a scimitar, and you will feel its sweet edge dividing you through your heart and marrow. Be it life or death, we crave only reality.
>
> —*Henry David Thoreau*

Our students were demanding better teaching. Tuition was growing every year and they wanted their money's worth.

But most of us were just scholars and researchers. No one had ever explained teaching and learning to us, so we just mimicked the way we had been taught. This wasn't good enough any more.

Our solution was to create a "teaching center." This center would organize seminars and discussions about teaching and help individual teachers who wanted to improve. Our center needed a director and, for reasons that are forgotten now, that task fell to me. Explaining teaching became my job.

It wasn't long before I began to feel frustrated. Teaching how to

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teach was trickier than I had imagined. I was beginning to wonder if it could be done at all.

Then came my brilliant idea. We would videotape our best teachers and find out what they do. Then we could extract their secrets and explain them to all the faculty.

Some teachers were flattered to be taped and put on a performance. Others were self-conscious and tightened up. But most interesting of all, some teachers refused to be taped.

My friend John was typical of these. He was not camera-shy. In fact he was a bit of a ham and liked the attention. But, like the aborigines, John feared that the machine would take away his soul. Well, not his soul but the soul of his teaching. Whatever was out there producing that magic in the classroom would just refuse to show up. The teaching gods were real, and they were stubborn. No video cameras!

* * *

Teaching is a mysterious process. Whether it is John in his class or our third grader with her homework, we are not sure how it works. We explain things, but even our best explanations may not help. Then, out of the blue and for no apparent reason, learning just happens.

So it is easy to understand why John felt as he did. Good teaching is fragile. It might not be a good idea to immobilize it on a piece of magnetic videotape, trapped like a firefly in a bottle. The light might fade for lack of air.

You may feel the same about this book. Won't the crude facts of science contaminate the magic in teaching and learning? Rather than helping, won't they just drain away its life and light?

But even if you tend to agree with John and are worried about losing the magic, I suspect you also understand what Thoreau is saying in his lucid and poetic claim for the power of simple facts. Part of our nature wants to understand, wants to put the mysterious on a firmer, factual footing. And we know that, far from destroying the light, facts give us light. That is why we crave them, why their edge is sweet.

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On Facts

It might sound quaint to begin with Thoreau and talk about facts. It is the twenty-first century, and we have learned to distrust absolutes. Rather than speak of facts, or reality, we talk about our *metaphors.* We explain what "happened," but we don't blame anyone.

Some call this more relative view of things postmodernism. As the name suggests, it implies that we have moved beyond the day of "modern" science, with its beliefs in absolute facts, and have come to a more sophisticated time where we recognize how relative our facts can be and how their meaning depends on our individual experience.

There is no doubt that this perspective has value. For example, it helps us recognize our differences. We each see the world through our own metaphors, and we all have our unique reference points for learning.

But in our common speech, we still talk about facts and reality. Science keeps moving ahead, discovering new facts. Facts and realities haven't disappeared. We still need them to understand each other. For example, we aren't talking about ultimate reality when we say "there is an oak tree in my yard." All we mean is every time we look out our window we see the tree, and if we accidentally run into that tree, we will be knocked flat on our backs. These things never change, and that is enough for us to call them facts. No matter how deeply we understand postmodernism, we still try not to run into trees.

This is what I mean when I talk about facts. I am going to build on things that come from repeated experiments and have been shown to be dependable. It is this reliability that make our facts so sweet and that makes us crave them.

A Bridge Too Far?

As I proceeded with this project, I became more and more aware of its difficulties. It is one thing to point out facts about the brain and another

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to translate them into facts about learning. An even greater challenge is to move from any facts that we may agree on about learning and convert those into facts about teaching. As John Bruer has argued, this may not be possible with our present knowledge. It may be "a bridge too far."[1]

But no one wants teachers to ignore biology. Ultimately, we will still have to reconcile everything with nature. If we find our theories about teaching to be in disagreement with biology, we must reconsider them. So, if it is too early to build bridges between biology and pedagogy, someone should still watch over our growing understanding of the brain. It is never the wrong time to look for ideas about how to help people learn—even if those ideas come from biology.

Getting, and Keeping, the Courage

We all have our beliefs about learning, and most of us will express them at any opportunity. The same can be said for teaching. We have all been to school, and so we all have our opinions about teaching. The difficulty is that these beliefs and opinions are both strong and different! So it was inevitable that if I took on this project, I would step on some toes, no matter what I said.

I also knew that not everyone would appreciate my point of view. But, along the way I drew courage from people like Edelman and Lakoff, who have argued powerfully for a biological understanding of cognition and learning.[2] I heard them affirm what I believe, which is that all the products of the mind come from the brain and its interactions with the body and the world. As a biologist, I think I understand Edelman better, and I was especially compelled by his insistence that we must recognize the biological origins of the brain in evolution and in development, if we are to understand the human mind and heart. As he says, "there must be ways to put the mind back into nature that are concordant with how it got there in the first place."

So, trusting these greater minds than mine and clinging tightly to my faith that better understanding always opens up new paths for action,

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I managed to persist. Facts about how the brain works were bound to have applications in teaching. Eventually, teaching would become the *applied science of the brain.*

How I Worked

How did I go about this risky project?

I was not trained as a neuroscientist, but for many years my work was directly related to one of the important questions neuroscientists ask: How do cells send signals to each other? As a result I knew something about cells and how they communicate, which is an important part in understanding the brain.

Beginning with this part of neuroscience, I began to pry open the other doors. And I do mean *pry.* Bit by bit I got myself through these doors, exploring what I found, learning about the anatomy of the brain, about brain imaging, about behavior, about the emotional brain, about sensory and motor systems, and so on to this day. Indeed, as I write I am still prying away!

But through all my prying, I understood my limits well. What I was finding was not "real knowledge" but "book knowledge." I would never understand the brain the way practicing neuroscientists do. My contributions would not come from new understandings about the brain.

But teaching was a different matter. There were possibilities for a contribution there, and that is where I focused. I just kept asking about teaching. Whenever I pried open another door, I looked around and asked, "Is there anything here for the teacher?"

And it seemed that I kept getting answers. Over and over I stumbled onto ideas that I had not known before. True, these were still just ideas, but at least they came from what I believed to be facts. And, they were what kept me going.

The Art of Changing the Brain

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I had always believed that the brain operates by physical and chemical laws, and thus, that learning is physical. But I had never been challenged to put that belief into any practical use. Now, I was trying to use the concept, and that forced me to be much more concrete. Whatever it meant to say "learning is physical," I had to apply to teaching as well. Inevitably I realized that if a teacher has any success at all, she has produced physical change in her student's brain. Teaching is the art of changing the brain.

I don't mean controlling the brain, or rearranging it according to some "brain manual." I mean, *creating conditions that lead to change in a learner's brain.* We can't get inside and rewire a brain, but we can arrange things so that it gets rewired. If we are skilled, we can set up conditions that favor this rewiring, and we can create an environment that nurtures it.

An art, indeed!

The Power of the Physical

When we don't understand, we are tempted to invoke some mystical authority, a teaching god or a wicked witch of the west. But ultimately true power lies in the mundane physical nature of the real world. Ultimately, even the spiritual is physical.

I came to understand this in a deeper way as I pursued my quest for the teaching secrets I hoped were buried in the physical structure and function of the brain. In fact, I came to think that physical experiences and images are required in order to understand anything at all.

Again, I am being quite literal. It seemed that I could only understand things when they were described in physical terms. My digging up facts about the brain began to help me see why. This seems to be an innate characteristic of the brain itself. All that the brain knows comes from the physical world, the things in its environment, the physical body that holds the brain inside itself, or the womb that holds that body as it develops.[3] A physical brain means a physical mind;

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meaning itself is physical. This is why we need metaphors. Without reference to physical objects and events, there is no meaning.

Education and Physical Models

As I followed this path, I realized that we also have physical models for teaching and learning. For example, some teachers believe that the student is a physical recipient of knowledge. She is a "blank slate" or a "vessel." Others believe that learners construct their understandings like a carpenter builds a house or an artist paints a picture.

So I began thinking about metaphors for the future of teaching. I imagined that we would begin to invent tools to create learning and to help us repair mistakes—tools for changing the brain. We will use that wonderful tool-building instinct that was an essential part of our survival throughout evolution. Just as we invented the hammer to drive a nail, we would invent tools to facilitate learning.

Again, let me remind you that I am not talking about inventing a "learning hammer" for driving knowledge into the brain. And I don't mean some new chemical that we can inject to improve learning. What I mean is that we will understand what conditions, what environments, and what practices make learning work better.

Biology, Philosophy, and Education

The last step along this path came as I thought more broadly about what these ideas mean for the way we help people learn. Ultimately, how we teach depends on how we believe the mind works, and how we understand behavior. It depends on our philosophies. I recognized that my physical view of things is really a philosophy.

This may surprise you, because we don't often think of biology as related to philosophy. It seems too technical for that. We think that science is about inventing new medicines, new machines, or new enjoyments for ourselves. But in some ways those are just side products.

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Ultimately the most important goal of biological science is to understand the physical basis for life, thought, love, and meaning.

So, biology is not really separate from philosophy. It is a search for meaning, and now, in the twenty-first century, it turns out that our search is leading somewhere. In fact, biology has created a revolution in philosophy. This has come about through application of new understandings about the structure of the brain and the mechanisms at work inside it, what we call cognitive science and cognitive neuroscience.

This impact of biology on philosophy is stated most directly by Lakoff and Johnson in their book *Philosophy in the Flesh,* which begins as follows:[4]

> The mind is inherently embodied.
> Thought is mostly unconscious.
> Abstract concepts are largely metaphorical.
> These are three major findings of cognitive science. More than two millennia of a priori philosophical speculation about these aspects of reason are over. Because of these discoveries, philosophy can never be the same again.

My guess is that these claims have not pleased all the philosophers of the world, but the arguments are strong and their connection with biology undeniable. Further, if philosophy will never be the same, neither will education!

Overview

Now you have seen why I believe that understanding the brain will enrich teaching. It will give us new ideas for educational tools, and it will change our ideas of how the mind works. It will change our practice and our philosophy.

I try to make this case in more detail in the remainder of the book. It is divided into four parts:

Part I (chapters 2–5) is about *foundations* for learning. The

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metaphor here is that there are things that underlie and thus can support our effort to help people learn. One of these things is the overall arrangement of the brain, a structure that produces learning naturally. Another part of this foundation is a requirement for a balanced use of the capabilities of different parts of the brain. And a third is the interaction of emotion structures with cognition structures in the brain, which helps us understand motivation, reasoning, and memory. In our foundation metaphor, emotion seems to be the mortar that holds things together.

Part II (chapters 6 and 7) focuses on neuronal networks, their relationship to knowledge and learning, and the practical impact of this information for the teacher. These chapters contain more specific suggestions about what teachers should actually *do.* One of the most fundamental ideas is that a teacher must start with the existing networks of neurons in a learner's brain, because they are the physical form of her prior knowledge. This emphasis on prior knowledge is well accepted in educational theory, but the biological meaning enriches our appreciation of it. The teacher's task is to produce physical change in those networks, and we learn how to do that by seeing how nature does it.

In Part III (chapters 8–12), I revisit the five major parts of the cerebral cortex: the sensory cortex, the post-sensory integrative cortex, the frontal integrative cortex, the motor cortex, and the major structures associated with emotion. Each of these chapters gives us ideas about different aspects of learning, such as the value of experience, why we need to reflect, how learners come to own their knowledge, how learning is confirmed and extended through action, and how the effective teacher can make use of knowledge about emotion.

Finally, you will find a short epilogue entitled "Enrichments." Here I summarize different ways that understanding the brain can enrich the teacher. Remembering that enrichment means adding to what we already have, I briefly argue that our *insights,* our *realities,* our *separateness* (or boundaries), our *ideas,* and our *values,* our *values* are all

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enriched when we think of teaching as the art of changing the brain.

Revisiting the Teaching Gods

You can see that I am now far beyond videotaping classes in my search for better ways to help people learn. But I haven't forgotten about John and his concerns. In fact, I still think about those teaching gods. A good class can be almost a religious experience. Things happen that we didn't predict, sometimes wonderful things and often mysterious!

As you can see, I don't deny the mystery. I only want to solve it. And the solutions must be buried in that physical structure we call the brain. It is physical. That means we can understand!

Notes

1. See J. T. Bruer, "Education and the Brain: A Bridge Too Far," *Educational Researcher* (November, 1997); also see Chapter 3 in H. Gardner, *The Disciplined Mind* (New York: Basic Books, 1998).
2. G. Lakoff, and M. Johnson, *Philosophy in the Flesh—The Embodied Mind and its Challenge to Western Thought* (New York: Basic Books, 1999); G. M. Edelman, *Bright Air, Brilliant Fire; On the Matter of the Mind* (New York: Basic Books, 1992).
3. We could say that our brain also comes from the programs that are coded in our genes. That might sound less physical, somehow. But, of course, those programs are just the result of the physical structure of DNA.
4. Lakoff and Johnson, p. 3.

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PART I

FOUNDATIONS

How does learning come from the structure of the brain? How does information become understanding? What is the origin of motivation? How do feelings affect reason and memory?

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2

WHERE WE OUGHT TO BE

THE NATURAL RELATIONSHIP BETWEEN BRAIN STRUCTURE AND LEARNING

> 'Tis the gift to come down where we ought to be.
>
> —*Shaker song by Joseph Brackett, Jr., 1848*

> It was so pretty, it had to be true.
>
> —*James Watson on discovering the double helix*

Being director of a teaching center had some terrific perks. One of the best was that I was expected to learn about learning. You might not consider this a perk, but I did. It was a luxury for me to read and study about how people learn. I never had time before.

So I looked for new reading. What I wanted wasn't in biology or psychology books I had seen. I needed to get beyond synapses, stimulus/response, habituation, and Pavlov's dogs. My hope was to understand understanding. What must a brain do to comprehend?

It was then that I discovered David Kolb's book, *Experiential Learning.*[1] It wasn't particularly about biology, but still it came closer to

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what interested me, so in I plunged.

Kolb began by talking about people I had heard of, but never read before, people like Dewey, Piaget, and Lewin. Combining their ideas about development and learning, he described a new “learning cycle.” He said deep learning, learning for real comprehension, comes through a sequence of experience, reflection, abstraction, and active testing. These four cycle “round and round” as we learn.

I was skeptical of this idea at first. Surely there were many other ways to explain learning. It seemed too simple, too arbitrary.

But I gave it a chance. And, without warning, as I sat in my office on one warm spring afternoon, it all came together. I still remember taking that slow, deep breath, holding it for a second, and then releasing it with a sound somewhere between a laugh and a sigh.

I stood up and began to pace and talk to myself. “It is biological! Of course, it has to be. Everything is in the right place! It’s too pretty not to be true!”

I surprised myself. I turned from skeptic to believer on that day. Things just came down where they ought to be.

* * *

In biology, the way things work depends on their structure—their physical structure. Genetic inheritance depends on the structure of DNA. Digestion depends on the structure of the gut. Any function found in any living organism must depend on some structure of some part of that organism.

This was my habit of thinking, and so it seemed that if the function we are interested in is learning, we should look for the structure that produces it, and the place we should look is in the brain. Ultimately, the structure of the brain should explain learning. It’s only natural.

That is what I saw on that warm spring afternoon. What I knew about the brain told me that the learning cycle should work, and it told me why. For the first time I saw a structure designed for human learning, for understanding and comprehension.

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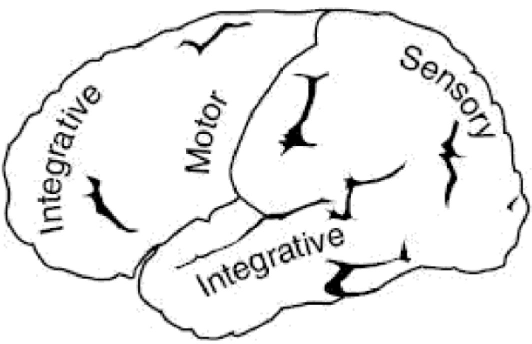
First Look

In this chapter I will give you my proposal for this natural connection between brain structure and learning. We don't need to know much about the brain to do this. Neurons and synapses can wait until later, as can the complicated structures that lie deep in the brain. For now we can simply look at the outside of the brain and talk a little bit about what different parts do.

In the illustration shown below you can see a view of the left side of what is called the *cerebral cortex.* The *cerebrum* is the large part of the human brain that is thought to be responsible for much of the thinking and learning we do, and the *cortex* is the layer of tissue that coats the cerebrum, like the bark of a tree; hence the name *cerebral cortex.*



This illustration shows three functions of the cerebral cortex, and roughly which parts of the cortex are engaged in each. The functions are *sensing, integrating,* and *motor* (which means moving). Notice that there are two integrating regions of cortex; we will discuss the difference between them later in this chapter.

These three functions of the cortex are not an accident. They do the key things that are essential for all nervous systems. They sense the environment, add up (or integrate) what they sense, and generate appropriate movements (actions):

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Sense ⇒ Integrate ⇒ Act

These three functions are seen in nervous systems ranging from those in simple animals to the human brain. In the paragraphs that follow I expand on this somewhat and describe more about these three brain functions.

The sensing function refers to the receipt of signals from the outside world. In people, these signals are picked up by the sense organs; eyes, ears, skin, mouth, and nose.[2] They are then sent on to special regions of the brain for each of the senses. These signals come in small bits and have no meaning in their raw form. They are just little individual pulses of electrical energy coming in from the sense organs.

Integration means that these individual signals get added up so that whatever is being sensed is recognized in the sum of all these signals. The small bits merge into bigger patterns that become meaningful things like images or language. In the human brain these meanings are then integrated in new ways that become ideas, thoughts, and plans. At their most basic, these integrated meanings become plans for actions. For example, they get added up in ways that generate a plan for *what* action is needed and *where* the action is needed.

Finally, the motor function is the execution of those plans and ideas by the body. Ultimately, motor signals are sent to the muscles that contract and relax in coordinated ways to create sophisticated movements. Importantly, we should realize that even *speaking* and *writing* fit in here because they involve some of the most sophisticated patterns of muscle contractions that the body carries out.

Brain Connections: An Overview

This transfer of signals from sensory input through the brain to motor output is a general pattern for all nervous systems, including the human brain. The most direct and simplest route for signaling in the brain, then, would be as shown in the illustration below. Sensory input could

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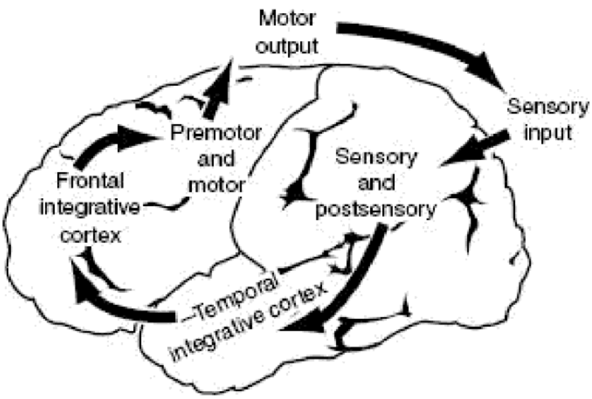
come from the outside world or from our own body, but once those signals have entered the sensory part of the cortex, they flow first through the integrative part of the brain nearest the sensory part, then through the integrative part nearest the motor brain, and then to the motor brain itself. Once action has been initiated, that action is detected by the sensory brain, so the output of the brain becomes new sensory input.



I want to stress that this picture is highly oversimplified. Later we will see that there are many other links, including parallel links and connections where signals go in both directions. What I have shown you is probably the simplest way to look at what the brain does.

Looking for Learning

Our objective is to get ideas about learning from the structure of the brain. We are looking for a structure that generates comprehension and understanding in people, something more than pure memory of facts or physical skills. It isn't necessarily obvious how this type of learning can come from the structure we have been talking about. Somehow deep learning should emerge from sensing, integrating, and acting.

But this is where biology takes us, so we have to keep looking.

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