DOCUMENT RESUME

ED 447 295 CE 080 929

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TITLE	Decision-Makers at the Crossroads: Changing Quantitative and Technological Tools.
PUB DATE	2000-04-10
NOTE	9p.; In: Cross-Roads of the New Millennium. Proceedings of the Technological Education and National Development (TEND) Conference (2nd, April 8-10, 2000, Abu Dhabi, United Arab Emirates); see CE 080 883.
PUB TYPE	Reports - Descriptive (141) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Adult Learning; Business Administration Education; Computer Oriented Programs; Computer Uses in Education; Curriculum Development; Data Analysis; *Decision Making; Decision Making Skills; Decision Support Systems; Higher Education; *Internet; Lifelong Learning; Management Development; Policy Formation; Professional Continuing Education; Public Administration Education; Public Policy; Skill Development; *Spreadsheets; *Statistical Analysis; Statistical Data; Student Projects; Summer Programs; *Technical Education; Technological Advancement; Thinking Skills; Workshops
IDENTIFIERS	Harvard University MA; *Mathematical Thinking; University of Arizona

ABSTRACT

Decision makers have always relied on a mixture of qualitative and quantitative information. Recently, two technological tools--spreadsheets and the Internet--have dramatically altered how decision makers analyze quantitative information, thus necessitating curriculum changes in programs to prepare students to use these tools effectively. Harvard and the University of Arizona have each developed new courses to help the next generation of decision makers master the numerical methods and data interpretation techniques required to analyze the increasing amounts of quantitative information available to decision makers in government and elsewhere. Both courses share a common philosophy and use similar tools, and both courses are driven by projects that allow students to use these tools in the context of a realistic decision. However, each course serves very different students. The Harvard course is part of a summer program that is an introduction to the Kennedy School of Government's master's program in public administration. It is targeted toward mid-career students who have extensive practical experience but have not studied mathematics recently. In contrast, the Arizona program is offered to undergraduate business majors through the department of mathematics. (MN)

TEND 2000

Crossroads of the New Millennium

Decision-Makers At The Crossroads: Changing Quantitative And Technological Tools

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Monday 10 April, 2000

Workshop 2

Abstract

Decision-makers have always relied on a mixture of qualitative and quantitative information. The past century has seen a steady increase in the use of quantitative arguments. Recently, however, two technological tools—spreadsheets and the Internet---have dramatically altered the way in which decision-makers analyse quantitative information. Spreadsheets make the manipulation of large quantities of data possible by non-specialists; the Internet makes data easily accessible.

Since changes in technology affect the way quantitative methods are practiced outside the classroom, we expect also to see changes in the classroom. This has started to happen.
For example, finance courses now use spreadsheets and statistics courses often use data from the Internet. What does this mean for the prerequisite quantitative courses? Significant curricula change is needed to prepare students to use these tools effectively. In particular, numerical methods, data interpretation, and simulation should be introduced into the curriculum.

This workshop centres on the quantitative preparation required by the next generation of decision-makers. It describes new courses at Harvard's Kennedy School of Government and the University of Arizona.

Decision-Makers at the Crossroads: Changing Quantitative and Technological Tools

THE ART AND SCIENCE OF DECISION-MAKING

Wise decision-making has always been both an art and a science. There is art in valuing a particular choice and in understanding an individual's reactions. There is science in analysing data and in predicting consequences. There is judgement in balancing the two.

Decision-making will remain both an art and a science. However, the scientific aspect of decision-making in business and public policy is currently changing. The implications of these changes for education are discussed in this paper.

A FRAMEWORK FOR DECISION-MAKING

In everyday life, making a decision has two stages: laying out the alternatives and choosing one of them. The more complex decisions of business or government can be analysed using the following five-stage framework due to Edith Stokey and Richard Zeckhauser: [1]

a) *Establishing the Context.* What is the underlying problem? What are the objectives?
b) *Laying out the Alternatives.* What are the possible courses of action? What additional information would be useful?
c) *Predicting the Consequences.* What are the possible consequences of each course of action? How likely is each?
d) *Valuing the outcomes.* By what criteria do we measure the value of each alternative?
e) *Making a Choice.* What is the preferred course of action?

Quantitative information can enter into the decision-making process at any of Stokey and Zeckhauser's stages. For example, establishing the problem underlying a stagnant economy involves analysing economic indicators. Laying out educational alternatives requires the computation of enrollments and budgets. Predicting the consequences of increased tariffs involves using a quantitative economic model. Deciding where to build a new power plant involves evaluating the efficiency of various locations. Making a choice of the final course of action often involves balancing quantitative and qualitative information: Which investment

[1] Edith Stokey and Richard Zeckhauser, *A Primer for Policy Analysis*, p.5, (New York: W.W. Norton, 1978).

promises the greatest yield, given past performance? Which investment is most likely to outdo its past performance? Which investment is in a company with the strongest record of community support? Thus, changes in the way in which quantitative information is analysed could affect every stage of the decision-making process.

THE CHANGING TOOLS OF QUANTITATIVE ANALYSIS

The mathematical tools available to decision-makers have expanded greatly over the last hundred years. Statistical methods came into wide use during the twentieth century. Much of operations research, such as linear programming, was an outgrowth of the Second World War. The mathematical theory of decision analysis began to be used by businesses in the early 1960s.[2] Finance has become much more mathematical, with some spectacular successes. For example, Black and Scholes' work in the1970s led to the development of the market for stock options.

Until recently, these new quantitative methods did not greatly affect the day-to-day decision-making of many business executives or public servants. Some methods were too hard to apply; some required too much background in mathematics. For example, not long ago, statistical studies required a mainframe computer and therefore particular expertise. Linear programming[3] could be done by hand, but not easily, or by a special purpose computer programme. Thus, although these new quantitative methods showed great promise, until recently they were more widely used by quantitative specialists than by practitioners in the field.

In addition to the technical difficulty in employing quantitative methods, decision-makers of the past decades did not always have accurate data. Decisions are only as good as the facts on which they are based. For many years, governments have tried to collect reliable data, such as census, health care, and economic data. Individual decision-makers, however, have not always had access to this data, either because they could not pay for it, or because they could not get it fast enough. Even organisations which collected data did not always use it fully, as the amount of data collected often outstripped the techniques available for analysis. For example, the scanners at a supermarket checkout desk collect vast quantities of data that is not fully analysed.

[2] Howard Raiffa, *Decision Analysis,* (Reading, Mass: Addison-Wesley, 1968).

[3] The name *linear programming* suggests computers; however, this is not its origin.

However, two recent developments dramatically affect how quantitative information is handled. The first is the advance in computer technology, particularly spreadsheets. The second is the Internet. These two tools put data analysis within the reach of non-specialists.

The Internet provides decision-makers with access to up-to-date facts in way that the telephone and regular mail cannot match. Data on the Internet is often easy to obtain; for example, stock prices can be downloaded directly into a spreadsheet. Not only is data easier to get than it used to be; it is also easier to analyse. A spreadsheet can be used to display data graphically and to do statistical tests and probability computations. Policy makers who want to know population growth rates or an economic indicator can now make the computations themselves. Thus, spreadsheets and the Internet should now be considered essential tools for *all* commercial and governmental decision-makers. A future decision-maker who cannot use these tools will be at a significant disadvantage.

IMPLICATIONS FOR EDUCATION

Since technology now enables decision-makers to use data easily and effectively, colleges must evaluate whether their graduates are learning the technical and quantitative skills they currently need. In countries where computers are widely available, young students have shown a remarkable affinity for them. This is reflected in the number of very young programmers found in many software companies. However, students who can make stunning web pages, for example, cannot always use computers to work with numbers.

John Maggio, Professor and Chair of Pharmacology at the University of Cincinnati Medical School, finds medical decision-making hampered by medical students' lack of skill with computers and quantitative arguments. He reports:

> "The idea of using computers for something other than email or downloading documents to print is one that only a minority of our class is comfortable with. When Step I of the Boards (the first of the exams toward licensure) went to computer format last year, some of our students were very concerned, far beyond the usual worries when a system changes that the new system will have glitches.
>
> I would say there is also a surprising level of illiteracy about things numerical. Even quite simple equations elicit fear and loathing in a small but significant fraction of the class. The number of incidents due to miscalculated drug doses (a very real problem)

becomes more understandable after one talks to the few students who take this attitude."[4]

Poor decision-making in medicine affects the health of patients. Poor decision-making in commerce and government affects the health and development of companies and countries. The challenge we face is to give all future decision-makers the skills to use quantitative methods well.

MEETING THE EDUCATIONAL CHALLENGE

To understand this educational challenge, we first consider the current focus of most mathematics teaching. Although many of Newton's arguments were geometric, calculus and most subsequent mathematics are usually expressed symbolically. Thus, much of the mathematics learned in high school and college is symbolic manipulation. Recall, for example, solving equations and simplifying expressions in algebra, or calculating derivatives and integrals in calculus.

Computers, however, tend to shift the emphasis away from symbolic manipulation towards numerical methods. This has significant implications for the teaching of mathematics. For example, numerical methods to solve equations and approximate integrals are not likely to be familiar to students from a traditional curriculum. Similarly, students trained on symbolic manipulation may have little understanding of round-off error, which plays an important role in most numerical approximations.

What does this mean in practice? It does *not* mean that we should stop teaching symbolic manipulation. Since spreadsheets use formulas, understanding algebra is essential for learning to use a spreadsheet. It does mean, however, that students need experience with numerical methods on the computer as well as with symbolic manipulation.

There are some very difficult questions, which I will not deal with here, about whether the amount of symbolic manipulation taught should be reduced, and if so, by how much. The answers to these questions are not yet known. There is currently little understanding of how much practice with symbol manipulation is necessary for conceptual understanding. Research is needed on the link between symbolic skill and the ability to interpret data. However, even

[4] Personal communication. January 31, 2000.

without the answers to these questions, it is clear that future decision-makers need more experience with numerical methods than they currently get.

Computer technology gives decision-makers two other new tools: simulation and the ability to do statistical calculations. A simulation enables users to get a feel for a phenomenon that is hard to analyse theoretically. There are dangers, of course, in working with phenomena whose theoretical underpinnings are not well understood. However, these are dangers that are faced regularly by decision-makers in the field; they should be encountered first in academic work.

The place of statistics in the curriculum varies with the country. In the US, statistics has traditionally been taught as though it were less important than calculus. For decision-makers, this most emphatically not the case. However, many institutions are now updating their curriculum to give statistics more emphasis.

In conclusion, our future curriculum should include numerical methods, an introduction to computer simulation, and statistics. In addition, we can no longer allow only the students going into mathematics and science to become skillful users of quantitative arguments. Such arguments now underpin successful decisions in business and public policy. Students of commerce and government must become equally skillful.

EXAMPLES OF NEW CURRICULA AND PEDAGOGY

My TEND2000 workshop centres on possible responses to this challenge. Both the business mathematics sequence at the University of Arizona and the Summer Programme for Public Administrators at the Kennedy School of Government at Harvard have been redesigned recently, with the goal of producing decision-makers able to use the new quantitative and technological tools.

Both courses share a common philosophy and use similar tools. Both courses are driven by projects that allow students to use these tools in the context of a realistic decision. However, they serve very different students. Harvard's programme is offered by the Kennedy School of Government as an introduction to its Master's Programme in Public Administration. Its students are mid-career students with much practical experience, but who often have not had mathematics recently. The Arizona programme was developed through an extensive collaboration between the departments of mathematics and finance, but is offered by the department of mathematics. Its students are undergraduate business majors.

Participants in the workshop have the opportunity to see materials from Richard Thompson and Chris Lamoureux's business mathematics[5] at Arizona and from the Information, Data, and Decisions course at Harvard.[6]

[5] See http://www.math.arizona.edu/busmath.

[6] Designed and written by Eric Connally and Deborah Hughes Hallett.

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