Scott E. Page

THE DIFFERENCE

HOW THE POWER OF DIVERSITY CREATES BETTER GROUPS, FIRMS, SCHOOLS, AND SOCIETIES

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Preface to the Paperback Edition

PRUFROCK AVOIDED

That is not it at all.
That is not what I meant, at all.
—T. S. Eliot, *The Love Song of J. Alfred Prufrock*

In January 2007, I stood in an upstairs ballroom of the Palmer House Hotel in Chicago, preparing to speak to a group of high school administrators. One hundred copies of *The Difference* lay stacked nearby on a catering table. Officially, the book had yet to be released, so this was, in effect, its coming out party. As I stared at the uncracked spines, I pondered the book's reception. Would people get it? Or would I spend the next few years quoting T. S. Eliot?

Happily, Prufrock has been avoided.

Not that I didn't have my moments of doubt. Initial readings were all over the map. Some in the blogosphere characterized the book as Jim Suroweicki's *Wisdom of Crowds* on steroids. Others framed it as a book about affirmative action. Still others said it described a portfolio model of people. My wife assured me that these were proof of my theory—evidence of diverse perspectives in action. I was less certain and dusted off my Eliot to work on cadence.

Perhaps because *The Difference* takes time to digest, eventually, accurate readings won out. Reviewers recognized that *The Difference* explores the pragmatic, bottom-line contributions of diversity. It does so using models and logic, not metaphor. The

book's claims that "collective ability equals individual ability plus diversity" and that "diversity trumps ability" are mathematical truths, not feel-good mantras.

Diversity, as characterized in the book, means differences in how people see, categorize, understand, and go about improving the world. I should hasten to add that the book's emphasis on cognitive diversity and the pragmatic benefits of diversity does not deny other dimensions of diversity. Those exist, and they matter. In fact, identity diversity and cognitive diversity often go hand in hand. Two people belonging to different identity groups, or with different life experiences, also tend to acquire diverse cognitive tools.

Unfortunately, rather than leverage those differences to our collective benefit, we often allow our differences to impede progress and innovation. When confronted with someone who looks or acts differently, many of us tend to recoil. Soon after the initial publication of *The Difference*, Robert Putnam released results from a large survey that demonstrated the scale of this negative response to diversity. He found that levels of civic engagement and trust decreased as communities became more diverse. Note that in his case, diversity means ethnic diversity.

His raw data painted a bleak picture. People in diverse neighborhoods not only trusted people belonging to other ethnic groups less, they trusted everyone less. Not good. Reality may not be as bleak as Putnam's most publicized graphs seem to imply, however. After he takes into account control variables—crime, income, city size, educational attainment, etc.—the negative effects of diversity decrease substantially.

But the media saw Putnam's work and mine as contradictory: "Putnam says diversity is bad. Page says diversity is good." The juxtaposition was ill posed. Putnam had done survey research. I had written theoretical models. Putnam was asking people about trust and happiness. I was constructing models of collective productivity, accuracy, and innovation. He was asking, do we get along? I was analyzing whether diverse teams make better mousetraps.

Interacting with a large number of diverse people should be more cognitively taxing than hanging out with your close friends,

who look, think, and act just like you. Situated in a diverse polyglot, people may indeed feel the need to hunker down (to use Putnam's phrase). Even so, they probably do not fully insulate themselves. They cannot avoid having their world view a bit more exposed to new ways of seeing and thinking, and as a result they cannot help but become a bit more productive. Thus, we should expect members of diverse communities, cities, and nations to be more productive, even if they are less trusting.

One might think, and I certainly do, that if we can be made more trusting, then we would become even more productive. The University of Michigan, where I teach, has a mission to improve society. Hence, it devotes time, energy, and resources to helping students, faculty, and staff learn to thrive in a diverse, interactive university community. Many other organizations do the same. Practice may not always make perfect, but it usually improves the imperfect.

Since the publication of the book, I have been involved in a number of discussions and conferences taking up the more practical issue of leveraging diversity. Leveraging diversity isn't easy. In theory, given the right conditions, two heads will be better than one, but in practice, team members don't always get along, and even when they do, outcomes can be lousy. We've all heard the story of the committee tasked with building a horse, but built a camel instead.

A good starting point for thinking about how to leverage diversity is to recognize (and then often restructure) the nature of the task. The organizational theorist I. D. Steiner distinguished between *disjunctive tasks*, those in which only one person needs to succeed for the group to be successful, and *conjunctive tasks*, those in which everyone's contribution is critical. Solving a vexing math problem is disjunctive: the more diverse heads, the better. In football, the offensive line's task of protecting the quarterback is conjunctive. If any one lineman fails to do his job, the quarterback gets sacked. Diversity works best on disjunctive tasks because multiple approaches can be tried simultaneously, and one good idea means success for everyone.

Most real world tasks are neither purely disjunctive nor purely conjunctive. In fact, how much of each a particular task is depends

upon how the task is structured. As the economic historian Paul David pointed out to me, one of the great challenges in constructing distributed organizations is transforming conjunctive tasks into disjunctive tasks. For example, success in open-source software development requires an initial template that modularizes the problem into a collection of disjunctive parts.

Moving from a theoretical science of distributed and collective intelligence to the practical art of distributed, decentralized organizations requires additional conceptual unpacking. Take the case of what is often called distributed information production. Examples of this include Wikipedia, Digg.com, and Epinions. For these collective projects to take off, knowledge must be dispersely held, people must have incentives to reveal their information, a significant percentage of the information must be useful, and biases and errors must be identifiable and correctable. Wikipedia has been such a smashing success because it meets all of these requirements. Information about the world is widely held. Contributing is easy. Most of the information is useful and accurate, and mistakes can be identified and corrected by editors at Wikipedia.

Prediction markets, where collections of employees or individuals bet on future outcomes, provide a second application of the ideas in *The Difference*. Prediction markets work best when many variables could potentially influence the outcome and when quantifying relevant information proves difficult. Participants must be both accurate and diverse for prediction markets to work. In some cases, sufficient diversity already exists. In other instances, it must be recruited or incentivized.

Prediction markets get lots of attention (it's cool that the Iowa Electronic Market predicts elections so well), but distributed problem solving—in the academy, the government, and the corporate sector—may be the more important application of diversity. Distributed problem solving allows a problem to be investigated simultaneously by a population of people with diverse tools. An example of this is the now famous Goldcorp challenge, in which the company made public all relevant information about its Red Lake Mine in Ontario, Canada. It broadcast this information over the Web and asked for advice as to where to dig. The result was,

literally, golden. Contestants identified over fifty new sites. More than three-fourths of these produced gold. Similarly, Netflix, the movie distribution company, recently made all of its information about user preferences publicly available and offered a million dollars to anyone who could improve on a baseline algorithm for making movie recommendations by 10 percent.

Distributed problem solving can be thought of as a form of innovation. This opening up of innovation activities to users is sometimes called *distributed co-creation*. The diverse toolboxes that people bring to problems enable large populations to produce novel breakthroughs. Examples include Lego.com, which encourages users to design their own products, and the T-shirt company Threadless, which allows anyone to design T-shirts. In each case, the best designs get produced and sold, with the designers sharing in the profits. Perhaps most germane to the subject of diversity, the Open Prosthetics Project (www.openprosthetics.org) enlists amputees to help design artificial limbs. The amputees bring perspectives to problems that limbed people do not possess, such as what features will function well for rock climbing.

I have often been asked, when do distributed problem solving and innovation work? I think we're still in the process of figuring that out, but we have some ideas. An organization must have some sense that improvement is possible, that it's stuck or locked into a few perspectives. It must also believe that people with relevant perspectives and heuristics exist who could be encouraged to think about the problem. Ideally, the problem itself will be both quantifiable and modularizable. Also, there must exist some fast, low-cost, effective way to compare solutions. And, finally, the act of stating the problem cannot give away valuable information, such as cost structures or proprietary data. Netflix could encrypt the names of users and movies, driving the value of the information down to zero. Goldcorp could not encrypt their data, but they were safe because they owned the mine.

When those conditions aren't met, decentralized problem solving or co-creation may well fail. The Schaumburg Flyers, a minor league baseball team, found out the hard way. For the second half of the 2006 season, the owners allowed fans to manage the team.

Fans voted on batting order, pitching decisions, etc. The failure of this attempt should come as no surprise. The members of the crowd knew little about the players, nor was there any filter to limit participation to those taking the task seriously. Add to this the fact that feedback was slow and noisy, and that fourth-place finish was unavoidable.

When decentralized problem solving and innovation do succeed, one can ask whether diversity deserves credit. In a few cases, we can look at the sequence of improvements and see the residue of diverse perspectives and heuristics in action and say with some degree of confidence that diversity deserves credit. The MATLAB programming contest provides just such an example. The contest works as follows: MATLAB proposes a computational problem. It could be gene sequencing, the traveling salesperson's problem (see pages 56–59), or solving Sudoku. Contestants write computer code in MATLAB to solve the problem in minimal time with maximal efficiency. Solutions have to be fast and correct. MATLAB engineers test the code and post both the results and the code itself, allowing other contestants to build off existing code.

This transparency allows contestants to apply their diverse skills to produce improvement. Not surprisingly, analysis of the results reveals diverse perspectives and heuristics at work. In one instance, someone knew a faster way to produce the Fibonacci sequence (see page 42), a better heuristic. Applying this heuristic decreases the computation time. In other instances, someone brings an entirely new approach—a new perspective on the problem—resulting in a dramatic improvement in efficiency.

A final key determinant in the success of decentralized organizational forms is culture. Culture has hundreds of definitions. Here, I mean norms and modes of behavior. We should not be surprised that distributed approaches have succeeded in open-source software and in the ATLAS project in physics. Both of these communities have norms of sharing and collaboration. The future success of distributed cognition depends partly on the spread of positive-sum thinking. We have to think of sharing ideas not as giving away the shop, but as collectively building the lever to lift the world.

Acknowledgments

THE CONTINUOUS LIFE

Great genius takes shape by contact with another great genius, but less by assimilation than by friction.
—Heinrich Heini

GIVEN the central claim of this book—that diversity produces benefits—I cannot both take credit for it and claim it to be as good as it could be. And, in fact, this book has been a joint effort. Over the past five years, I've presented bits and pieces of this book to a diverse set of audiences: undergraduates, academics, Wall Street investors, Silicon Valley entrepreneurs, health science researchers, government agency employees (some may even have been spies), human resource professionals, Fortune 500 diversity committee members, political activists, and even alumni at a University of Michigan family camp. Those presentations have led to brief comments, long emails, and even copies of books that I "had to read." What I learned from those interactions has been folded into and improved this book.

Though what you're reading consists entirely of my words, my editor, my wife, some graduate students, and more than a few friends have painstakingly rearranged them. Eric Ball, Jonathon Bendor, Scott de Marchi, Patrick Grim, Ken Kollman, Bill McKelvey, Jennifer Miller, Mike Ryall, Cosma Shalizi, Elizabeth Suhay, and Troy Tassier gave detailed comments on earlier drafts. The path from personal friend to personal hero is paved with red

pens. The oh-so-many other people who read parts of earlier versions or heard my ideas and provided comments ranging from adoring to critical include Daron Acemoglu, Susan Ballati, Jake Bowers, Aaron Bramson, Elizabeth Bruch, Dan Catlin, Rui de Figueiredo, Patricia Gurin, Erika Homann, Norman Johnson, John Ledyard, Michael Mauboussin, John Miller, Lester Monts, Katherine Phillips, Jeff Polzer, Cindy Rabe, Jim Surowiecki, Bill Tozier, Nick Valentino, Jennifer Watkins and Michael Wellman. Not included in this list are Mita Gibson and Howard Oishi, who run the Center for the Study of Complex Systems at the University of Michigan. Howard and Mita not only handled all of the administrative tasks associated with the writing of the book, they were valuable sounding boards for many of the ideas contained in it.

I have two academic homes: the University of Michigan and the Santa Fe Institute. One has Blimpy Burgers and one has mountains. At Michigan, I have had the opportunity to think on a regular basis with Rick Riolo, Michael Cohen, Bob Axelrod, Carl Simon, Mark Newman, Mercedes Pascual, and a young man named John Henry Holland—the so-called BACH group. Many of the ideas that follow are probably not my own, but belong more properly to BACH. For that, I promise to dedicate a portion of the proceeds to the stock of M&Ms. Many people at the Santa Fe Institute (SFI), especially Susan Ballati, Bill Miller, Ginger Richardson, and Geoffrey West, have nurtured and encouraged this work. SFI has been instrumental in pushing me out into what they call "the real world." Pat Gurin, Julie Peterson, and Lester Monts have played a similar role at Michigan. I'm shy and unassuming, so being forced out of my shell proved good for me.

I also have four academic birthplaces: Middleville Thornapple Kellogg Schools, the University of Michigan, the University of Wisconsin, and Northwestern University. My Ph.D. advisor, Stan Reiter, once told me that the two most important decisions I'd ever make were who my parents were and when I was born. Choosing a good advisor falls not too far behind on that list. Stan offered his usual wisdom and guidance in the writing of the research papers that were the basis for this book. As is true with the BACH group,

where my ideas end and where his begin is a blur. Throughout my career, Stan has been an inspiration both as an intellect and as a human being. Among other contributions to my family, he and his wife, Nina, have provided wise counsel, sculpture, and yoga tapes.

Writing a book like this requires resources. The James S. McDonnell Foundation provided funding for this inquiry into the logic of diversity. Few foundations are as innovative and bold as the McDonnell Foundation. Without its support, the book would be just another collection of loose unfinished ideas floating around in my head and in folders on my computer. The University of Michigan Center for Research on Learning and Teaching also provided a seed grant that led to the larger McDonnell Foundation grand. In addition, a National Science Foundation IGERT grant provided financial support for a community of bright, challenging graduate students, who kept me on my toes throughout the writing of this book. Even with all of these overlapping grants, Howard and Mita made sure that none of this money went to the BACH group's M&Ms or to pay for any lunches for Carl Simon and me at Zanzibar.

Writing a book also requires an editor. Mine, Tim Sullivan, was incredible (indeed!). He cut two hundred pages and personally rewrote most of those that remain. What had been a messy, complex tome, destined to be misunderstood by its twelve readers, Tim transformed into what you see. I had only to remove his many insertions of the word *indeed*.

The orginal manuscript was edited by Madeleine Adams, who corrected more punctuation errors in one month than most seventh grade teachers can claim in a lifetime. The final galley proofs were subject to the expert eye of Andrea Jones-Rooy, who spent three hours, twenty-six minutes, and fourteen seconds with me on the phone not only explaining the subtleties of subject-verb agreement but also helping me to tighten the prose and highlight the main points. My wife, Jenna, also read and edited the final version—more on her later.

While writing this book, I was coauthoring a book with John Miller of Carnegie Mellon University and SFI. John did most of the late heavy lifting on that project, allowing me the space to

finish this one. Both books benefited. I can only imagine how good this one might have been had he written it as well! Writing two books at the same time could spell the end of my days as an author of anything longer than fifty pages. For that reason, I'll thank Christine Schad, my favorite grade school teacher, who still sends me postcards on her birthday (it's also my birthday). Mrs. Schad (then Miss Harrison) taught me to say "good morning" in German and to begin each day with the chant "good better best, never let it rest 'til the good is better, and the better is best." (This mantra was later expanded into book form with the title *Good to Great*.) So when Tim, my editor, said that draft number eleven was "better, and good enough," let's just say I wasn't going to let it rest.

The listing of a single author on the title page causes me to feel equal parts shame and embarrassment. Lu Hong deserves equal billing for the bulk of this research. The parts of this book that are original belong as much to Lu as to me. For the two years I spent writing the core of the book, Lu was in Ann Arbor along with her husband, Tom Nohel, and their son, Jeremy, who at three knew more about rockets than I did at forty. My wife refers to Lu's arrival as a psyche-preserving event for me. It was. I hope this book will become Lu's and my second most remarkable achievement. Number one? We once couldn't find Toronto by car from Syracuse. In our defense, Canada is big and it was dark out, really dark. And we missed Toronto only by seventy miles—less than 2 percent of the length of Canada. By golf standards, we left ourselves a tap in.

Many of the names that appear in the book are drawn from friends (yes, Rebecca and Arun, it's you!) and family. My parents, Ray and Marilyn, and my sister Deb play starring roles. My other siblings, Brenda and Jeff, my many nieces and nephews, Noah, Carter, Maggie, Emily, Natalie, Cole, Katie, Joe, Rose, Brody, and Logan, and my mother-in-law, Karen, as well as most of my brothers- and sisters-in-law, Jeff, Mary, Joe, Rick, and Laura, also appear at various places in the book. It's an odd way to say thanks, but it's all I can do—it may not be to each according to his (or her) needs, but it is from me according to my abilities.

Hey, Orrie and Cooper! (I know—I've read *Flat Stanley* many times—"hay is for horses.") Guess what? The completion of this book means more time for playing with LEGOs and Playmobil, more time for riding bikes and climbing trees, more time to work on our story about pirates, and more time to mix up a little baking powder and vinegar to make explosions in the backyard. In answer to your question, does my book contain pirates and knights? Of course it does. (There they were.) It even includes a dragon that breathes water instead of fire, which makes him no fun at dragon parties. And best of all, some sentences are written in snake crayon. So that only Owls and Coyotes can understand them. Cool, eh?

This book is dedicated to my wife, Jenna. During the time I've been writing this book, she wrote her own book on the design of robust federations. (It's far more scholarly than this one.) She won a teaching award. And she found time to refine and clarify every single idea and model contained in this book (most have been subjected to her ear, eye, and pen several times). Her kindness, intelligence, and patience (especially her patience) have kept her three boys (Orrie, Cooper, and me) on a relatively even keel throughout this entire multiple-book-writing process. Without her, this book would have far less substance, gravity, and wisdom.

And so would I.

Prologue

HOW DIVERSITY TRUMPS ABILITY: FUN AT CALTECH

Oh do not ask what is it. Let us go and make our visit.
—T. S. Eliot

In 1993, I got my first real job, as an assistant professor of economics at the California Institute of Technology in Pasadena, California, home of the Tournament of Roses. I lived one block from campus and one and a half blocks from the Caltech gym. I wore shorts to work every day—even when temperatures fell into the sixties. Apart from being hit in the head by a falling palm frond during a spell of Santa Ana winds, I had a wonderful time. Caltech offered me abundant resources and an environment that encouraged freewheeling exploration.

One winter evening in 1995, to have a little fun I constructed a computer model of diverse problem solvers confronting a difficult problem. Put aside for now what counts for fun at Caltech; "fun" at Caltech rarely makes sense to the outside world. In my model, I represented diversity as differences in the ways problem solvers encoded the problem and searched for solutions. I referred to these ways of solving the problem as tools. In working through the implications of my model, I stumbled on a counterintuitive finding: diverse groups of problem solvers—groups of people with diverse tools—consistently outperformed groups of the best and the brightest. If I formed two groups, one random (and therefore

diverse) and one consisting of the best individual performers, the first group almost always did better. In my model, *diversity trumped ability.*

This result proved to be no house of cards. With the help of my good friend and coauthor Lu Hong, I unpacked a logic that underpins that finding. In doing so, Lu and I hit on a fundamental insight: *in problem solving, diversity is powerful stuff.* It doesn't always trump ability, but it does so far more often than we'd expect. The power of diversity is not a new idea. (Evolutionary biologists see the selection of fortuitous diversity as the reason we're here. What could be more powerful than that?) However, as became clear to Lu and me, the idea that our individual differences—the differences in how we think, in the cognitive tools we possess, in our perspectives—was far outside the mainstream in a society that prizes individual talent and achievement. It shouldn't be. Progress depends as much on our collective differences as it does on our individual IQ scores.

The claim that diversity should get equal billing with ability is a strong and controversial one. Anecdotes, metaphors, and decorative quotes won't be sufficient to convince skeptics. Hence, in this book, I make the case using frameworks and models. I show with modest rigor how diverse perspectives, heuristics, interpretations, and mental models improve our collective ability to solve problems and make accurate predictions. An advantage of using logic is that it gives conditions—these results hold when and if the following are true. Another advantage is that it provides the greatest chance of getting hit on the head by a palm frond (just a conceptual one). Models and logic don't come without some costs. They limit what we can claim. We're tied to the mast of our assumptions. They also require careful reading. Don't worry, though; the book doesn't read like that undergraduate economics textbook you resold for ten cents on the dollar. It's fun.

This book can be read from multiple perspectives. Parts of this book have strong connections to two recent books on collective wisdom. The first is Howard Reingold's *Smart Mobs*, which describes how emergent collections of people can carry out tasks and can solve problems.[1] The second book is Jim Surowiecki's

Wisdom of Crowds, which shows how crowds of people can make accurate predictions.[2] The words *crowds* and *mobs* are a bit misleading, as these intuitions apply to groups of ten as well as groups of a thousand. A board of directors is not a mob or a crowd, but it too benefits from diversity.

In this book, I also consider a third benefit of diversity: the increased probability of a savant. If we sample widely, we're more likely to find the one person who can solve the problem or who can make the key breakthrough. We did not get the theory of relatively from a crowd. We got it from a diverse, novel thinker in a patent office.

This book also has bearing on claims of the legal, instrumentalist benefits of identity diversity arguments. For a long time, my research papers and presentations included no mention of identity diversity. They considered only the differences inside people's heads, not differences in skin color, gender, or ethnicity. Yet, audiences continued to make a connection between cognitive differences (who we are inside our heads) and identity differences (who we are on the outside). Although promoting greater identity diversity in groups—particularly in groups that possess power—has long been the concern of the political left (usually for reasons of justice and fairness), the people who brought up this connection more often than not came from the corporate sector.

This reaction did not surprise me. Though the business world's concern is, and always has been, with the bottom line (we don't see many business leaders chanting "a people united will never be defeated" or anything of the sort), over the past few decades business leaders have moved in the direction of pro-diversity. Two fundamental changes have led to this directional shift: the business world has become more global (and therefore more aware of ethnic diversity) and the practice of work has become more team focused. The homogenous hierarchy has given way to the diverse team.[3] To paraphrase one business executive, "Look, companies spend billions of dollars each year trying to manage diverse employees. That's not going to change."[4]

Some people dismiss claims that diversity is beneficial as empty rhetoric. And people have good reason to be dubious. These

claims do not seem to be based on anything more than hope and metaphor (making them easy to dismiss). This book provides a foundation for those claims. Identity diversity does produce benefits—not every time, not in every context—but there is a there there.[5]

This book also provides a logic for greater interdisciplinary research. What, after all, are the different disciplines but collections of different sets of tools and understandings? That said, at the end of the day this book has to be a contribution to social science. That's the job of the social scientist—to add to the base of knowledge.

This book contributes to social science by unpacking the processes of problem solving and prediction, processes that social scientists often ignore or "black box." Two examples help to clarify what I mean. First, most social science models rarely differentiate among problem solving (curing a disease), prediction (estimating the outcome of the next election), and information aggregation (surveying people to find the grocer with the lowest prices). Even though these tasks differ, many economists would respond (perhaps correctly), "Yeah, yeah, yeah, it's all basically information aggregation. People have different information and the noise cancels." Second, many political science models in effect assume that information arrives on people's doorsteps in the form of *signals*. The story goes as follows: the president proposes a tax policy, a voter wakes up and finds a placard that reads "new policy to lead to a 3% increase in economic growth" on her doorstep the next morning. Moreover, each voter gets a *unique* placard and *on average* those placards are correct. But why are they correct? That is what I unpack.

In what follows I nourish these diverse readings. When possible, I point out the linkages to smart mobs, to wise crowds, to identity diversity, to globalization, and to interdisciplinary science. I do this not just to try to make everyone happy, but because the same logic that shows how cognitive diversity improves the performance of a predictive market can show how including identity diverse—and experientially and vocationally diverse—people improves the performance of a problem-solving team. To quote Dan Ackroyd

from his *Saturday Night Live* days, "It's a floor wax *and* a dessert topping."

Before starting, I will put what follows in some context by returning to the original finding that diversity trumps ability. Does this logic imply that we should abandon the meritocracy? That we should remove those "my child is an honor student at Neil Armstrong Junior High" bumper stickers from our minivans and randomly allocate spots in our top colleges? Of course not. Ability matters. But—here's the catch—so does diversity. Comparisons between the two (which matters more: diversity or ability?) require some care. We're comparing an apple to a fruit basket. Ability is a property of an individual—a nice shiny apple. Neither a person nor an apple can be diverse. Diversity is a property of a collection of people—a basket with many kinds of fruit. Diversity and ability complement one another: the better the individual fruits, the better the fruit basket, and the better the other fruit, the better the apple. So while we might equally proudly affix "my other child's different" bumper stickers to our vehicles (anyone with two kids can claim that to be true), ideally, our children would be individually able *and* collectively diverse. If so, what they could accomplish would amaze us.

In sum, rather than being on the defensive about diversity, we should go on the offensive. We should look at difference as something that can improve performance, not as something that we have to be concerned about so that we don't get sued. We should encourage people to think differently. Markets create incentives to be different as well as to be able, but perhaps not to the appropriate levels. We should do more.

Of course, difference does not magically translate into benefits. My claims that diversity produces benefits rest on conditions. These conditions require, among other things, that diversity is relevant—we cannot expect that adding a poet to a medical research team would enable them to find a cure for the common cold. Further, for diverse groups to function in practice, the people in them must get along. If not, the cognitive differences between them may be little more than disconnected silos of ideas and

thoughts. Diversity, like everything else (excepting, of course, moderation), has its limits.

Understanding diversity and leveraging its potential requires a deeper understanding than we currently possess. We won't get far with compelling anecdotes and metaphors, which in the diversity realm exist in abundance. We have (as Kermit would say) "so many songs about rainbows and what's on the other side." What we need are formal definitions, assumptions, and claims. We need theorems about rainbows. We need a logic of diversity. This book provides that logic—not all of it, but enough to get us started.

I'll end with this observation: as individuals we can accomplish only so much. We're limited in our abilities. Our heads contain only so many neurons and axons. Collectively, we face no such constraint. We possess incredible capacity to think differently. These differences can provide the seeds of innovation, progress, and understanding.

INTRODUCTION

Unpacking Our Differences

You see, wire telegraph is a kind of a very, very long cat. You pull his tail in New York and his head is meowing in Los Angeles. Do you understand this? And radio operates exactly the same way: you send signals here, they receive them there. The only difference is that there is no cat.
—Albert Einstein

Alph's Wanted Poster

In the summer of 2001, Alpheus (Alph) Bingham, a vice president of Eli Lilly, created a Web site for seekers—not Quidditch-playing adolescents in pursuit of golden snitches à la J. K. Rowling's Harry Potter series—but large pharmaceutical companies in pursuit of solutions to scientific problems. These problems ran the gamut from tracing metal impurities to assessing the risks of breast cancer to detecting organic chemical vapors. Seekers posted their problems on Alph's site along with an award of up to one hundred thousand dollars that they would pay for successful solutions. Anyone willing to register could be a solver. Solvers included dentists from the Far East and physicists from the Midwest. Only the people running Alph's site knew the identities of both seekers and solvers. In the parlance of the Web, the participants were double blind.

Alph called his site InnoCentive. With it, he created a modern-day version of the Wild West wanted poster. But rather than

nailing his posters to trees all over the Dakota Territory, Alph pasted his on the Internet. He built it, and they came: by 2005, more than eighty thousand solvers had registered. They hail from more than 170 countries and span the scientific disciplines. And best of all, they've proven themselves up to the task. A study of InnoCentive revealed that solvers found solutions to nearly one-third of the posted problems.[1] A slight majority of these problems required reduction to practice—the solutions had to be demonstrable in the laboratory. For the remaining 40-some percent, pencil-and-paper solutions sufficed. One-third may seem a low success rate, but keep in mind that the typical seeker is not a seventh grader stuck on a chemistry problem, but a company like Proctor and Gamble, which has nine thousand people as its R&D staff and spends nearly two billion dollars a year on research and development. Suddenly, one-third looks good.

How could these individuals and small teams of scientists find solutions that Proctor and Gamble, with its vast and focused resources, could not? In their study, Karim Lakhani, Lars Bo Jeppeson, Peter Lohse, and Jill Panetta discovered that postings that are solved successfully tend to attract a diverse and differentiated pool of solvers. If a problem attracted a physical chemist, a molecular biologist, and a biophysicist, it was far more likely to be solved than if it attracted only chemists. In other words, InnoCentive works because it exploits diversity.

It's not information diversity that the seekers are after—for that they can Google or Ask Jeeves—it's problem solving diversity they seek. Consider this posting:

> **INNOCENTIVE 3084200:**
> **Reduction of Chemical Vapor Emissions**
> **POSTED: NOV 04, 2005**
> **DEADLINE: DEC 07, 2005**
> **$5,000 USD**
> *The Seeker is looking for creative ideas for reduction of chemical vapor emissions in a specific industry setting. You do not need to be a chemist to work on this problem. What matters most is your creative and practical mind as a scientist.*

InnoCentive takes advantage of new technology to exploit an old idea: the use of diverse, talented people to solve problems. We have to be careful here. Alph is not trying to exploit the wisdom of crowds. He's not averaging anything. He's trying to find a needle in a haystack. He's looking for a person or team who can solve the problem or part of the problem.

InnoCentive therefore, differs from Bletchley Park, the famous British code-breaking organization. At Bletchley Park people worked together—not necessarily in peace and harmony either; some of these people had sharp edges. Like InnoCentive, the Bletchley Park idea was to cast a wide net. Unlike InnoCentive, the idea was to have all the diverse fishes swim together.

To see how this worked, we need some background: during World War II, the British brought together twelve thousand people in Bletchley Park, about fifty miles northwest of London, to crack the Nazi Enigma code. The Nazis had distributed ingenious machines, smaller than manual typewriters, among their forces to create random ciphers that allowed them to communicate secretly with one another. Breaking the code was a priority for the Allies, since it allowed the Nazis to coordinate attacks both on land and at sea, deliver needed supplies, and generally coordinate their far-flung military might. The German navy was especially adept at using the Enigma code and sank, on average, sixty supply ships a month.

Many of the people brought to Bletchley Park—Brits, Americans, Poles, Aussies—had training we might think appropriate for code breaking. These included mathematicians (most notably Alan Turing), engineers, and cryptographers. But other people working in secrecy in the James Bond–like trappings of Room 40 and Hut 8 had been trained as language experts, moral philosophers, classicists, ancient historians, and even crossword puzzle experts. Imagine the drama as it unfolded:

> CRYPTOGRAPHER: Quick, we need a five-letter German word, second letter is an *o*, that means explosive device!
>
> CROSSWORD PUZZLE EXPERT: Bombe. B-o-m-b-e, bombe.
>
> LINGUIST: It's pronounced BOM-bah!

Bletchley Park cracked the Enigma code (twice). Churchill called it "the goose that laid the golden egg and never cackled." Like the solvers at InnoCentive, the goose consisted of many diverse parts.

As captivating as these examples may be, they do not show the full range of diversity's benefits. Yes, diversity can contribute to problem solving, but it can also enable collections of people to make accurate predictions. Collections of people, none of whom count as experts, none of whom can predict well alone, have proven able to make accurate predictions, not just once in a blue moon, but consistently, as has been shown in analyses of stock prices, betting lines, and information markets, such as the Iowa Electronic Markets. James Surowiecki calls this "the wisdom of crowds."

The existence of smart mobs like those created by InnoCentive and of wise crowds like those described by Surowiecki is not in dispute. Without collective intelligence, decentralized markets and democracies would have little hope of functioning effectively. Yet we do not fully understand the causes of successful collective performance. We tend to think that it rests in ability, that if we make the individuals smarter, we make the group (or mob) smarter, the crowd wiser, and the team more effective. That logic certainly holds true (with some caveats). But here I show that if we make the individuals more diverse, we get the same effects: better teams, smarter groups, wiser crowds. Unpacking this second, subtler logic takes up the bulk of what follows.

The Diversity Conjecture

One place to start our analysis is with the *Diversity Conjecture*. A conjecture is a guess. And to many, that's what this is.

The Diversity Conjecture: *Diversity leads to better outcomes.*

The diversity conjecture, as stated, suffers from vagueness and imprecision. For us, it's a great jumping-off point. We can refine it and identify conditions so that it is no longer a conjecture,

but a conditional statement. Clearly, the conjecture fails to hold universally. That's why we will proceed slowly, defining our terms along the way. Speaking of defining our terms, notice that in the conjecture, not only is the term *diversity* not defined, neither are the tasks for which it supposedly produces better outcomes. So our first steps will be to define diversity and to identify those tasks for which we expect it to be beneficial. For instance, if a loved one requires open-heart surgery, we do not want a collection of butchers, bakers, and candlestick makers carving open the chest cavity. We'd much prefer a trained heart surgeon, and for good reason. But in other circumstances, such as constructing a welfare policy, designing a physics experiment, cracking a secret code, or evaluating post–heart attack treatment, we'd want diversity. Understanding when, and why, diversity proves beneficial is the purpose of this book. We learn that often, diversity merits equal standing with ability and that sometimes, although not every time, it even trumps ability.

I show these benefits of diversity by using simple models and frameworks. I do this because simple models can be powerful drivers and clarifiers of intuition. For a glimpse of their power in clarifying thinking, consider these two seemingly conflicting sayings: "Two heads are better than one," and "Too many cooks spoil the broth." Let's construct a model of cooking. Cooking requires a recipe, which lists the ingredients and how we combine them. Most recipes consist of an irreversible sequence of instructions: *simmer the onions until brown specks form around the edges and then add two teaspoons of cayenne pepper.* In cooking, as in life, we cannot go backward. We can't uncook an onion; we cannot remove the cayenne pepper. These irreversible actions require a single course of action, a single recipe. Following multiple recipes simultaneously spoils the broth (so to speak). Too many cooks, as it turns out, aren't a problem at all. Most great restaurants employ more than one cook, but those cooks work from a single set of recipes. Moreover, even though once we have fired up the grill, we want a single plan, we may, in developing that plan, want lots of cooks. Even Julia Child didn't work alone. She had Simone Beck. Thus, it might be better to draw on the expertise

Perspectives provide one framework for how people see the world differently. A second framework, *interpretations*, highlights the different categories people use to classify events, outcomes, and situations. For example, one financial analyst might categorize companies by their equity value, while another might categorize them by industry. One voter might categorize senators by their ideology. Another might categorize them by their home state. The first refers to Olympia Snowe as a Republican. The second refers to her as a Mainer. Formally speaking, interpretations create many-to-one mappings from the set of alternatives that form categories. Informally speaking, interpretations lump things together.

A third framework captures the different tools people use to solve problems. I call these *heuristics*. These can range in sophistication from simple rules of thumb—if it's bleeding put a bandage on it; no blood, no foul—to sophisticated analytic techniques such as Fourier analysis or wavelet transforms.[5] Heuristics must be applied with respect to a particular representation of a problem, a perspective, so I'll often speak of perspective/heuristic pairs. Because people often apply heuristics in combination, a person who knows two heuristics often knows three—the third being the combination of the first two. Often these combined heuristics prove far more powerful than the individual heuristics that form them.

The fourth framework for capturing cognitive diversity, *predictive models*, describes causal relationships between objects or events. Predictive models serve as a shorthand to make sense of the world. When someone says Nebraskans are nice people or Ford trucks are durable, they map categories—Nebraskans and Ford trucks—onto the categories nice people and durable machines. Predictive models can differ: Ben Franklin believed that "cheese and salty meat should be sparingly eat." Doctor Atkins believed differently. Both sold lots of books.

If we combine perspectives, interpretations, heuristics, and predictive models, we create *cognitive toolboxes*.[6] These toolboxes provide a new way to think about intelligence and ability. We often think of people as having a level of intelligence as measured by an IQ test—where they fall on a scale that starts at zero and goes up (way up, in some cases). IQ provides us with a convenient

measuring stick. The move from measuring sticks to toolboxes obliges more than a switch of metaphors. Toolboxes change how we conceive of intelligences and how we compare them. Ranking people, as we shall see, can be a dubious exercise in the world of toolboxes.

Part II: The Benefits of Diverse Tools

In part II, I'll demonstrate *how* diversity produces collective benefits. This idea is not new. Plato said it a couple of thousand years ago. The scholar T. C. Chamberlain stated it in the scientific context more than one hundred years ago.[7] When we say that diversity leads to better outcomes, what do we mean? Do we mean better solutions to hydraulic engineering problems? Do we mean better weather forecasts? Do we mean better government welfare policies? Yes, yes, and yes.

We consider two main types of tasks: *problem solving* and *prediction*. These tasks encompass much of what collections of people do: we generate alternatives and we evaluate possibilities. Who performs these tasks? Small work teams, large organizations, and entire societies do. Teams of civil engineers solve water-flow problems (problem solving). Financial analysts predict the stock price of Kodak (prediction). University hiring committees choose a new employee (problem solving—what kind of scholar do we need?—and prediction—can this person do good research?).

If we hope to reap diversity's benefits, we need this logical connection. We need to understand the conditions under which diversity produces benefits. We cannot convene diverse groups and expect an instant utopia bursting with ice cream, ponies, and cedar plank–grilled salmon soaking in a black truffle oil and white wine reduction, but it will help.[8]

In analyzing problem solving, I focus on the roles played by diverse perspectives and heuristics. Diverse perspectives increase the number of solutions that a collection of people can find by creating different connections among the possible solutions. What one person sees as a small step—attaching our mittens to a string

of yarn running through our coat sleeves—may seem a giant leap for another. Diverse heuristics have similar effects. Given a solution, more heuristics allow problem solvers to explore more potential improvements.

The analysis of problem solving culminates in two main results. First, I state a claim that *diversity trumps homogeneity*: collections of people with diverse perspectives and heuristics outperform collections of people who rely on homogeneous perspectives and heuristics. Second, I state a conditional claim that *diversity trumps ability*: random collections of intelligent problem solvers can outperform collections of the best individual problem solvers. This result relies on four conditions: (1) The problem must be difficult; (2) the perspectives and heuristics that the problem solvers possess must be diverse; (3) the set of problem solvers from which we choose our collections from must be large; and (4) the collections of problem solvers must not be too small.

I then consider predictive tasks. People might want to predict any number of outcomes: the price of a stock, the winner of an election, the box office receipts of a movie, the winner of a sporting event, or the sales of a new product. In making predictions, people rely on predictive models. Aggregating predictive models differs from aggregating information (where some people know the answer and others do not). Models of incomplete information are commonplace in economics and political science, but those models rely on signals. The predictive model framework provides a plausible source of these signals and, in doing so, establishes a central role for cognitive diversity in the smooth functioning of democracies and markets.

In the chapter on prediction, I show two main results: that diversity and accuracy contribute equally to collective predictive performance, and that a crowd's collective prediction must always be at least as good as the average prediction of a member of the crowd. I call these the *Diversity Prediction Theorem* and the *Crowds Beat Averages Law*. The first result implies that we should not think of predictive ability as of paramount importance and predictive diversity as something that contributes only around the margins. Ability and diversity enter the equation equally. This

result is not a political statement but a mathematical one, like the Pythagorean Theorem. In this chapter, I also compare crowds against experts as well as information markets against polls. I show how information markets create incentives for both accuracy and diversity, which may explain why they work better than polls.

Part III: Diverse Values: A Conflict of Interests (Or Is It?)

Up to this point, the results should bring joy and happiness. We might all think diversity is a wonderful thing. That's because we've ignored *diverse preferences*, differences in what we value. Preference diversity differs from toolbox diversity: Toolbox differences do not create conflict. Preference diversity can and does. For this reason, management books stress agreeing on a common goal—a common *fundamental* preference. If people disagree about what they're trying to accomplish, they function poorly as a collective.

Common fundamental preferences need not imply agreement. People can also have diverse *instrumental* preferences. They can differ on how they think it best to cross a particular finish line. In other words, people can disagree over means as well as ends. Instrumental preferences are preferences about means, so they implicitly contain predictive models. We like (or don't like) a policy of a higher minimum wage because we think it helps (hurts) workers. This distinction between fundamental and instrumental allows two people to agree over the destination—a romantic dinner at Charlie Trotter's restaurant in Chicago—but to disagree over how to get there—cab or train.[9]

My treatment of the potential problems created by preference diversity is at best a flyover of the relevant results—"Look, there's the Grand Canyon." The first result, Arrow's Theorem, gives conditions under which individual preferences do not aggregate into a collective preference. The second result, proved by Charles Plott, states that with majority rule voting, any proposed

alternative can be defeated by some other alternative. The third result, proved by Richard McKelvey and Norman Schofield, states that if people vote sincerely, then a sequence of majority rule choices could lead anywhere. We could even have action figure governors! The final result, proved simultaneously by Mark Satterthwaite, an economist, and Allan Gibbard, a philosopher, states that people have incentives to misrepresent their preferences.

These four results paint a bleak picture only if we believe preference differences to be fundamental. In many organizations and communities, members all pull for the same goal. What preference diversity does exist is instrumental. If so, I'll argue that the negative results aren't so bad after all.

I complete this third part of the book with a brief analysis of how toolbox and preference diversity interact. In doing so, I turn some of the intuitions from the previous chapters on their heads. Diverse perspectives, which we touted as a panacea, have a dark side—they lead to the discovery of lots of possible alternatives. If people have diverse fundamental preferences, they less likely agree when they have more possible choices. On the flip side, diverse fundamental preferences, which cause so many problems when making choices, prove beneficial for problem solving. What we desire influences how we look at problems, the perspectives we choose. Thus, collections of people with diverse preferences often prove better at problem solving than collections of people who agree. Difference of opinion not only makes a horse race, it also makes for effective, albeit sometimes contentious, teams.[10]

Part IV: Does Diversity Produce Benefits? The Pudding

The first three parts of the book present a logic of diversity. They explain how diversity produces benefits. Yet, many people care about "facts." These people want to know whether the logic has empirical support, if evidence fits the theory. In the fourth part of the book, I take on that question. I do so with some trepidation. If we do not know how something works, demands for empirical support are premature. If we don't understand how

Overall, the group-level findings are similar to what has been found at the city and country level. If well managed, identity diversity can create benefits, provided it correlates with cognitive differences and provided the task is one in which diversity matters.

Summing all this up, yes, race, gender, and ethnicity matter, but so do our *experiences*: the friendships, road trips, chance meetings, and pancake breakfasts that combine to form a life. *Education* and *training* also influence our collections of cognitive tools. Diversity has many causes. That's good.

Part V: Going on the Offensive

Part V takes the logic out into the real world. I show how to go on the offensive, how to leverage diversity to produce better outcomes. Length considerations preclude this part of the book from reaching greater depths. What I cover, though preliminary, provides a useful start. (Given the power of diversity, I'm also guessing that others out there will see even more applications.)

My advice tends to be more general than specific—how organizations might best leverage diversity, how the models might be applied to hiring decisions as well as college admissions. Some of the advice is intuitive—bring in outsiders—but other bits of advice are less so: encourage preference diversity, avoid lumping, and distinguish aggregation from compromise. My final piece of advice is to maintain humility and embrace the mysteries of diversity. We cannot expect to understand the mysterious origins of new ideas and breakthroughs.

The Logic in Context

Before continuing, let's stop and situate the contributions in three larger contexts. First, the logic points to potential benefits from globalization beyond great food, awesome music, and amazing art. Yes, cultural awareness prevents boneheaded actions.[15]

But the logic suggests that the benefits of a globalized workforce extend far beyond better understandings of local markets. People with different life experiences and training, people from different cultural backgrounds, likely see the world differently. And those differences—differences in perspectives—can be valuable when solving problems or making predictions.

Second, the logic can and should be read as supportive of interdisciplinary research. People with different disciplinary training naturally bring diverse understandings and tools to problems. That diversity of tools can lead to breakthroughs that would not occur, or would occur more slowly without interdisciplinary research. Many university administrators preach interdisciplinary research. This book provides a logic for continuing to break down the barriers that separate the disciplines.

Finally, the logic applies to recent defenses of affirmative action policies. Affirmative action policies take many forms. The reasons for affirmative action have shifted over time, at least in the eyes of the courts. Initially, affirmative action policies were motivated by the desire to redress past and current discrimination. Later, following rioting in the 1960s, some saw affirmative action policies as a way to hold society together. Police departments were allowed to have racial goals so that their officers reflected the communities they served. Schools have also attempted to have teachers match their communities' demographics, but the courts have not always supported those policies.

The logic in this book can be used to support an *instrumental* argument for affirmative action. If diversity produces benefits, then schools, firms, and organizations should be able to give a leg up to underrepresented people. The instrumental defense has become central in recent court decisions.[16] The extent to which this logic supports race-based affirmative action depends on empirical facts: *either identity diversity correlates with cognitive diversity or it does not.*

Not all advocates of affirmative action view the instrumental argument positively. Some fear that it covers historical injustices and current discrimination under a large multicolored rug.[17] This book helps us to think through when it would and would not

hold. It helps us sort the logical from the illogical. For example, in his dissenting opinion on the cases involving the University of Michigan's law school admissions policies, Supreme Court Associate Justice Antonin Scalia wrote that Michigan was suffering from logical dissonance. On the one hand, Michigan wanted a "super-duper" law school (that's legalese meaning "really good"). On the other, it wanted to be diverse. Justice Scalia presented these two facts as contradictory.

They are not. Diversity and super-duperness can go hand in hand: a great law school may require a diversity of perspectives, interpretations, heuristics, and predictive models. A great law school benefits from including people with diverse preferences (law students like to argue, even more so than lawyers). So if we believe that differences in race, gender, ethnicity, physical ability, religion, sexual orientation, and so on correlate with cognitive diversity, then being super-duper *may* require some identity diversity. And, moreover, super-duperness may *always* require identity diversity, long after discrimination ends.

That same logic does not necessarily translate to every sector of the corporate world. Universities have different goals than companies. Despite their reputation as EMOs (endowment maintenance organizations), universities seek to do research, educate, and serve. In a university classroom, students and faculty learn from one another. Far less cross-fertilization of ideas takes place in a firm that employs traveling salespeople.

And Away We Go

With the requisite captivating example, background, overview, and contextualization in place, we can now turn to the fun part—the frameworks and models. Once built, they allow us to demonstrate that when confronted with a difficult task, be it solving a problem, predicting the future, or making a choice, we benefit by including diverse people. In such situations, we might think about gathering together the best and brightest minds, but that's a flawed approach. We also need to pay attention to the

diversity of those minds, all the more so if the old saying that "great minds think alike" holds true.

As a note of warning, what follows contains a little bit of mathematics. Anything difficult has been relegated to the notes. What the editors allowed to remain should be accessible to almost everyone. If you can handle equations like "force equals mass times acceleration" ($F = MA$) and the Pythagorean Theorem ($A^2 + B^2 = C^2$), you'll be fine.[18]

For those more mathematically inclined readers (hint: my professional colleagues), accept in advance this apology for the necessary overgeneralizations. Many of the claims in the book can be stated with greater clarity and precision. Those who want the details in more detail can peruse the academic papers that Lu Hong, Jenna Bednar, and I have written in the stark, cold language of the academy.[19] These papers (all available on my Web site) contain the mathematical chest thumping—the epsilons and sigma algebras—that one expects from a card-carrying mathematical social scientist.

Churchill called Bletchley Park "the goose that laid the golden egg," and so it was. Someday, InnoCentive-inspired organizations may well become gaggles that produce golden eggs by the truckload. We can hope. But we must keep in mind that as plastic as our brains may be, they're individually limited. Collectively, they're less limited, but only if they're constructed differently. One light bulb, even the one over Edison's head, is not as bright or as interesting as a string of multicolored lights. Those Apple Corporation ads give sound advice: Think different. In difference lies the potential to contribute.

Part One

UNPACKING THE TOOLBOX

As the excerpt from the essay "Experience" makes clear, Emerson believes that how we experience the world influences how we perceive it. That is certainly true. But what are the implications of those differences? To answer that question, we need first to make better sense of what those differences are. In what follows, we too see mountains; we call them rugged landscapes. These represent difficult problems. And to quote Emerson yet again, "The difference between landscape and landscape is small, but there is a great difference in the beholders." Those beholders who see landscapes sublimely we call geniuses. We can quibble about what it means to be a genius, and even about the extent of Emerson's contributions, but we cannot deny his ability to see clearly what for so many others was muddled and confused. And so, it's appropriate that we begin at his front porch. And as we take leave, we remind ourselves to follow his sage advice, to slow down the wheel.

We slow down the wheel for a specific purpose: to understand the potential benefits of diversity. Our goal is to understand when and how diversity is beneficial. We want to move beyond metaphor and reach a deep understanding. Eventually, we do that. I'll state formal results that show that when solving a problem, diversity can trump ability and that when making a prediction, diversity matters just as much as ability. In order to make those formal claims, I need to lay a foundation.

As an analogy, consider the mathematical theorem that the area of a rectangle equals the base times the height. That result makes sense only if we know that we mean by *base* and by *height*. We have to define those terms. The same holds here. To show that diversity is beneficial, we need to define terms and concepts, so we do. I define *perspectives* (ways of representing the world), *heuristics* (techniques and tools for making improvements), *interpretations* (ways of creating categories), and *predictive models* (inferences about correlation and cause and effect).

These formal ways of capturing diversity we then lump together and call them a person's toolbox. That's how we think of people's capabilities—as their collections of tools. We then use this toolbox framework to explore if, why, how, and when toolbox diversity produces benefits. We have to wait to do that, though. First, we must learn about the tools themselves.

CHAPTER 1

Diverse Perspectives

HOW WE SEE THINGS

Those French, they have a different word for everything.
—Steve Martin

We all differ in how we see and interpret things. Whether considering a politician's proposal for changes in welfare policy, a new front-loading washing machine, or an antique ceramic bowl, each of us uses a different representation. Each of us sees the thing, whatever it is, in our own way. We commonly refer to the ways we encode things as *perspectives*. But if asked what a perspective is, most of us would have only a crude idea. In this chapter I provide a formal definition, but before I get to that I'll present an example of a famous perspective: the periodic table.

In the periodic table each element has a unique number. These numbers help us to organize the elements. They give structure. Compare this perspective to the perspective that uses common names such as oxygen, carbon, and copper. By convention we know what those names mean—copper is a soft brownish metal that conducts electricity—but the names don't create any meaningful structure. They are just names. We could just as well give copper the name *Kamisha*.

Mendeleyev's periodic table gave us a meaningful structure. Coming up with that perspective took hard work. To discover

the structure of the elements, Mendeleyev created cards of the sixty-three known elements. Each card contained information about an element including its chemical and physical properties. Mendeleyev then spent hours studying and arranging these cards, transforming the problem into a representational puzzle. Eventually, Mendeleyev pinned the cards to the wall in seven columns, ordering the cards from lightest to heaviest. (Imagine playing solitaire on the wall using thumbtacks.) When he did this, he saw a structure that was completely understood only three decades later with the introduction of atomic numbers. Before Mendeleyev, atomic weight had been considered irrelevant. A scientist could order the elements by atomic weight from lightest to heaviest, but he could also arrange them alphabetically or by the number of letters in their name. Why bother?

As some of the elements had not been found, Mendeleyev's table had gaps. New elements were soon found that filled those gaps. Mendeleyev took information, turned it into the pieces of a puzzle, and showed us that pieces were missing.[1] Mendeleyev's representational puzzle, unlike the problem of finding the chemical composition of salt, lacks a physical analog. He was not searching for an existing structure; he was creating a structure out of thin air. That structure revealed order in the stuff of which we're made. His story is not unique. We can find stories like Mendeleyev's throughout the history of science—think of Copernicus and the heliocentric universe, or of Einstein and the construction of relativity theory. In both cases, someone saw the world differently—Einstein linked space and time—and what had been obscure, confusing, or unseen became clear.

Scholars from a variety of disciplines have studied how people and groups make breakthroughs. The common answer: *diverse perspectives*. As the philosopher of science Steven Toulmin wrote, "The heart of all major discoveries in the physical sciences is the discovery of novel methods of representation."[2] New perspectives, what Toulmin calls "novel methods of representation," are often metaphorical. The canonical model for earthquakes, for instance, involves blocks connected by springs, which can then be analyzed rigorously using mathematics.[3] Though we know perspectives