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The New Literacy

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As information becomes ever more quantitative and as society relies increasingly on computers and the data they produce, literacy requirements expand beyond natural language to include logical reasoning and quantitative practices.

Ever since computers opened the floodgates of the information age, we have been caught in a rising tide of numbers. The ascendancy of quantitative information has changed profoundly not only the environment in which we live and work, but also the entire framework of civic life. Headlines proclaim deficit projections and unemployment numbers, holiday deaths and political polls. Editorialists debate the impact of unemployment figures on stock market trends, the cost savings of managed health care, and the impact of estrogen supplements on breast cancer rates. Behind the scenes, the mechanisms of everyday life depend increasingly on digital technology—from cellular phones to ATM machines, from bar codes to the World Wide Web.

Like hundreds of other matters small and large that command our daily attention, these constructs of modern civilization depend at their deepest level on *quantitative* information. Does the Dow Jones average really measure the state of the economy? How can one best evaluate the quality of health care? Do polls influence or just predict how people vote? How strong is the evidence linking estrogen supplements to increased rates of breast cancer in older women? Do the new bar code readers make more or fewer mistakes than trained check-out clerks? How secure are bank accounts from ATM fraud?

Numeracy is the new literacy of our age. As the printing press gave the power of letters to the masses, so the computer gives the power of numbers to ordinary citizens. The entire federal budget is on-line, available for down-loading and analysis by any person with access to a networked computer. So too are school board budgets, mutual fund values, and local used car prices. Every desktop computer includes spreadsheet software more powerful than programs available to professional accountants twenty years ago. No longer is the calculation of car loans or mortgage rates an esoteric specialty known only to bankers. Now all numerate citizens may determine for themselves the economic impact of their own decisions, and of the decisions their elected representatives are making on their behalf.

But just as literacy was relatively rare five centuries ago, so is numeracy today. Only one in ten U.S. adults can reliably solve problems that require two or more steps. [1] Even fewer can comprehend the complexity of issues that underlie clinical trials of new treatments for AIDS or think through the implications of a flat tax system. Reports from international comparisons continue to show only mediocre performance from U.S. students. [2] Data from the SAT and the National Assessment of Educational Progress (NAEP) document major gaps between national goals and accomplishments. [3] The majority of today's high school graduates—not to mention drop-outs—still lack fundamental "walking around" skills in quantitative literacy. When it comes to numeracy, our nation is still very much at risk.

Facing the Challenge

People often compare today's intractable problems with our success in landing on the moon. If we can put a man on the moon, why can't we cure cancer, or eliminate welfare, or reduce crime? The difference between these challenges lies not in their difficulty, but in the precision with which they are defined. Even though the moon is a moving target, it moves predictably; we know precisely where it will be, and we know when we have touched down. But cancer, welfare, and crime are not so clear; they are amorphous, evolving, and embedded in larger biological or social structures.

So too with quantitative literacy. Whatever this phrase may mean—and as the essays in this volume testify, it means very different things to different people—quantitative literacy is clearly an artifact of our culture. It serves many functions, including home, school, recreation, finance, work, testing, parenting, and citizenship. It requires a working synthesis of literacy and numeracy; it evolves with technology; and it both shapes and is shaped by society.

Regardless of name—numeracy, mathematics, quantitative literacy, or the derisive "'rithmetic," —this kind of literacy is widely recognized as of fundamental importance. Yet beyond "the basics," there is little agreement about specific goals appropriate for tomorrow's world. No wonder, then, that we have made so little progress in achieving numeracy. The tension between easy agreement about importance and continuing confusion about goals produces an unhealthy paralysis in our nation's effort to become quantitatively literate. The chief purpose of this volume is to unfold for public discussion these diverse and often conflicting perspectives.

Authors in this volume speak from dissimilar professional experiences—industry and academia, government and education—and express contrasting views about the nature and importance of quantitative literacy. Although all the authors have studied mathematics in school and use quantitative tools in their lives and work, their careers have been, for the most part, in what educators like to call the "real" world: outside the classroom. Thus they speak about quantitative literacy not as mathematics educators, but as mathematics consumers. Different (but equally diverse) perspectives of mathematicians and mathematics educators are provided in the concluding chapter.

An Informed People

Expectations for numeracy have changed very rapidly in the last two centuries. In 1800, the most quantitatively literate members of society were merchants, not scientists. In fact, many people who today are just marginally numerate make more use of numbers than did scientists at the end of the eighteenth century. [4] Numbers became really useful only after the French introduced the metric system in an attempt—still not fully successful—to overcome computational complexity and regional units of measure.

The advent of numbers as a staple of civil service enabled the rise of central administrative bureaucracies which were essential to new democratic societies. Nation-building depended on the flow of information "from the periphery to the center," [5] which most usefully took the form of numbers that could be added, averaged, graphed, and analyzed. Indeed, the term "statistics" first arose at this time as the science of the state. [6] In post-revolutionary France and America, literacy and numeracy took on special political importance. An informed citizenry is "the only sure reliance for the preservation of liberty," Thomas Jefferson wrote to James Madison in 1787. [7] To participate in democracy, citizens needed the literacies of the state—which for the first time included numeracy.

To advance civic affairs, Jefferson relied not only on arithmetic and calculation, but even more on the mathematical legacy of deductive inference. The influence of axiomatic reasoning on the rhetorical style of the Declaration of Independence is revealed in its anchoring words: "We hold these truths to be self evident ... ." The source of civic consensus in a democracy, these revolutionists declared, is neither divine authority nor decisions of a monarch but deductive logic from "self-evident" propositions. Every since, U.S. society has been constrained by a rule of law adjudicated by a Supreme Court whose decisions—and dissents—are highly mathematical arguments based on propositions, stipulations, deductions, exceptions, exclusions, and conclusions.

At the time of the Civil War, literacy meant only the ability to sign one's name. By World War II, literacy for conscripts was defined as a fourth grade education; in mathematical terms, that meant basic arithmetic—what Lewis Carroll mocked as "ambition, distraction, uglification, and derision." Twenty-five years later, in launching the Great Society's war on poverty, the U.S. government defined literacy as an eighth grade education—implying, in mathematics, a practical understanding of percentages as well as the ability to solve simple multi-step problems.

Today most analysts agree that these "basics" are not enough, although few agree on just what more is needed. Mathematics educator Bob Moses speaks of algebra as "the new civil right." [8] Many educators and scientists urge higher order thinking—open-ended problems, cooperative learning, communication skills. Worried parents urge emphasis on basic skills and argue for teaching methods that they remember from their school days. Indeed, the most abiding public concern seems to be that education proceed in an orderly and predictable fashion. The public emphasis on basics is not "just the basics," but "first the basics." [9]

Yet despite increasing civic, educational, and economic incentives for quantitative literacy, evidence of innumeracy is not hard to find. Only two in five adults can figure correct change and tip from a restaurant bill, while only one in five can draw correct inferences about the length of a trip from a bus schedule. [10] On national measures of quantitative literacy, fewer than one in ten adults score in the highest category—which itself is only comparable to the expectations of first year algebra. [11] Indeed, when asked a question about alternative tax plans that was remarkably similar to policy proposals under debate in the recent presidential election, only one out of twenty adults responded correctly. As we approach the twenty-first century, civic numeracy falls far short of the Jeffersonian ideal.

An Empowered Public

Numeracy is the currency of modern life. As it has grown in importance, it has also expanded in scope—from arithmetic in 1940, to percentages in 1960, to data analysis in 1980, to spreadsheets in 2000. And as its importance and scope have expanded, so have the economic and social consequences of innumeracy.

Much of the current emphasis on quantitative literacy is motivated by concerns about changes in a job market in which competition is no longer just regional or national, but global. The importance of quantitative literacy for employment is primarily a phenomenon of the post-war era, and most notably of the computer age. Quantitative methods of inventory and quality control were introduced to support the industrialization surge during World War II, and have in various forms dominated industry ever since. Today’s managerial buzzwords such as total quality management (TQM) and statistical process control (SPC) are direct descendants of methods introduced during the war effort. More recently, the spread of computers has brought in its wake an extraordinary reliance on quantitative methods in the work place, often centered on various manifestations of spreadsheets and graphical presentation software.

Biologist and National Science Board (NSB) member Shirley Malcom views quantitative literacy, particularly algebra, as a fundamental tool that can empower everyone—but especially the disenfranchised—regardless of background. Algebra is not just about solving equations, but about modeling the world. "To go from unknowns to knowns is a very powerful idea. We must learn to see algebra as a powerful friend with extraordinary explanatory power." [12] In like fashion, the NCTM *Standards* [13] uses the metaphor of "mathematical power" to build the case for a three-year high school curriculum for all students. These *Standards* focus on providing all students—not just the college-bound—with the power of algebra, despite lack of agreement even among professionals on just what algebra is supposed to be [14, 15].

Although "algebra for all" is a valuable policy lever in the campaign to remedy innumeracy, it is but one aspect of quantitative literacy, much of which ranges far outside the traditional boundaries of school mathematics. Some goals for numeracy are drawn from the world of work, whereas others focus more on preparation for life. In this broader context, the focus of quantitative literacy would not be algebra, but whatever quantitative skills are needed to function in society. In today's world, spreadsheets may be more important than factoring polynomials, control charts more important than quadratic equations.

But even these broader skills are insufficient to meet the challenges of today's data-drenched society. Algebra, whether old (equations) or new (spreadsheets), is still about quantities—numbers and values, variables and parameters. For engaged citizenship in the twenty-first century, logical thinking, analysis of evidence, and statistical reasoning are far more important than traditional algebraic and mathematical skills. [16] The new literacy, from this perspective, is really about reasoning more than 'rithmetic: assessing claims, detecting fallacies, evaluating risks, weighing evidence.

What *Are* We Talking About?

It may be about time to attempt to clarify terms. For most people, *quantitative literacy* and *numeracy* are essentially synonyms, although the latter is more commonly used in British English. Both suggest a very close relation with numbers and quantities, even though there is much more to mathematics than numbers. (In some circles, however, the term "quantitative literacy" has taken on a more narrow meaning, referring to particular parts of the school curriculum centered on exploratory data analysis and elementary statistics . [17])

Because numerical manipulations are less subtle than logical thinking—and more easily mechanized—many people believe that *quantitative reasoning* describes with far greater felicity what we are trying to achieve. Certainly the goals of engaged citizenship and high-performance work require constant thoughtfulness, not merely accurate calculations. They also require action, not just observation. For this reason, some advocate *quantitative practices* as a way of emphasizing purposefulness and accomplishment.

Mathematicians and mathematics educators (but few others) sometimes talk about *mathematical literacy,* leaving unclear whether this term is intended as a synonym for quantitative literacy. Since mathematics is generally recognized as being about more than number and quantity, the umbrella of "mathematical literacy" can provide a more welcome home for notions of reasoning (logic), space (geometry) and data analysis (statistics). But for most lay persons (as well as most mathematicians), mathematical literacy conveys a sense of advanced accomplishment more suitable to pre-professional purposes than to general literacy. [18]

School mathematics also intrudes into this discussion since it is the primary source of quantitative literacy for most adults. The *de facto* achievement of mathematics education in the United States has been something approximating the traditional seventh or eighth grade curriculum: percentages, a bit of algebra, and simple geometry. That's all the mathematics that typical adults can remember ten years after they finish school.

There appears to be reasonable consensus among individuals of widely differing perspectives on the natural growth of numeracy from the basic arithmetic of grade school through the more sophisticated numerical reasoning of measurement, ratios, percentages, graphs, and exploratory data analysis that is now the centerpiece of middle school mathematics. Confusion over definitions and disputes about priorities emerge primarily beyond this level—at the core of high school mathematics. Many people identify quantitative literacy with the mathematics required of all high school graduates, whereas others view mathematical performance and quantitative literacy as two rather different enterprises.

What Do Others Think?

Around the world, all nations emphasize the use of mathematics in everyday life and its applications to other subjects. In addition, some countries stress its utility in employment, some its utility in promoting the power to reason, and a few (e.g., Italy, France) take as an explicit goal to promote precise use of language. Other goals found internationally are to stimulate the imagination; to stress the qualities of methodical, careful work; to learn to enjoy mathematics; and to value mathematics as a subject in its own right. [19]

One of the most influential and well-researched analyses of numeracy is *Mathematics Counts* [20], the 1982 report of a British committee of inquiry on school mathematics. This report identified among the mathematical needs of adult life the role of mathematics as a means of communication and an "at homeness with numbers" that permits an understanding of information presented in mathematical terms. Mathematics, these authors argue, is useful precisely because it provides “a means of communication which is powerful, concise, and unambiguous."

In our own country we can find any number of similar recommendations. An influential 1981 report from the Alfred P. Sloan Foundation [21] identified analytic skill as a "new liberal art" that provides "prodigious power." To ignore analytic skills is to "ignore the nature of the world in which the graduate will live." A few years later *A Nation at Risk* [22] argued that high schools should equip graduates to "apply mathematics in everyday situations." And in 1986 NAEP adopted a new definition of literacy that included two parts (document and quantitative) that are both actually components of numeracy. [23]

In 1988, John Allen Paulos' popular book *Innumeracy* [24] created instant public awareness of the issue and the word. For Paulos, innumeracy was signaled by the public's inability to deal with big numbers or to estimate the likelihood of coincidences. This kind of innumeracy leads to massive public confusion about issues such as political polling, medical consent, and safety regulations. For Paulos, numeracy requires, among other things, recognition of the "irreducibly probabilistic nature of life."

Perhaps because of increased public concern about the economy, recent statements about quantitative literacy have focused a bit more on issues with pocketbook implications. In 1991 the SCANS report [25] from the U.S. Department of Labor described "what work requires of schools" in terms (resources, information, systems, interpersonal, and technology) that are very different from the traditional curriculum that is organized into separate disciplines. Following this, in 1995 the National Research Council reported related goals for the mathematical preparation of the technical work force: "The type of problem solving the workplace demands and schools should emphasize is very different from the type many schools now teach." [26]

What Are Our Goals?

This broad and jagged range of goals for numeracy, both national and international, was summarized in a special issue of *Daedelus* devoted to "Literacy in America" under five different dimensions of numeracy: *practical*, for immediate use in the routine tasks of life; *civic*, to understand major public policy issues; *professional*, to provide skills necessary for employment;

recreational, to appreciate games, sports, lotteries; and *cultural*, as part of the tapestry of civilization. [27] This categorization, though relatively comprehensive, does not so much define quantitative literacy as provide a framework for continued discussion. What remains is the hard question: establishing priorities.

One view widely supported by mathematics educators uses "quantitative literacy" as an umbrella for important aspects of mathematics, for example, data representation; numbers and operations; variables and relations; measurement; space and visualization; and chance. [28] It is easy to see behind these terms the names of common mathematics courses such as statistics, arithmetic, algebra, geometry, and probability. They also parallel closely the fundamental strands of mathematics identified in a 1990 report of the National Research Council: quantity, change, dimension, shape, uncertainty. [29]

An important alternative view favors "reasoning" over "literacy," in part because calculation—the analog of reading—is no longer the primary need of citizens. Indeed, quantitative reasoning has been described as a "cognitive emulsion" of four very different kinds of thinking: logical, algorithmic, visual, and verbal. [30] One can see in these categories echoes of the "four-fold way" that has become the mantra of recent reform efforts in mathematics education—that students need to learn to make transparent transitions among four different mathematical representations: algebraic, numerical, graphical, and verbal. [31]

Many people, especially those who focus on the role of mathematics in employment, believe that the goals of quantitative literacy need to be more specific and pragmatic. "Problem solving" is one of the banners under which pragmatism sails. Since a problem can be thought of as something you don't know how to do, in solving a problem you are really transforming the problem into something you do know how to do. Solving open-ended real-world problems requires responsiveness to two masters: solutions must be both mathematically defensible and useful in the real world. [32] This requires not only the tools of quantitative literacy and quantitative reasoning, but also a wealth of external problem-solving strategies that depend on the scientific, managerial, and social contexts in which problems arise.

For many managers and engineers, quantitative practices are more important than literacy. Practices encapsulate the actions, habits, procedures, and processes of people who actually do things, whereas literacy emphasizes the descriptions, theories, models, and rules of people who study things. [33] Practices are messy, frequently *ad hoc*, sometimes inexplicable, and always evolving in harmony with technology. To empower citizens for active participation in the world in which they live and work, numeracy must include robust, action-oriented quantitative practices.

Providing Context

Too often we take for granted the practical benefits of numeracy. Since the age of Plato and Euclid, mathematics has been recognized as a formal science of patterns abstracted from real contexts that are irrelevant and distracting. Circles and squares are Platonic forms with properties derived from logic, not from the measurements made on imperfect real-world models.

The abiding mystery of mathematics, in Eugene Wigner's memorable phrase, is its "unreasonable effectiveness." [34] Quantitative properties of the world do generally conform to mathematical predictions. Moreover, the context of real-world problems shapes the practice of mathematics—by revealing patterns, imposing constraints, suggesting challenges, and foreshadowing theories. Nonetheless, deduction, not measurement, is the arbiter of truth in mathematics.

The role of context in mathematics poses a dilemma which is both philosophical and pedagogical. In mathematics itself, context obscures structure, yet when mathematics connects with the world, context provides meaning. [35] Even though mathematics embedded in context often loses the very characteristics of abstraction and deduction that make it useful, when taught without relevant context it is all but unintelligible to most students. Even the best students have difficulty applying context-free mathematics to problems arising in realistic situations, or in applying to a new situation what they have learned in another context.

Scientists are among those who often argue that quantitative literacy must be contextual. In science, as at work and in life, almost every number of interest is a quantity—a measurement with a unit and an implicit degree of accuracy. Even the numbers that dominate discussions of civic policy (e.g., indices of population, inflation, trade, crime) are numbers in contexts. Unfortunately, too many mathematics classrooms are "the natural home of measurement-free numbers." [36]

The practice of separating symbols from context in mathematics instruction has also contributed to a widespread impression that what is taught in school is not what is most relevant for work. Much of the current impetus for improving quantitative literacy arises from the perception that advancement along a career path depends increasingly on quantitative and analytical skills. According to Robert Reich, former Secretary of Labor, the greatest imbalance between demand and supply is found in mid-level technical jobs that require modest levels of quantitative literacy. Indeed, many relatively elementary mathematical skills are undersupplied relative to demand in today's job market. There is some evidence that wages are influenced most by mastery of mathematical skills normally taught no later than eighth grade [37] and that many employees believe they could do their jobs better if they had greater facility with these kinds of quantitative skills. [38]

In recent years, the U.S. Departments of Education and Labor have supported development of occupational and industrial skill standards designed to clarify the prerequisites for entry level jobs in a variety of industrial sectors. [39] Unfortunately, the mathematical content of these occupational standards is relatively low—primarily eighth or ninth grade level. While these minimal expectations conform to current employment practices, they pose a major challenge for education: how to justify and motivate secondary school mathematics when important government and business reports appear to say that eighth grade mathematics is sufficient.

Schools, of course, must prepare students both for work and for postsecondary education. For many reasons, the traditional means of meeting these two goals simultaneously—vocational tracking—is no longer acceptable. Programs that "stress the applied at the price of the conceptual" are no longer acceptable. [40] "Curricular ghettos will not work in the new economic reality," comments NSB member Malcom. [41] Schools can no longer prepare some students just for work and others for college. Today, they must prepare all students for both. Yet despite the virtually unanimous urging of educational and policy experts, schools still permit, even encourage, tracking.

In reality, the quantitative requirements of modern high-performance work involve problems that require sophisticated reasoning and practice, but often with only elementary mathematical skills. In contrast, the mathematics that students study to prepare for college requires advanced skills with abstract concepts deployed in simple (and simplistic) problem situations. [42] The difference in balance between these dimensions of quantitative literacy—higher-order problem solving on the one hand, advanced abstract mathematics on the other—accounts for much of the strain in education between vocational and academic programs.

A more promising strategy may be to engage students in challenging work-based environments that provide context for their academic courses. Conceive of work broadly, with long-term goals. Instead of carpentry or plumbing, introduce students to the entire construction industry; instead of electronics, focus on telecommunications. Engage significant mathematics at work. Test major topics against the key question: does anyone pay to have this kind of problem solved? Eliminate topics that are of little value, while stressing neglected mathematical skills that are much in demand in the work place. A well-designed broad-based work-centered curriculum will not only provide a powerful context for mathematics, but can also demonstrate to parents, teachers, and students that vocational training is not incompatible with high mathematics standards. [43, 44]

Can Education Help?

"You know, they put those numbers in front of us and we just had to figure them out. It was never fun. It was just grueling...something you didn't really want to do."

"When I tried to do it, I felt like I had to throw up. It just wouldn't make any sense at all. I couldn't comprehend what's going on...I would just shut down completely. I wanted to learn, but I just couldn't get it."

These parents participating in California's "Family Math" project speak for millions who have suffered through mathematics in school. [45] No wonder mathematics is the butt of cartoons and a sure target for comedians. ("So long as there is math, there will always be prayer in schools.") Family Math parents want to help their children, but are paralyzed by fear of doing something wrong. "I feel frustrated because the way I was taught is not the same method that is being used to teach my daughter." "I see the books my son [in fourth grade] brings home, but most of the time I don't understand the math that is done there, so I can't help him."

Too often numeracy in school turns out to be just a sterile version of formula appreciation. The incantation $A = \pi r^2$ carries about the same meaning for most people as does $E = mc^2$. Most of the reform efforts in mathematics education for the last half century or more have struggled with the problem of restoring meaning to mathematics. "If you change the way mathematics is taught, you'll be surprised at who can learn mathematics. The idea of fitting the subject to the audience is real uncharted territory." [46] What we do know is that memorizing formulas doesn't make anyone literate.

Despite lip service paid to the importance of applications, school mathematics continues to emphasize school-focused goals rather than the goals expected by the outside world. [47] Becoming numerate is much more than knowing mathematics. It involves, among other things, a synthesis of literacy and numeracy that is rarely encouraged in school and a range of contexts from computation through decision-making to interpretation. Too often, school mathematics stops with computation.

So too does mathematics in college. Relatively few colleges or universities actually focus on quantitative literacy for all students. Of those that do, it is rare to find any that exceed in expectations what the NCTM now recommends for all high school graduates. Both the Mathematical Association of America (MAA) and the American Mathematical Association of Two year Colleges (AMATYC) have recently issued reports [48, 49] containing recommendations for quantitative literacy in undergraduate courses, but very few institutions have programs that meet these guidelines. Students need multiple opportunities and multiple inducements to develop their quantitative skills. These skills cannot be mastered in any one course, but, like writing, must be reinforced by repeated use in many courses and not just offered by mathematics departments. [50]

Why Numbers Count

The relentless quantification of society continues unabated. The tendency to reduce complex information to a few numbers is overwhelming—in health care, in social policy, in political analysis, in education. The production of uniformity through numbers seems to make the world more administrable, although not always more fair. As numbers shape public policy, they take on "totemic significance." [51] Although the widespread availability of data should enrich public discourse, inevitable over-simplifications and misinterpretations may ultimately cheapen it. The power and ubiquity of computers make it possible for many people to calculate and communicate numbers they do not understand. Instead of enhancing Jeffersonian democracy, limited numeracy can easily shift the balance to a technocracy.

Innumeracy hurts in other ways as well. For example, public policy issues may increasingly move beyond the intellectual grasp of citizens who lack appropriate skills in quantitative reasoning. Innumeracy encourages the view that all opinions are equally valid, that whenever there is disagreement the truth lies somewhere in the middle. [52] Innumeracy thus becomes another means of disenfranchisement: by reinforcing the idea that truth is relative and unknowable, people with the least defenses against charlatans will be most vulnerable.

Innumeracy also perpetuates welfare, harms health, and weakens families. Without requisite quantitative skills, individuals will find it very difficult to make a transition from welfare to work. Without critical skills to assess medical claims, individuals will often fall victim to false claims and questionable treatments. Without the skills to manage a household budget, many become victims of easy credit or consumer fraud. In short an innumerate citizen today is as vulnerable as the illiterate peasant of Gutenberg's time.

As the technology of literacy advances from ink on paper to images in cyberspace, the practices of literacy take on multiple facets reflecting the multiple modes of modern communication. Literacy is no longer just a matter of words, sentences, and paragraphs, but also of data, measurements, graphs, and inferences. Pattern and number lurk behind words and sentences, in machines and computers, in organizations and networks. Literacy is about reading and reasoning, writing and calculating; it is about solving problems and using technology; it is about practices as well as knowledge, procedures as well as concepts. Numbers count because ideas count.

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