Fostering Quantitative Literacy
Clarifying Goals, Assessing Student Progress

By Joy Jordan, assistant professor of statistics, and **Beth Haines,** associate professor of psychology and director of general education, both of Lawrence University

A cursory look at articles in the May 28 edition of the *New York Times* demonstrates how critical it is to understand quantitative concepts and arguments:

- "Hormone therapy doubled the risk of Alzheimer's disease and other types of dementia in women who began the treatment at age 65 or older, a large study has found" (Grady 2003).
- "President Bush signed a bill on Wednesday that offers $330 billion in tax breaks to families, businesses and investors and $20 billion in state aid" (The Associated Press 2003).

To make informed, intelligent decisions about critical issues such as health, politics, and the economy, college students must feel competent and confident in their quantitative skills. For this reason, the number of national discussions of quantitative literacy (QL) has increased significantly in the last decade. Educational and professional organizations have clearly articulated the need for QL in college curricula to ensure that all college graduates can successfully enter an increasingly technological and quantitative world (see, for example, Sons 1992; National Research Council 1989). For such curricula to flourish, QL goals in higher education must be carefully and explicitly defined, and progress in meeting those goals must be routinely assessed.

Defining QL in Higher Education

Central to the discussion of quantitative literacy is its definition; what does it mean for college students to be quantitatively literate? In an effort to address this question and to clarify QL discussions, the National Council on Education and the Disciplines recently published the interesting and thought-provoking book, *Mathematics and Democracy: The Case for Quantitative Literacy*. In its case statement, the design team considers quantitative literacy from three perspectives: elements of QL (e.g., contextually appropriate decision making, interpretation of data); expressions of QL in all aspects of life (e.g., the necessity of understanding data and statistical inference in order to think critically about any major public issue); and a list of QL skills (e.g., using computers, understanding and generating graphs and statistics) (Steen 2001).

Drawing on the case statement, psychological and educational research, and QL policy discussions, we propose a QL model for higher education. Our model describes QL in terms of three component parts: (1) foundational statistical and mathematical skills, (2) quantitative reasoning skills, and (3) positive, confident attitudes and beliefs about mathematics and quantitative reasoning. These components do not stand alone, but instead work in concert to form quantitative literacy.

Foundational abilities in mathematics and statistics are integral components to the understanding and use of quantitative reasoning. Mathematical skills provide a basis for calculations as well as abstract reasoning, while statistical training teaches students broad applications of quantitative reasoning skills.

Fostering appropriate and thoughtful quantitative reasoning is perhaps the most challenging component. By *quantitative reasoning* we mean the ability to select, apply, and explain a variety of quantitative methods across different contexts. Unfortunately, most college teachers are familiar with students' difficulty in transferring quantitative concepts from one context to the next, or even from one problem to the next. While cultivating and assessing students' quantitative reasoning will be a formidable task, this work is likely to produce the best insights for improving QL pedagogy.

The final aspect of quantitative literacy involves students' attitudes and beliefs. More than simply a positive attitude about mathematics, students should also have an appreciation of, and comfort with, the various quantitative methods needed to face today's world. While statements like "I'm just not good at writing" are typically answered with encouragement and reassurance that good writing can be developed through training and practice, statements like "I'm just not good at math" are all too often answered with silence or a sympathetic nod. Quantitatively literate college students understand, appreciate, and welcome the need for quantitative methods in answering difficult societal questions.

Promoting QL through General Education Requirements

Curricula that infuse quantitative reasoning at all levels and across disciplines are likely to have the most success in developing all three components of QL. As Lynn Steen (2001, 115) writes, "numeracy must permeate the curriculum." We advocate using an approach similar to the writing-across-the-curriculum pedagogy (Bean 2001; Townsend 2001). There are a variety of models for across-the-curriculum approaches to QL (see box on page 18 for examples).

The primary goal of such QL curricula is to teach students to use appropriate quantitative reasoning skills when opportunities arise—in different academic contexts, in their careers, and in everyday problem solving. This type of transfer across contexts is a standard litmus test of learning, and consequently, there is more than a century's worth of research to inform the design of QL curricula. Unfortunately, applying the existing research to curricular design is challenging for two reasons. First, only a small percentage of the research examines transfer of specific quantitative reasoning skills following actual classroom instruction, while the majority of the research is drawn from laboratory-based tests of transfer. Second, much of the laboratory-based research suggests that it is much easier to prevent or disrupt transfer across contexts than it is to successfully promote it (Detterman and Sternberg 1996). As Douglas Detterman (1996, 13), research psychologist, concludes in his review, "The surprise [from transfer studies] is the extent of similarity it is possible to have between two problems without subjects realizing that the two situations are identical and require the same solution."

Although transfer research does not provide an empirically successful method, it does support our argument to infuse QL into the curriculum so that sound quantitative reasoning is modeled, encouraged, and highlighted across disciplines. Space permits only a few research examples to support our case, but Barnett and Ceci (2002) offer a rich review for interested readers.

Research shows that people often fail to notice opportunities to apply learned quantitative skills unless *the analogy is explicitly pointed out to them* (Reed and Evans 1987). Most people decide whether problems are analogous based on the surface content of the problem (e.g., "this problem is about acid solutions and I don't know anything about acid"), rather than on the underlying quantitative principle involved in the problems (e.g., "aha, this acid solution problem is based on the same principle [weighted average] as the temperature prediction problem that I just did"). Consequently, if we want students to apply quantitative reasoning skills broadly, instructors may need to work collaboratively to map out conceptual analogies across classes and to derive the underlying principles that may be broadly applied in solving problems. Such interdisciplinary faculty collaboration would provide support for students in their quest to apply quantitative reasoning across different contexts. In this vein, Macalester College uses analysis of a public policy issue to create interdisciplinary demonstrations of quantitative methods in problem solving.

A small body of research has compared the effects of disciplinary training on specific quantitative reasoning skills. For example, in Lehman and Nisbett's (1990) research on undergraduates, social science training produced the largest gains in statistical and methodological reasoning, whereas science and humanities training produced substantial gains in conditional logic. Given that part of the challenge for a QL curriculum lies in stimulating confidence and positive attitudes toward quantitative reasoning, teachers might draw on these findings to highlight reasoning skills that are already integral to their disciplines. These findings also underscore two component skills, statistical reasoning and conditional logic, to place on a list of transferable skills that could be built into a QL curriculum.

Creating a QL Assessment Framework

Assessing QL in higher education can begin with relatively simple student and teacher assessments of skill improvement, but must progress to actual measurement of students' abilities to apply QL skills across a broad range of everyday contexts. A good general measure of college-level QL will be most useful if it evolves from cross-disciplinary identification of important component quantitative skills. Furthermore, the creation of discipline-specific measures of quantitative reasoning, in conjunction with a general QL instrument, will allow exploration of important questions about the transfer of quantitative skills across different contexts and about the contribution of discipline-specific training to overall QL. Research and experience tell us that transfer of skills across contexts is difficult, so discipline-specific measures are important to identify training that successfully promotes the transfer of quantitative skills as opposed to situations where students see skills as context specific.

At Lawrence University, we have taken the initial step of designing and implementing student assessments of quantitative competency. Students provide self-reports of changes in their quantitative reasoning skills at the completion of all quantitative-intensive courses. The evaluation form also asks students to identify concepts and skills they have learned that will have practical applications in other areas.* These data reveal some interesting and useful information. For example, students see some disciplines as promoting broad application (e.g., "statistics can be applied to everything"), yet their comments on other disciplines (e.g., "unsure [of practical applications], but am told they exist") suggest that transfer of learned concepts is unlikely. Previous research confirms this tendency for learners to see certain disciplines as content specific and not broadly applicable (Bassok and Holyoak 1989). Obviously, a measure of actual QL skills is necessary to determine whether students' sense of what will transfer will indeed transfer.

To measure the attitudinal component of QL, we have administered to statistics courses pre- and post-course attitudinal assessments based on the Dartmouth College Mathematics Across the Curriculum Survey (Korey 2000). We were delighted to find that 84 percent of the students thought statistics helped them to

ACROSS-THE-CURRICULUM APPROACHES

Dartmouth College

Dartmouth's Math Across the Curriculum initiative led to the creation of many interdisciplinary quantitative courses (e.g., Geometry in Art and Architecture).

http://hilbert.dartmouth.edu/~matc

DePauw University

After taking or passing out of the "Introduction to Quantitative Reasoning" course (taught by faculty from a variety of disciplines), each student is required to take a quantitative reasoning course, offered in several different subject areas.

www.depauw.edu

Lawrence University

As part of the general education requirements, each student must take a quantitative-intensive course. The quantitative courses are taught in an array of disciplines (e.g., anthropology, chemistry, economics, mathematics).

www.lawrence.edu/dept/faculty_dean/gened/quant.shtml

Macalester College

Macalester recently developed a Quantitative Methods for Public Policy program. This program is interdisciplinary and all participating courses use the same policy issue to illustrate the use of quantitative methods.

www.macalester.edu/qm4pp

* *To obtain a copy of Lawrence University's "Mathematical Reasoning or Quantitative Analysis Course Assessment" form contact Beth Haines (beth.a.haines@lawrence.edu).*

understand the world; unfortunately, we also found that only 23 percent of the students wanted to study statistics further. This finding, along with years of research on math anxiety (Ashcraft 2002; Tobias 1990), demonstrates that promoting a positive and confident approach to quantitative learning remains a hurdle for a QL curriculum. Seeing practical applications in a single course may not be sufficient to promote attitude change without support and reinforcement of learned concepts throughout the curriculum.

In summary, we advocate an across-the-curriculum approach to QL that incorporates and assesses three components: (1) foundational statistical and mathematical skills; (2) quantitative reasoning skills; and (3) attitudes and beliefs about mathematics and quantitative reasoning. Results of this type of general QL assessment, informed by analysis of discipline-specific quantitative training, will help build a consensus about appropriate goals and optimal pedagogies for QL in higher education. ■

References

Ashcraft, Mark. 2002. Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science* 11, 181-185.

The Associated Press. 2003. Bush signs tax cut bill. *The New York Times* on the Web, 28 May. <http://www.nytimes.com>

Barnett, Susan and Stephen Ceci. 2002. When and where do we apply what we learn?: A taxonomy for far transfer. *Psychological Bulletin* 128, 612-637.

Bassok, Miriam and Keith Holyoak. 1989. Interdomain transfer between isomorphic topics in algebra and physics. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15, 153-166.

Bean, John. 2001. *Engaging ideas: The professor's guide to integrating writing, critical thinking, and active learning in the classroom.* San Francisco: Jossey-Bass.

Detterman, Douglas. 1996. The case for the prosecution: Transfer as an epiphenomenon. In Douglas Detterman and Robert Sternberg, eds. *Transfer on trial: Intelligence, cognition, and instruction.* Norwood, NJ: Ablex.

Detterman, Douglas and Robert Sternberg, eds. 1996. *Transfer on trial: Intelligence, cognition, and instruction.* Norwood, NJ: Ablex.

Grady, Denise. 2003. Hormone use found to raise dementia risk. *The New York Times*, 28 May, sec. A.

Korey, Jane. 2000. Dartmouth College of Mathematics Across the Curriculum evaluation summary: Mathematics and humanities courses. *Mathematics Across the Curriculum at Dartmouth College,* March. <http://hilbert.dartmouth.edu/~matc/Evaluation/humeval.pdf> (September 2001).

Lehman, Darrin and Richard Nisbett. 1990. A longitudinal study of the effects of undergraduate training on reasoning. *Developmental Psychology* 26, 952-960.

National Research Council. 1989. *Everybody counts: A report to the nation on the future of mathematics education.* Washington, DC: National Academy Press.

Reed, Stephen and Arthur Evans. 1987. Learning functional relations: A theoretical and instructional analysis. *Journal of Experimental Psychology: General* 116, 106-118.

Sons, Linda, ed. 1992. *Quantitative reasoning for college graduates: A supplement to the standards.* Washington, DC: Mathematical Association of America.

Steen, Lynn, ed. 2001. *Mathematics and democracy: The case for quantitative literacy.* Princeton, NJ: The National Council on Education and the Disciplines.

Tobias, Sheila. 1990. *They're not dumb, they're different:* Stalking the second tier. Tucson, AZ: Research Corporation.

Townsend, Martha. 2001. Writing intensive courses and WAC. In Susan H. McLeod, Eric Miraglia, Margot Soven, Christopher Thaiss, eds. *WAC for the new millennium: Strategies for continuing writing-across-the-curriculum programs.* Urbana, IL: National Council of Teachers of English, 233-258.