AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

Conf-940646--2
SAND94-1155C

MATH AND SCIENCE ILLITERACY: SOCIAL AND ECONOMIC IMPACTS

Janet L. Williams, P.E.
Sites Planning Department

Sandia National Laboratories

Albuquerque NM 87185-1355
(505) 883-3369 (w)
(505) 881-9853 (FAX)
73232.3606@compuserve.com

ABSTRACT

Today's highly competitive global economy is being driven by increasingly rapid technological development. This paper explores the problems of math and science illiteracy in the United States and the potential impact on our economic survival in this environment during the next century. Established educational methods that reward task performance, emphasize passive lecture, and fail to demonstrate relevance to real life are partly to blame. Social norms, stereotypes, and race and gender bias also have an impact.

To address this crisis, we need to question the philosophy of an educational system that values task over concept. Many schools have already initiated programs at all grade levels to make math and science learning more relevant, stimulating, and fun. Teaching methods that integrate math and science learning with teamwork, social context, and other academic subjects promote the development of higher-order thinking skills and help students see math and science as necessary skills.

Introduction

In reviewing some of the most recent literature published regarding educational needs for the future, there seems to be a clear consensus on at least two points: 1) we have a problem in this country with math and science illiteracy, and 2) math and science literacy is becoming increasingly important, even essential, for survival in our technology-driven world. What do we mean by these terms, and why are they so important?

Just as the term literacy refers to the ability to read, so math and science literacy refers to the ability to understand the basic principles and use the fundamental tools of these two related fields. They also extend beyond this narrow definition to the realm of being able to relate the concepts of math and science to everyday life in our society. Does the voting public really grasp the meaning of a national debt in the trillions, or the statistical chances of contracting the AIDS virus? Do people understand the enormous potential of renewable energy sources, or inertial confinement fusion, or genetic engineering, in shaping our future on this planet?

The answer, according to many prominent authors on the subject, is no. Several sources from the fields of math, science, and education contend that science and math illiteracy is created and perpetuated by a number of factors, among them cultural myths and paradoxes, race and gender bias, educational methods, and even the attitudes and actions of mathematicians and scientists themselves. All agree that the present and potential future impacts on society are tremendous. We need to explore these factors more fully to see the complete picture of math and science illiteracy and ultimately understand the impacts of math and science illiteracy.

What's math got to do with it?

John Allen Paulos, known for his books on innumeracy (the phrase he uses to describe mathematical illiteracy), puzzles over a population with so little understanding of probability and statistics that it is paralyzed by the fear of various forms of terrorism but doesn't give a second thought to driving without a seat belt. He is appalled by the widespread belief in pseudo-sciences such as astrology. He is also amazed that people who can quote Shakespeare and offer spirited intellectual discussion of historical events will actually brag about their inability to balance a checkbook. The public seems blithely unaware of the importance and effect of math and science on their daily activities. This lack of awareness helps perpetuate a number of myths and misconceptions about math and science and the professionals who work in these fields.

MASTER

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000.

"I've never been good at math"

Dr. Paulos concedes there are differences among individuals in math abilities, but adds that does not mean a person can't learn the basics. Would we allow a student to stop writing because he or she is not a highly talented writer? Certainly not! Yet we as a society still offer nods of understanding to classmates, colleagues, and friends who say "I'm just a right-brained person," or "I'm a people person, not a numbers person," implying the two are mutually exclusive. These kinds of statements feed deeply ingrained stereotypes and undermine ongoing attempts to address math and science illiteracy.

The predominance of some stereotypes makes them almost insidious. Glance at the comics for a week, and inevitably there is a strip that portrays a scientist, mathematician, or engineer as a "nerd" or "geek" - sporting a white lab coat and glasses, generally unattractive, and almost always a "nerdy" white male. Textbook publishers are also guilty of unconsciously reinforcing the public perception of scientists as white males. As a Newsweek article cited by Brush (6) phrased it, "real men don't do science, real women don't even think about it."

This last point evokes another myth that has been disproved but not debunked among the general public. Gender bias has been documented in both math and science education, from elementary years to graduate school. (5,6,7,8) While boys may outperform girls in later years, girls test as well or better than boys in the elementary grades. Studies that claimed female brains were inferior have been re-evaluated and overturned by subsequent studies. And sex-biased test questions on the SAT have been shown to account for the apparent difference in boys' and girls' scores. (6) Unfortunately, this myth persists despite evidence to the contrary.

Professionals in math and science are partly to blame for the myth that math and science are reserved for only the elite. Professors tend to portray their fields as mysterious and inaccessible to protect their status as intellectuals. There is also a general lack of communication between professionals and educators that helps promote the myth of inaccessibility to all but the brightest students. (7) The acceptance and perpetuation of all these stereotypes are pervasive and reinforce the public's attitudes that math and science are superfluous and limited to a select and isolated portion of the population.

Computation vs. Critical thinking

Paulos points out that there is a difference between the ability to perform mathematical computations (easily done with a calculator or computer) and having a feel for numbers - that instinct that tells us when and how to apply computational techniques, and whether or not the answer makes sense. (1,4) In more general terms, educators often refer to the need to develop critical thinking skills, or higher-order thinking skills, among our students. According to Hopkins, these skills will be in high demand in the future workforce. Employers will need not just functional skills dedicated to a specific purpose, but also the general ability to assess and solve problems in the workplace. This shift in the skills employers seek is linked to an increasingly technological society. "Technology squeezes the non-thinking tasks out of work, and so places a premium on employees' intellectual skills, particularly on their ability to acquire, organize, and interpret information." (4) The development of critical thinking skills and a feel for numbers are aspects of learning that seem to be missing in our math and science programs. Young students may know how to multiply and divide as straight computational functions, but have no concept of using these operations to figure out everyday problems, such as how much interest will be earned on a savings account, or how to cut a recipe in half.

Who teaches the teachers?

The literature enumerates many other criticisms of our educational system. Teachers themselves, seldom trained as scientists or mathematicians, are intimidated by math and are often poorly trained to teach math creatively. Many universities require less than 12 credits of math classes to become certified to teach elementary school math; some require none. (4) Such teachers are ill-prepared to present material in a relevant and stimulating way. Students seldom work with any science professionals employed in industry and academia; their impressions of scientists are shaped by their science teacher and the prevailing societal stereotypes. In the academic setting, university professors are rewarded on the basis of their research, not their teaching methods.

Can you relate?

The way math is generally presented - as a stand-alone, cold, exact, unforgiving subject - turns students off. Under pressure to cover the planned curriculum and help students do well on standardized tests, teachers concentrate on computational techniques. There is little connection to other subjects, and few applications to real life are discussed. Math also tends to be taught hierarchically, rather than in an integrated fashion. This decreases opportunities to demonstrate relevance to other areas of mathematics. Some math topics that are especially relevant, such as probability and statistics, are seldom addressed prior to college. Yet even young

students can gain an appreciation for these areas of math in their daily lives by discussing topics such as what a 50% chance of rain really means.

Pipeline Filters

Science education endures similar criticisms. Only one in four college graduates qualifies as scientifically literate; only one in ten education majors qualifies. The pipeline flow of students pursuing higher education in scientific and technical fields is diminishing, and minorities and women are severely underrepresented within that group. Undergraduate and upper level high school math and science programs are designed to "filter out" all but the brightest or most persevering students. Sadly, this large lecture/examination format affects a disproportionate number of women and minorities. (8) Educators are also challenging the traditional passive lecture format as singularly unsuitable for making math and science education more experiential, "hands-on," and connected to everyday life.

The "Co-" Criteria

There seems to be no argument that we have a crisis in math and science education that could significantly affect our ability to function as a technology-based society. What can we do about it? Steen (8) outlines several criteria we can apply to math and science curricula to address many of the current educational concerns:

Community : Intellectual stimulation must be teamed with the social, emotional, and ethical contexts to sustain motivation and prevent discouragement in learning difficult material.

Construction : Students learn better when they can construct their own representation of knowledge to reinforce facts and formulas. Through active investigation, argument, and participation, students become more intuitively connected with the material, as opposed to regurgitating memorized data.

Connections : Students must be encouraged to make some sort of connection to social, historical, personal, or other contexts in order to make sense of science and math. Good teaching includes techniques for helping students identify the context that will help them make the connection that works best for them.

Continuity : Science and math should be presented "as a seamless fabric of learning from pre-school years through graduate study and research," not as discrete and ancillary subjects. Furthermore, good science and math education at the college level will produce well-trained teachers, which will in turn generate good teaching at the elementary and secondary levels, thus ensuring continuity in the quality of teaching.

Several programs employing many of the principles outlined by Steen have been launched to improve math and science education.

No one "right way"

Schools in Montgomery County, Maryland have implemented Project IMPACT, a program offered in kindergarten through second grade that features early, hands-on exposure to problem-solving and a teacher training component to provide teachers with creative ideas and techniques for presenting curriculum. One of the central tenets of the program is that there is no one "right way" to do math problems, so that children learn early on that there may be a variety of ways to solve a particular problem, making them more confident and comfortable with math from the early years on. (4)

"We did it!"

Another program that reflects Steen's concepts is offered at the Challenger Center for Space Science Education. Unlike Space Camp or other NASA-sponsored programs, Challenger Learning Centers are classroom-based programs for middle-school students that use the mystery and excitement of space as a vehicle for encouraging study and achievement in math and science. They operate according to the principle of "learning by doing." Participants act as math and science professionals working together to successfully complete a mission, and that success reinforces math and science as a positive experience. The Learning Centers are funded by corporate contributions and congressional grants, and operated by a foundation whose members are teachers who were finalists in NASA's Teacher-in-Space Program. (4)

"I learned it on TV"

While television and video technology has been blamed for inhibiting students' ability to problem-solve and sustain the mental organization and attention needed to perform in school, it can also be used as a tool to present math and science in a stimulating and provocative light. Several acclaimed series that have been aired by PBS - including *3-2-1-Contact, Square One TV, Voyage of the Mimi, and Newton's Apple* - take advantage of the

opportunity to garner young people's undivided attention to stimulate awareness and interest in contemporary and relevant math and science topics. A special *3-2-1-Contact* episode on the destruction of the rain forests showed kids how science can so've problems in the world around them, while *Square One TV* covers a variety of math topics and introduces deductive reasoning through the adventures of two crime-solving detectives. Among the high-tech educational materials being marketed are elaborately staged videos that use analogy, humor, and catchy techniques to introduce science concepts, as well as curricula using CD-ROM and other computer-based technology. (4)

Stand and Deliver

While technology can certainly enhance learning, many advocate simple teaching concepts such as hard work, practice, and desire to succeed on the students' part, and the teachers' love of both students and teaching. Jaime Escalante, the highly acclaimed math teacher whose work at predominantly-Hispanic Garfield High School in East Los Angeles was documented in the movie *Stand and Deliver*, is now teaching teachers. His techniques for teaching math incorporate several of Steen's criteria. He presents the material in a social context that students can relate to -- their own cultural surroundings. He also involves the students in collaborative problem solving, encouraging students to reach intuitive understanding of problems. His methods have been phenomenally successful, particularly for minorities: a quarter of the nation's Hispanic students passing the advanced-placement calculus exam come from Garfield High. Uri Treisman at the University of California at Berkeley and others have also found collaborative learning to be particular successful for minority students. (4) Again, this taps into Steen's concepts of community and construction, and helps develop more of the skills discussed above as critical to develop a workforce prepared for the future. (4)

Social and Economic Impacts

The problems of math and science illiteracy and what educators and other professionals propose to do about it are easy to enumerate. What may not be quite so obvious is the potential impact on our society and economy if these problems are not addressed. Hazen and Trefil (2) advocate scientific literacy with a three-pronged argument. First, they assert that we have a civic duty to understand the issues of our times in order to make responsible decisions as citizens and voters. They also argue that we are governed by the laws of nature and science, and that we gain a tremendous appreciation of the natural world around us when we understand how it works. Finally, they note that the intellectual climate at various times in history has been shaped by the scientific findings of the time. In fact, scientific findings in a given period may be hindered by a public without the knowledge base and skills to evaluate the importance of intellectual developments of the times. Consequently, a scientifically literate public is crucial to supporting future technological developments.

Like Hazen and Trefil, Paulos argues that mathematical literacy is "essential to an informed and effective citizenry." He goes on to assert that "a shortage of mathematically talented individuals is also a primary factor in the U.S.'s declining world position in many new scientific technologies." (4)

The importance of a work force that has the ability to reason and apply creative solutions to problems in the work place has already been discussed. In a competitive, rapidly changing global economy, specific functional skills will quickly become obsolete, and employers will value highly the broader skills in critical thinking and creative problem solving. A country whose work force lacks these skills cannot hope to compete and maintain an economic advantage in the global economy.

What next?

All these positive approaches to the problems in math and science education are encouraging, but the scope of the problems related to math and science illiteracy is formidable. It may be years before we see results from the many programs created to address the problems. More importantly, finding funding to sustain the current revolutionary trends will be a challenge. It would be infinitely more cost effective to ensure that children are well-educated from the start, instead of pouring billions of dollars into remedial education after the system has failed. Government, corporate America, and the general public must be convinced that to sustain its top rank in the global economy, the United States must produce a work force prepared to face the challenges of the 21st century. They must apply long-term strategic planning to establish priorities, and direct resources to achieve those priorities, to create a first-rate education system. Individual citizens, who may play multiple roles as parents, teachers, students, and professionals, must make a commitment to literacy in math and science to help dispel stereotypes and capitalize on the strengths of all the members of our work force. In summary, significant changes will be needed in many arenas - in the classroom, in government, and in social attitudes -- to address math and science illiteracy at its roots.

Jan Williams is an engineer in the Sites Planning Department at Sandia National Laboratories in Albuquerque, NM. Selected as a 1994 Distinguished New Engineer, she has been active at local, regional, and national levels of SWE and will co-chair the 1997 SWE National Convention in Albuquerque.

REFERENCES

Books

1. *Innumeracy: Mathematical Illiteracy and Its Consequences*, by John Allen Paulos, Hill and Wang, 1989

2. *Science Matters: Achieving Scientific Literacy*, by Robert M. Hazen and James Trefil, Doubleday, 1991

3. *Overcoming Math Anxiety*, by Sheila Tobias, W.W. Norton and Company, 1978 (updated edition soon to be published)

Articles

4. *Fighting for our Future: Science & Math Education for the 21st Century*, Special Advertising Section, Business Week, Nov. 25, 1991. A compendium of articles by Kevin Hopkins and John Allen Paulos outlining problems with math and science illiteracy and education, and what school systems and educators are doing about them

5. *Gender and Numbers: Women still shy away from math and science*, by Dierdre McMurdy, Maclean's, Nov. 9, 1992

6. *Women in Science and Engineering: Women are still seriously underrepresented in the sciences, and they have made comparatively little progress in the past five years. Why?*, by Stephen G. Brush, American Scientist, Sept.-Oct. 1991

7. *Running the Numbers*, by Janet Stites, Omni, April 1993

8. *Achieving Science Literacy: What Works?* by Lynn Arthur Steen, Current Nov. 1991

9. *Scientific Elites and Scientific Illiterates*, by David L. Goodstein, Engineering & Science, Spring 1993

10. *Closing the Math and Science Gap*, by Priscilla Ahlgren (condensed from Agenda: America's Schools in the 21st Century), The Education Digest, September 1991

DISCLAIMER

DATE FILMED

6/22/94

END