

Lawrence University: Quantitative Reasoning Across the Curriculum

Beth Haines and Joy Jordan
Lawrence University, Appleton, WI 54912

Program History

Lawrence University (LU), with an enrollment of 1350 students, is a selective undergraduate college of liberal arts and sciences with a conservatory of music. Following a 15-year hiatus, LU reviewed its general education requirements (GERs) and in 2000 adopted new multidimensional GERs. These include three components: competency requirements (in foreign language, quantitative reasoning, speaking, and writing), distribution requirements, and diversity requirements. The GERs went into effect in fall 2001 so the class of 2005 will be the first to graduate under the new requirements. In this article, we discuss Lawrence's successes and challenges in implementing its new quantitative reasoning requirement. We also reflect on how an across-the-curriculum approach to fostering quantitative reasoning skills contributes to the development of quantitative literacy in college students.

Lawrence's quantitative requirement, called the "Mathematical Reasoning or Quantitative Analysis Requirement," evolved out of discussions with faculty, students, and alumni, as well as transcript analysis and study of curricula at other schools. It reflects the belief that our college could and should do more to explicitly foster abilities, like critical thinking and quantitative reasoning, associated with a liberal arts education. Explicit identification of those aspects of the curriculum that develop quantitative reasoning skills does not reflect a lack of confidence in the liberal arts education, but rather provides an opportunity to define quantitative literacy goals in higher education and assess the college's success in meeting them. Lawrence's quantitative requirement is based on an across-the-curriculum approach in which particular courses in a wide variety of disciplines are designated as meeting the requirement. Students are required to take one designated course. In addition to the designated quantitative courses, and following the well-established writing-across-the-curriculum pedagogy, faculty are encouraged to demonstrate, explain, and provide practice in the application of quantitative reasoning in other courses throughout the curriculum.

In order to support faculty and student needs, LU built a new Center for Teaching and Learning (CTL), with a well-equipped quantitative lab. Lawrence also appointed a faculty member (Haines) to serve half-time as the director of the general education program, and hired a quantitative consultant to staff the CTL. An advisory board was established to implement the quantitative requirement and support faculty development initiatives in this area.

Program Goals and Learning Objectives

The LU faculty approved a set of criteria for courses designated as meeting the quantitative requirement. The criteria specify that: 1) at least 50% of the final grade be based on evaluated quantitative exercises, 2) students do a substantial amount of quantitative work distributed over the course of the 10-week term, and 3) teachers provide explicit instruction in quantitative methods and quantitative reasoning. During the implementation year, faculty submitted course proposals explaining how their courses would meet the criteria. Advisory boards for each competency area worked to operationalize the criteria, provide faculty with feedback, and address any concerns, resulting in the approval of courses in 12 departments by the Committee on Instruction (COI). Courses in traditionally quantitative disciplines were approved (e.g., chemistry, economics, physics) as well as a few courses in other disciplines (e.g., anthropology, psychology). The COI also approved the mathematics and computer science department request that all of its courses meet the requirement. In addition, some departments developed quantitative reasoning courses for non-majors (e.g., Physics of Music, Topics in Astronomy).

The implementation process helped to identify several challenges for LU's quantitative reasoning program. First, as the quantitative advisory board and COI transformed the criteria into operational goals, it became clear that despite extensive faculty discussions, there was not agreement on particular learning objectives associated with the quantitative requirement. For

example, there was debate regarding whether teaching of abstract mathematical concepts, like those in a calculus course, develops students' understanding of quantitative reasoning. On the flip side, there was debate about whether using measurement and statistics in biological anthropology provides understanding of quantitative analysis at a sophisticated enough level. It became clear that LU needs to define particular learning objectives and the level of quantitative expertise expected of its graduates, and we have initiated faculty discussions of these issues.

A second and related programmatic challenge concerns the relationship between LU's criteria for quantitative courses and the broad goal of cultivating quantitative literacy in its students. That is, in order to be more explicit in promoting quantitative literacy, LU might want to further delineate the criteria to specify the types of quantitative reasoning and methods that promote QL. Conceptual work on quantitative literacy emphasizes breadth of application of quantitative reasoning skills and recognizes the importance of repeated practice in a wide variety of contexts. This work suggests that foundational mathematical skills are an important contributor to QL, but the abilities to critically apply foundational skills and interpret quantitative reasoning on diverse real world problems are necessary as well (Steen, 2001). Steen and colleagues also point out that instruction in advanced mathematics promotes highly abstract reasoning, whereas advanced quantitative literacy moves toward breadth of application rather than increasing abstraction. Consequently, some LU faculty are concerned that the criteria do not put enough emphasis on application of reasoning and are too broad in allowing all mathematics courses to satisfy the requirement. Our assessment plan (described below) will examine how specific types of training relate to students' level of QL. The plan also recognizes the importance of assessing whether the single-course requirement in combination with the across-the-curriculum approach, is sufficient in achieving our QL goals. For example, the statistics education reform movement emphasizes broad application of skills and suggests therefore that a statistics course would be a useful component of a QL curriculum (Scheaffer, 2001). At LU many departments require statistical training, however, our current curriculum could not accommodate a requirement that all students take an elementary statistics course.

Thus, a third challenge involves balancing practical curricular constraints with our vision of the optimal QL curriculum. Lawrence's previous GERs required a course in mathematics. One motivation behind the new quantitative requirement was to alleviate the burden on faculty in mathematics of teaching introductory courses.

Consequently, although the substantial interest in elementary statistics can be viewed in a positive light when considering QL goals, it recreates the burden on the mathematics department to offer many sections of introductory statistics. Another QL goal is to spread quantitative courses across the curriculum, allowing students to practice skills in a variety of domains. However, creating quantitative courses in the humanities and fine arts often requires interdisciplinary co-teaching, which even when faculty interest is high, is costly for the university. Practical constraints do not always mesh with learning objectives based on QL standards, which only highlights the importance of assessing the most efficient ways to promote the development of QL.

A final challenge concerns student placement into the quantitative program. Lawrence does not use a placement test, however, students may "place out" of the quantitative requirement with appropriate advanced placement credit. Unlike the policy that students take a writing-intensive course at LU regardless of Advanced Placement (AP) credit, AP credit in mathematics or statistics is allowed to satisfy the quantitative requirement. Some faculty are concerned that AP credit does not signify that a student has sufficiently developed quantitative reasoning skills. The policy difference reflects, in part, curricular pressures to provide sufficient seats in quantitative-intensive courses. In addition, students are allowed to enter the calculus sequence at a more advanced level. Consequently, students with advanced mathematics skills could satisfy the quantitative reasoning requirement with an advanced calculus course. Part of our assessment plan involves examining the extent to which various types of disciplinary training are associated with QL skills.

Cross-Disciplinary Curricular Approach and Courses

As noted above, LU takes an across-the-curriculum approach to developing QL through its quantitative reasoning GER and the incorporation of opportunities to practice quantitative reasoning throughout the curriculum. That is, a critical component of the across-the-curriculum approach lies in encouraging all faculty to explain the quantitative reasoning employed in their disciplines when opportunities arise in courses. The vast literature on transfer of learning (e.g., Barnett & Ceci, 2002; Detterman, 1993), shows that transfer of concepts and skills is most likely to occur if teachers point out how quantitative concepts they teach relate to quantitative applications in other disciplines. In an effort to establish these important curricular practices, we have held luncheons and a workshop to begin

conversations about QL goals and discuss the types of quantitative reasoning taught in various disciplines.

For our first quantitative workshop, we invited three speakers who helped LU develop its cross-disciplinary approach to fostering QL. Joan Garfield from the University of Minnesota, helped us to consider the importance of statistical reasoning to QL. John Schlotterbeck talked about his experience teaching a quantitative-intensive history course at DePauw University and providing faculty support for an across-the-curriculum program. Dorothy Wallace talked about the Mathematics Across the Curriculum program at Dartmouth, and helped us to identify curricular needs for our program. The workshop participants concluded that LU could use two or three additional quantitative intensive courses aimed at students majoring in the humanities or fine arts. This conclusion is consistent with research showing that students are better able to master sophisticated problem solving skills in contexts that are familiar to them (e.g., Kuhn, 1990). Although a chemist, a mathematician, and an artist were excited about the possibility of developing a course in art and mathematics, they simultaneously recognized the difficulty of carving a place for one more course in their teaching schedules. On a more positive note, a theatre professor and a historian are considering developing quantitative courses in their disciplines.

Given that LU is now in the third year of its new quantitative curriculum, we are able to evaluate our progress to date. As supported by our initial assessment results below, LU has successfully offered courses satisfying the quantitative requirement in 12 departments. Those courses with a connection to the social sciences, humanities, or fine arts, like Biological Anthropology, Physics of Music, and Symbolic Logic, are popular among students majoring in the humanities or arts. Nevertheless, we recognize that the addition of two or three quantitative-intensive courses in the humanities or arts would strengthen our quantitative curriculum. Lawrence has also seen increasing pressure on its statistics curriculum from two sources. First, more departments now require a statistics course for their majors. Second, students seem to flock to the statistics course as a way to fulfill the quantitative requirement. Although the interest in statistics is encouraging from the perspective of achieving QL goals, it also creates a significant staffing challenge for the mathematics department. A final challenge lies in promoting cross-disciplinary discussions of QL goals and in encouraging faculty in all disciplines to sign onto teaching quantitative reasoning with the same commitment and enthusiasm they bring to teaching writing across the curriculum. We believe that the greatest QL challenge lies in promoting transfer of skills to new contexts.

Reinforcement of concepts and opportunities to practice solving quantitative reasoning throughout the curriculum is necessary to build students' repertoire of QL skills.

Program Assessment

As an initial assessment step, Lawrence designed and implemented a quantitative-intensive course evaluation form. At the completion of all quantitative-intensive courses, students are asked to report on the types of quantitative work they did in the course, evaluate the opportunities to develop quantitative reasoning and the usefulness of feedback on quantitative work, and provide self-reports of changes in their quantitative reasoning skills. The evaluation form also asks students to identify concepts and skills they learned that have practical applications. These student perception data have been collected for seven terms, beginning in the first year the new requirement went into place.

Data from the first term illustrate some interesting points. These data include responses from 335 students in 21 courses representing 7 disciplines. Students rated (on a 10-point scale) opportunities to develop quantitative reasoning quite highly in both the lower-level courses (mean = 7.4) and upper-level courses (mean = 7.9). Introductory statistics (mean = 8.3), symbolic logic (mean = 9.5), and introductory computer science (mean = 8.4) stood out as particularly strong in this area. In terms of applications to other courses or practical applications, the overall means for lower- and upper-level courses were also encouraging (means for all items were 7 or above on a 10-point scale). For example, statistics courses were rated highly (mean = 8.1) in terms of practical applicability. In terms of applications to other courses, upper-level statistics (mean = 8.8) was rated significantly higher than the upper-level mathematics courses (mean = 6.8). This finding is consistent with the argument that advanced math is increasingly abstract, whereas statistics emphasizes conceptual application, which contributes to QL (Steen, 2001).

With regard to pedagogy, students reported that feedback on their quantitative work and explicit instruction on quantitative skills were particularly useful (means for all items above 7). Students also indicated that they were asked to explain the reasoning behind their work more often in upper-level courses (mean = 8.3) than in lower-level courses (mean = 7.4). This difference may be accounted for by the smaller class sizes in upper-level courses. Nevertheless, if the goal is to improve QL, this result suggests that an area for possible improvement is encouraging students to explain their reasoning at all course levels.

After collecting this baseline perception data, we incorporated a few questions from this more extensive form into every course evaluation (we anticipate that the extensive form will be used as a part of the regular evaluation cycle for the quantitative GER). Hence, the student perceptions will always be a part of Lawrence's general education assessment plan.

Besides measuring student opinions, we plan to assess actual quantitative skills. Although this is a very difficult task, assessing quantitative competence is a necessary part of a comprehensive assessment plan. We proposed an assessment instrument that would measure (1) foundational mathematical and statistical skills; (2) quantitative reasoning skills, both general and discipline-specific; and (3) attitudes and beliefs about mathematics and quantitative literacy. Use 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 the contribution of discipline-specific training to overall QL. Because Lawrence takes an across-the-curriculum approach to developing QL, students take discipline-specific courses rather than a general course focused exclusively on QL. Thus, it is essential to determine whether discipline-specific training successfully meets Lawrence's QL goals. In a similar vein, Lehman and Nisbett (1990) demonstrated that particular types of disciplinary training were related to improvement in specific types of quantitative reasoning. For example, students majoring in the social sciences showed substantial improvements in statistical reasoning, whereas majors in the humanities and natural sciences showed smaller gains in this area. Furthermore, students majoring in the natural sciences or humanities showed improved understanding of conditional logic, though majors in the social sciences did not. Disciplinary analyses will help us to uncover strengths and weaknesses of various types of training, and thereby identify areas where students may need additional experiences to have well-rounded QL skills.

We think it is also important to measure students' developmental progression in acquiring QL. To this end, we plan to include assessment questions that measure students' ability to *identify* sound quantitative reasoning, as well as questions that measure students' ability to *generate* sound quantitative reasoning. Research in statistics education indicates that students may be able to identify strong statistical reasoning prior to their ability to generate it on their own (Garfield, 1998). Identifying a sound quantitative argument is an important skill in everyday problem solving (e.g., making sense of a political argument about tax cuts).

Another element of QL is a "confidence with mathematics" (Steen, 2001, p. 8). Therefore, we also plan to measure student attitudes about mathematics and quantitative literacy. The Dartmouth College Mathematics Across the Curriculum Survey (Korey 2000) provides a good starting point. As a first step, we administered to an introductory statistics class ($n = 33$) pre- and post-course attitudinal assessments based on the Dartmouth survey. The attitudinal survey contained 51 items, 35 from the Dartmouth study that focuses on mathematics and 16 items reworded to focus on statistics. The items generally cover three areas: anxiety and concern about mathematical or statistical competency, level of interest in pursuing further study in mathematics or statistics, and perception of the practical utility of mathematical or statistical concepts.

Overall, we found reduced post-course student anxiety about mathematical and statistical competency. For example, in the post-test, students reported significantly lower anxiety about learning statistics. Also, we were delighted to find that 84% of the students thought statistics helped them to understand the world; unfortunately we also found that only 23% of the students wanted to study more statistics. That is, even when students became convinced of the applicability of statistics in other areas, they were reluctant to pursue further study. Garfield and Ahlgren (1994) found similar results in their evaluation of the nationwide Quantitative Literacy Project. This reluctance may reflect a variety of concerns. For example, students may recognize that it is challenging to transfer skills to new contexts and may be reluctant to take on this challenge. Hesitancy to pursue further study may also reflect students' lack of confidence in their quantitative skills, coupled with their comfort in relying on intuitive, experiential reasoning.

Interestingly, it is not simply student attitudes that can be improved. An additional challenge is to boost faculty members' comfort level with quantitative methods and reasoning. At our quantitative workshop and luncheon, some faculty members expressed concerns about their expertise in teaching quantitative concepts and whether the kinds of quantitative applications they taught were sophisticated enough to meet the requirement. Lawrence's goal of an across-the-curriculum quantitative program can only be achieved if faculty from all disciplines embrace the importance of quantitative reasoning and feel confident in their ability to include quantitative elements in their courses

Conclusions and Future Directions

In reflecting on the success of our new quantitative GER in fostering quantitative literacy, we have mentioned several positives about the program as well as several steps LU could take to strengthen the program. We see the fact that LU has adopted an across-the-curriculum approach to fostering QL as a strength consistent with the available research on transfer of learning and QL. Sophisticated quantitative literacy is more likely to develop in an environment where students have opportunities to practice quantitative reasoning skills in a wide variety of contexts. However, the success of this across-the-curriculum approach requires cross-disciplinary commitment to providing these opportunities, in courses designated as quantitative-intensive and in as many other courses as possible. That is, we need a structure for teaching quantitative reasoning that parallels the approach taken for writing-across-the curriculum and speaking-across-the curriculum courses. Just as all faculty expect to model and teach good writing and speaking skills, faculty should be aware of and comfortable with modeling and teaching quantitative reasoning. We realize that increasing faculty comfort with teaching QL may be a significant faculty development challenge.

Given our society's propensity towards math anxiety and view of mathematical ability as a fixed inherent trait, we anticipate a need for at least two types of faculty development initiatives. First, it is important to have multi-disciplinary discussions of appropriate QL goals and to create a shared language for talking about specific quantitative concepts. We have noticed, for example, disciplinary differences in the way that faculty talk about and use statistical concepts such as significance testing and measurement error. It is no surprise then that students may not see how concepts are parallel or related if the surface presentation is different across courses. Faculty often seem to fear appearing unknowledgeable when opportunities arise to analyze or even ask about an unfamiliar quantitative application. For example, in our cross-disciplinary Freshman Studies course, faculty generally feel comfortable analyzing and asking questions about works of literature, yet they are sometimes reluctant to engage with quantitative works and even dismiss the works as incomprehensible. In order to create student enthusiasm about quantitative reasoning, faculty need to model a willingness to engage with complicated quantitative questions. Identifying specific quantitative learning goals and creating a shared language for discussing quantitative concepts would help to build faculty confidence and simultaneously model good quantitative reasoning skills. We anticipate that cross-disciplinary commitment

to promoting QL will increase as faculty confidence increases.

Second, establishment of a strong QL curriculum will require leadership from faculty members who are comfortable with teaching quantitative reasoning. Chemists, mathematicians, physicists, statisticians, and social scientists are among the faculty who might serve as models of how to ask good quantitative questions and apply quantitative concepts to solve academic and everyday problems. Effective models will make their reasoning explicit and will also demonstrate how they stumbled and worked through a challenge. That is, they will model what psychologists term metacognitive problem-solving skills: skills in monitoring one's own cognition. This type of modeling clarifies the reasoning process and can be used to teach people how to avoid reasoning biases, an important element of QL.

Obviously, these types of faculty development initiatives require time and resources. Using funding from an Andrew W. Mellon grant, LU provides course development grants to faculty interested in creating quantitative-intensive courses. Lawrence also supports co-teaching, making it possible for cross-disciplinary teams to co-teach quantitative-intensive courses in, for example, quantitative concepts in art. However, it is challenging to find room in teaching schedules to meet all of the curricular demands on faculty time. At a small college, it is difficult to juggle the need to teach courses required for disciplinary majors with the desire to offer quantitative-intensive courses aimed at a general audience. Nevertheless, given the demands of our sophisticated technologically-based society and the abundant examples of poor quantitative reasoning available in any newspaper, colleges like ours should take on the challenge of creating strong QL curriculums for their students.

References

- Barnett S.M. & Ceci, S. J. (2002). "When and Where Do We Apply What We Learn? A Taxonomy for Far Transfer." *Psychological Bulletin*, 128 (4), 612-637.
- Detterman, D. K. (1993). "The Case for the Prosecution: Transfer as an Epiphenomenon," in *Transfer on Trial: Intelligence, Cognition, and Instruction*, Detterman, D.K., & Sternberg, R.J. (Eds.) Norwood, NJ: Ablex Publishing, 1 – 24.
- Garfield, J. B. & Ahlgren, A. (1994). "Student Reactions to Learning About Probability and Statistics: Evaluating the Quantitative Literacy Project." *School Science & Mathematics*, 94 (2), 89-95.
- Garfield, J.B. (1998). "Challenges in Assessing Statistical Reasoning", presented at the symposium: Innovative Assessment Strategies for Improving the Teaching and Learning of Statistics.
- Korey, J. (2000). "Dartmouth College of Mathematics Across the Curriculum Evaluation Summary: Mathematics and Humanities Courses," *Mathematics Across the Curriculum at Dartmouth college*.<http://www.math.dartmouth.edu/~matc/Evaluation/humeval.pdf>.
- Kuhn, D. (Ed.). (1990). *Developmental Perspectives on Teaching and Learning Thinking Skills*, Karger, Switzerland.
- Darrin R. Lehman, D. R., & Nisbett, R.E. (1990). "A Longitudinal Study of the Effects of Undergraduate Training on Reasoning." *Developmental Psychology*, 26 (6), 952-960.
- Scheaffer, R. (2001). "Quantitative Literacy and Statistics." *Amstat News*, 293, 2-3.
- Steen, L. (Ed.) (2001). *Mathematics and Democracy: The Case for Quantitative Literacy*, Princeton, New Jersey: The National Council.