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www.aacu.org/peerreview
In 2012, founder and editor-in-chief of the FiveThirtyEight blog Nate Silver aggregated poll data to perform a statistical analysis that allowed him to correctly predict that Barrack Obama would be the presidential election winner. He also correctly forecasted the outcome of all thirty-five US Senate races held that year. After the election, Trudy Steinfield, New York University’s executive director of career development, wrote in forbes.com that Silver had “made math cool” and she reported “a notable increase in the number of students asking how they might investigate careers involving polling or data analysis.” She finished her remarks by listing a range of over twenty careers—from animator to urban planner—for which math skills “can make all of the difference.”

While not every student will use complex math skills professionally, in this data-rich era when information from the Internet is available instantly, all students must graduate with the ability to analyze and synthesize knowledge of the world around them. From deciding whether it is more advantageous financially to buy or lease a car to understanding the devastating effects of greenhouse gases on climate change, graduates need the ability to process quantitative information. This capability is called many things: quantitative reasoning, quantitative literacy, and numeracy.

The National Numeracy Network, an organization dedicated to developing this capability in all citizens, addresses the use of these various terms with this explanation:

Some call it numeracy, an expression first used in the UK’s 1959 “Crowther Report” to include secondary school students’ ability to reason and solve sophisticated quantitative problems, their basic understanding of the scientific method, and their ability to communicate at a substantial level about quantitative issues in everyday life. Others call it quantitative literacy, and describe this comfort [and] competency... in working with numerical data as being as important in today’s highly quantitative society as reading and writing were in previous generations. Still others refer to it as quantitative reasoning, emphasizing the higher-order reasoning and critical thinking skills needed to understand and to create sophisticated arguments supported by quantitative data.

In this issue of Peer Review, we use all three terms in various articles below, depending on the particular focus of each article.

This issue of Peer Review offers many lenses on this important topic, including discussions on why quantitative reasoning should be taught interdisciplinarily and across the curriculum, and why quantitative reasoning classes must move beyond calculation to include issues surrounding social constructions. Also included are articles highlighting innovative courses, including one that blends service learning with a quantitative reasoning curriculum and an introductory math course that uses faculty taskforce findings to increase student success. Another author provides practical advice based on lessons learned after establishing a campus quantitative reasoning skills center. Finally, we explore how the quantitative literacy movement has progressed in the past twenty-five years.

The Association of American College and Universities’ LEAP Essential Learning Outcomes include quantitative literacy as one of its six intellectual and practical skills important for all students to acquire as part of a high-quality liberal education. This facility with quantitative information, as defined in the VALUE rubrics, is “a habit of mind,” competency, and comfort in working with numerical data. Individuals with strong quantitative literacy skills possess the ability to reason and solve quantitative problems from a wide array of authentic contexts and everyday life situations. They understand and can create sophisticated arguments supported by quantitative evidence and they can clearly communicate those arguments in a variety of formats (see page 17 for the full rubric and next steps for use of the VALUE quantitative literacy rubric).

Strong quantitative reasoning skills empower students to gain insight into many of the world’s most complex problems. An earlier Peer Review article from 2011 got it right. Shannon W. Dingman and Bernard L. Madison suggest that “[T]he educational experiences we offer to students need to reflect this complicated world in which they operate... in fact, we must work to ensure that students possess both the knowledge and skills desired of a learned citizenry.”

—SHELLEY JOHNSON CAREY

FROM THE EDITOR
We live in an age where vast amounts of information can be accessed on the Internet. Much of this information is quantitative in nature and students (and adults) must be equipped to analyze the information as they sift through the data to make decisions in their everyday lives. And, as “big data” analyses move from pure research applications to business, education, health, and government settings where our graduates will be working, this imperative becomes more critical. Even in our own institutions of higher education, we are crunching large data sets of student information to monitor and predict student performance and success. All of these situations require strong quantitative reasoning skills.

WHAT IS QUANTITATIVE REASONING?
Quantitative reasoning. Quantitative literacy. Quantitative fluency. Numeracy. These are often-used terms when discussing a key learning outcome for undergraduate education. Here are a few high-profile examples of calls for prioritizing such quantitative skills:

- Quantitative literacy is one of the LEAP (Liberal Education for America’s Promise) Essential Learning Outcomes (ELOs) developed by the Association of American Colleges & Universities (AAC&U), one of a number of practical intellectual skills, including inquiry and analysis, critical and creative thinking, written and oral communication, information literacy and teamwork, and problem solving.
- The Lumina Foundation’s Degree Qualifications Profile (DQP) calls this skill quantitative fluency and places it, like LEAP, among several important intellectual skills all students should attain, including analytic inquiry, information literacy, engaging diverse perspectives, and communication fluency.
- The Western Association of Schools and Colleges (WASC) Senior College and University Commission has recently shifted its focus to five core competencies—writing, oral communication, quantitative reasoning, critical thinking, and information literacy—in its revised institutional review process.

The ability to think quantitatively clearly plays a central role in undergraduate education. But what do terms like quantitative reasoning, quantitative literacy, and quantitative fluency really mean for student learning, the curriculum, program development, faculty development, or accreditation? Why is it such an important outcome? How do we teach and measure it? Who is responsible for ensuring that students achieve this competency?

By one definition, quantitative reasoning (QR) is the application of basic mathematics skills, such as algebra, to the analysis and interpretation of real-world quantitative information in the context of a discipline or an interdisciplinary problem to draw conclusions that are relevant to students in their daily lives. It is not just mathematics. Carleton College, for example, views QR as “the habit of mind to consider the power and limitations of quantitative evidence in the evaluation, construction, and communication of arguments in public, professional, and personal life.” The term numeracy is also used in conjunction with these skills.

Ultimately, QR requires students to think critically and apply basic mathematics and statistics skills to interpret data, draw conclusions, and solve problems within a disciplinary or interdisciplinary context (fig. 1). Indeed, it requires the kind of mathematical and statistical skills that should be developed in high school, so all college students should have the basic skills required to achieve this broader, more ambitious college-level outcome. It is a competency of integration and application, both of which are intellectual capacities up near the top of the cognitive skills taxonomy originally described by Bloom (1956). Assignments that develop QR can also elicit demonstration of achievement of other key outcomes like writing and/or oral communication as well as...
WHY QR SHOULD BE TAUGHT ACROSS THE CURRICULUM AND IN INTERDISCIPLINARY CONTEXTS

The development of intellectual skills is paramount for undergraduate students. AAC&U (2007) states that intellectual and practical skills should be “practiced extensively, across the curriculum, in the context of progressively more challenging problems, projects, and standards for performance.” The DQP provides another lens through which to view these skills, stating that “students hone and integrate” these skills across the curriculum when dealing with problems in their major field of study, but also with “broad, integrative problem-solving challenges.” Thus QR appears to be much more than a general education learning outcome; it must be accomplished within the major, but also beyond it. QR is located at the intersection of critical thinking, basic mathematics skills, and the disciplines or real-world contexts for learning (fig. 1).

Deborah Hughes-Hallett (2001) argues that QR must be taught in the context of the disciplines because a critical component of the outcome is the ability to identify quantitative relationships in a range of contexts. She also argues that the very nature of QR is interdisciplinary because it involves contextual problem solving in real-world situations. Yet general education is where many campuses locate the teaching, learning, and assessment of core competencies like QR. One of the first decisions a campus must make when approaching QR learning is where in the curriculum students will be expected to gain these skills, and thus, where the faculty will both teach and measure it.

Examples of QR in everyday life abound and can be drawn upon to teach QR in the context of virtually any discipline. They can be found in areas such as health, economics, politics, science, engineering, social science, and even the arts. For example, virtually all parents face the vaccination question early in the life of their children. Parents might ask questions like, “What are the risks associated with vaccinating my child? What are the benefits?” In order to answer these questions, they must take into account quantitative information, such as disease occurrence rates in populations over time, or numbers of cases of complications with certain vaccine preparations. In today’s information age, the Internet is the most readily available source of information, so students (and adults) must be able to discern reliable versus non-reliable sources.

Returning to our vaccination example, there is rampant misinformation online about a connection between autism and vaccinations that must be recognized as such when parents formulate their decisions. Making judgments based on political polling data, understanding the national debt, interpreting nutrition facts, evaluating medical treatment or screening options, making investment decisions, and even purchasing decisions—these are all everyday challenges that require us to use QR skills. However, according to a 2003 survey by the National Assessment of Adult Literacy, only 13 percent of adults are deemed proficient in quantitative literacy; 33 percent perform at intermediate levels, 33 percent at basic levels, and 22 percent are below basic.

Larger societal issues, such as climate change, also require the application of QR skills—and the closing of a widening gap between those who have these skills and those who do not. Issues like these are politically contentious, beyond the practical implications for everyday life and decision making (should I buy a hybrid car? Should I buy carbon credits?). The “hockey stick” graph of rising CO2 levels made worldwide news as politicians debated the science behind climate change, or global warming as it was known in the past decade.

Jon D. Miller is a political scientist at University of Michigan who has been studying the civic scientific literacy of US adults. In surveys that ask basic factual scientific questions, he finds that less than 30 percent are scientifically literate (Miller 2010). Anthony Carnevale, director of research at the Center on Education and the Workforce at Georgetown University, argues that “the remedy for the widening gulf between those who are literate in mathematics and science and those who are not is democratization—making mathematics and science more accessible and responsive…to the needs of all citizens” (Steen 2004, 65). One way to achieve this literacy may be through a more intensive focus on quantitative reasoning in college. There are implications for all levels of education, preschool through college, but our focus here is on the undergraduate curriculum.

One of the primary misconceptions regarding QR is that it is already taught in mathematics classes. However, QR is different from math. QR utilizes basic mathematics skills in the service of carrying out information literacy aspects. While many espouse the importance of QR, higher education faculty and administrators need to expand the ways we provide students with learning opportunities to understand and practice this set of skills.
complex reasoning and decision-making processes. It is less about the how to perform the calculation and more about the meaning of the calculation results. Figure 2 contrasts math and QR to highlight the differences between them (Steen 2004).

A recent paper by Rocconi and colleagues (2013) reports that students in STEM fields are more engaged in QR-related activities than those in non-STEM fields, with students in education and the humanities showing the least engagement. This may not be surprising, but it is illuminating, given that QR skills are important for all students. It is easy to assume that the responsibility for QR should rest with the mathematics portion of general education or mathematics faculty. But experts argue that QR goes beyond basic math skills, and that most math courses don’t teach QR skills. There is a disciplinary context to the deep demonstration of QR skills by students that can most likely only be achieved by repeated exposure across the curriculum, along with culminating assessment in the major or a capstone experience. Faculty in mathematics departments may be best suited to take a leadership role in leading a campus-wide effort, but that effort must include faculty in other disciplines to have the broadest impact.

HOW DO WE GET THERE?
A 2001 study by the Mathematical Association of America summed up the challenges:
1. Most higher education students graduated without sufficient QR skills
2. Faculty in all disciplines needed professional development support to enhance QR in their courses
3. QR was not part of assessment activity
4. Education policy leaders were insufficiently aware of the increasing need for QR

While this study is more than a decade old, we may not be much further along today. QR is a complex outcome that requires immediate attention from faculty across the disciplines. Many institutions have embraced the core competencies of writing and communication, but far fewer attend to this equally critical outcome. In addition, there are special difficulties in reaching students. As Hughes-Hallett (2001) notes, they find it hard, especially when QR is taught in the context of the disciplines. She describes results from a study where students were given a quantitative problem to solve in the abstract and then in the context of a scientific problem. No scientific understanding was required to solve the problem, but students had trouble with the contextualized problem, in part because their perceptions of science or science phobia interfered. Other challenges might be related to creating awareness and buy-in across the campus for establishing and measuring QR outcomes. Campuses are already measuring many outcomes as accreditors ask for more specific and deliberate outcomes assessment (such as WASC’s new required attention to five core competencies discussed above). Many campuses have yet to define this outcome. Thus, an initial hurdle may be just starting the conversation about what QR means.

LEARNING OUTCOMES FOR QUANTITATIVE REASONING
As with any core competency or higher-order intellectual skill, using the “backward design” process (Wiggins and McTighe 1998) to define the desired outcomes and create appropriate assessments before designing learning experiences for students is useful. The outcomes may be simple or complex, depending on the focus or the locus of QR in the curriculum (i.e., general education or the major or some other institution-level requirement). These outcomes may include the kinds of math skills required, the types of data students should be able to interpret, the methods to be used for problem solving, the desired results of the application of these skills, and the ability to clearly communicate findings. Other outcomes may include student attitudes toward accomplishing these kinds of tasks, or ability to make connections to learning in the major or across the curriculum. Steen (2004b, 24) argues that there are three essential components to QR: (1) engagement with the real world (which may set it apart from traditional mathematics), (2) ability to apply quantitative thinking to unfamiliar contexts, and (3) adaptable reasoning, which is the ability to make judgments even in the “absence of sufficient information or in the face of inconsistent evidence.” How often in the real world do we have all the information we need to make a solid judgment? Rarely. Thus, we should be preparing our students to grapple with that kind of uncertainty.

Several universities have already developed outcomes for QR. One example of a comprehensive set of outcomes for graduating seniors at the University of
Students who are not seeking a degree or performance. Students seeking a degree in a major field (or another field), accurate calculations and operations are used in either his or her specific field of study or in interpreting social and economic trends.

At the bachelor’s level, the student
- Presents accurate calculations and symbolic operations, and explains how such calculations and operations are used in either his or her specific field of study or in interpreting social and economic trends.
- Constructs, as appropriate to his or her major field (or another field), accurate and relevant calculations, estimates, risk analyses, or quantitative evaluations of public information and presents them in papers, projects, or multimedia events.
- Students who are not seeking a degree in a quantitatively based or quantitatively relevant field articulate and/or undertake multiple appropriate applications of quantitative methods, concepts, and theories within their field of study.

A key component of WASC’s new core competency requirement is that colleges and universities establish standards of performance that students should reach at or near graduation. This means that standards regarding how well or at what level students will be expected to perform must be established.

**ASSESSMENT**

Many different approaches to assessing QR have been developed, ranging from direct to indirect measures of learning. Available tools include ready-to-use instruments and rubrics as well as survey and interview questions that assess attitudes toward mathematics in real-world contexts. Examples are available on the national organizations’ websites described in the next section, but I will describe three specific tools below.

The Center for Assessment and Research Studies at James Madison University has developed the Quantitative Reasoning Test (Sundre 2008). This instrument has been administered at over fifty universities to more than 20,000 students. It is a twenty-five-minute multiple-choice exam that focuses on two key outcomes. These are ability of students to
- use graphical, symbolic, and numerical methods to analyze, organize, and interpret natural phenomenon; and
- discriminate between association and causation, and identify the types of evidence used to establish causation.

With funding from the National Science Foundation, Eric Gaze and colleagues have developed another tool, the quantitative reasoning and literacy test (QRLA) for measuring students’ QR skill levels. This twenty-three-item test analyzes the following areas: computation and estimation, probability and statistics, graphical analysis and common functions, and logic/reasoning (For details, see http://serc.carleton.edu/qrla/index.html).

AAC&U’s VALUE (Valid Assessment of Learning in Undergraduate Education) project has published a rubric for assessing quantitative literacy with six criteria: interpretation, representation, calculation, application/analysis, assumptions, and communication (see page 2). Each of these criteria is described in detail, and the performance rating system ranges from the highest level (4 or “capstone”) through mid-range “milestones” (3, 2) to the beginner level (1). The rubric may be downloaded from the web; as with all its VALUE rubrics, AAC&U encourages institutions to modify this one to reflect local emphases. Dingman and Madison (2011) have developed another tool, the quantitative reasoning and literacy test (QRLA) for measuring students’ QR skill levels. This twenty-three-item test analyzes the following areas: computation and estimation, probability and statistics, graphical analysis and common functions, and logic/reasoning (For details, see http://serc.carleton.edu/qrla/index.html).

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**FIGURE 3. UNIVERSITY OF VIRGINIA QUANTITATIVE REASONING OUTCOMES**

A graduating fourth-year undergraduate at the University of Virginia will be able to

1. Interpret mathematical models such as formulas, graphs, tables, and schematics, and draw inferences from them.
2. Communicate mathematical information symbolically, visually, numerically, and verbally.
3. Use arithmetical, algebraic, and geometric methods to solve problems.
4. Estimate and check answers to mathematical problems in order to determine reasonableness.
5. Solve word problems using quantitative techniques and interpret the results.
6. Apply mathematical/statistical techniques and logical reasoning to produce predictions, identify optima, and make inferences based on a given set of data or quantitative information.
7. Judge the soundness and accuracy of conclusions derived from quantitative information, recognizing that mathematical and statistical methods have limits and discriminating between association and causation.
8. Solve multistep problems.
9. Apply statistics to evaluate claims and current literature.
10. Demonstrate an understanding of the fundamental issues of statistical inference, including measurement and sampling.
with respect to assessment because of the increased demand over the past few years by accreditors and the public. In order to lessen the workload, campuses might consider how QR can be added to existing assessment strategies. For example, many programs have capstone courses with signature assignments in which writing and critical thinking are already assessed using rubrics (or a single rubric). Those assignments and accompanying rubrics could be modified to add a QR component.

**QR Programs and Centers**

Some universities have set up programs for mathematics or QR across the curriculum, much like the writing across the curriculum movement that swept the nation a decade or more ago. Dartmouth College’s MATC program has helped faculty from mathematics and the humanities create nine integrated courses. Other institutions have built QR centers that host programs—workshops, tutoring, peer mentoring, etc.—to help students achieve QR skills. For example, Bowdoin College has created a QR program that provides advising, study groups, tutoring, and supplemental instruction in support of QR learning goals.

**Learning, Teaching, and Faculty Development**

There is no single pedagogy for QR, although problem-based or inquiry-focused learning approaches may be the most appropriate. Having students analyze data that is relevant to the course or discipline is a good place to start. News media are ready sources of data that can be used in classes. For example, Dingman and Madison (2011) take a student-centered approach to a general education course that moves the instructor into a moderator role, working with students on problems that stem from their interests and current events. Texts come primarily from the Internet. Grave (2012) describes several resources for teaching and measuring QR, such as those provided by three national organizations, the Mathematical Association of America, Project Kaleidoscope, and the National Numeracy Network. Other resources are available on the Science Education Resource Center website. These organizations’ websites offer a variety of curricular materials, along with assessment resources. NNN also publishes a national journal, *Numeracy*, that “supports education at all levels that integrates quantitative skills across disciplines.”

This type of teaching has implications for faculty development: not only do faculty members need to be comfortable with the content of QR, but they also need to become skilled in adapting real-world materials to instruction and using more active, less lecture-focused instructional methods. As the writing across the curriculum movement has learned, one of the best ways to help faculty members incorporate QR learning into their courses may be workshops sponsored by the faculty development center. These workshops can help faculty members gain confidence and skills in generating assignments and developing classroom activities for QR in disciplines that do not routinely use mathematics, such as in the arts and humanities. Faculty in these disciplines may also have math anxiety, much as faculty in the sciences and engineering may have anxiety about teaching and grading writing.

**Conclusion**

Hughes-Hallett (2001) asserts that what we need is a partnership among departments to help students achieve QR learning outcomes. She argues that this partnership must involve high schools, community colleges, colleges, and universities. Like the writing across the curriculum programs of the past decade, QR deserves the same institutional attention and focus.

**References**


Beyond Calculation

Bernard L. Madison, professor of mathematics, University of Arkansas
David Deville, graduate student in mathematics, University of Arkansas

Ten years ago, the first author wrote “Two Mathematics: Ever the Twain Shall Meet?” (Madison 2004) for an issue of Peer Review that focused on quantitative literacy (QL). In the ensuing decade QL, now referred to by many as quantitative reasoning, has gained considerable recognition as an effort by colleges and universities to ready their graduates for life in the quantitatively demanding US society and global community. In many ways, the quantitative demands of that society differ from the disciplinary world of academe, adding significant challenges to education for QL. Just what kind of course or program can prepare students for confronting the myriad quantitative issues in their everyday lives, saying nothing about the demands of their chosen professions?

A DECADE OF PROGRESS

Before we look at some principles to consider and possible course models, we note some progress in QL education over the past decade. Starting in 2000, historian Robert Orrill and mathematician Lynn Steen led an initiative to promote better education for QL in high school and the early years of college. Part of that initiative was the creation of the National Numeracy Network (NNN), initially conceived as a confederation of QL centers but reconstituted as an interdisciplinary membership organization in 2004. Now NNN has hundreds of members and its journal, Numeracy: Advancing Education in Quantitative Literacy, is publishing in 2014 its seventh volume of two issues annually. Textbooks aiming at QL and instruments for assessing QL have been written, scores of institutions have added courses or learning centers for QL, some institutions have integrated QL across the curriculum, and the Mathematical Association of America has created a special interest group in QL that is noting its tenth anniversary this year. QL is becoming accepted as an expected learning outcome of college. For example, the Arkansas Department of Higher Education approved the inclusion of a QL course as part of the State Minimum Core of collegiate courses as an alternative to college algebra for students not majoring in science, engineering, or mathematics.

In 2009, AAC&U’s Valid Assessment of Learning in Undergraduate Education (VALUE) project included QL as one of the ten intellectual and practical skills and developed a rubric for assessing QL at the institutional level (see page 22). Subsequently modified by Boersma et al. (2011) for assessing individual student work, the rubric identified six criteria for QL: interpretation, representation, calculation, analysis/synthesis, assumptions, and communication. These VALUE rubric core competencies, described below, provide a way to structure students’ work toward QL and a guide for developing instructional materials, as well as a framework of an assessment instrument.

- **Interpretation**: Ability to glean and explain mathematical information presented in various forms (e.g., equations, graphs, diagrams, tables, words).
- **Representation**: Ability to convert information from one mathematical form (e.g., equations, graphs, diagrams, tables, words) into another.
- **Calculation**: Ability to perform arithmetical and mathematical calculations.
- **Analysis/Synthesis**: Ability to make and draw conclusions based on quantitative analysis.
- **Assumptions**: Ability to make and evaluate important assumptions in estimation, modeling, and data analysis.
- **Communication**: Ability to explain thoughts and processes in terms of what evidence is used, and how it is organized, presented, and contextualized.
CHALLENGES THAT REMAIN

The progress toward better QL education has been significant, driven by the recognition that QL is absolutely necessary for understanding democratic processes and thriving in a rapidly moving, economically volatile US society. Yet, significant educational questions remain. What learning theory best identifies issues in QL? Is it situated learning, since, from our view, all QL learning is situational or contextual? What pedagogy is most effective for QL education? What is/are the community/practices of practice for QL? How should QL fit into higher education? In mathematics? In statistics? Across the curriculum? Elsewhere?

Currently, in K-12, QL depends almost completely on the mathematics strand, and in higher education, many QL courses are housed in mathematical science departments or interdisciplinary learning centers. As of now, there are no established guidelines for QL courses and no accepted, effective measures of long-term retention and transfer. Mathematics and statistics courses are usually described by their content (e.g., calculus, differential equations, probability, or experimental design). And mastery of content is the measure of success. Such a description for a QL course is elusive, as the mathematical and statistical content needed for QL currently does not have a clear description and consequently varies from course to course. In the absence of accepted mathematical content and measures of success, one must look elsewhere for building or evaluating QL courses. The first author (Madison 2014) has described such a process that stems from evaluating a QL course at the University of Arkansas that is housed in the mathematical sciences department.

MATHMATICS AS SENSIBLE, USEFUL, AND WORTHWHILE

At about the time “Two Mathematics” was published in Peer Review ten years ago, a QL course was introduced at the University of Arkansas and has been evolving since. Dingman and Madison (2011) wrote for this journal that teaching this course altered their perspectives on several things, including the role of the instructor, relevant mathematical content, use of technology, and sense-making in the messy world of realism. In the past three years our QL faculty members have begun to understand better the structure of QL courses and some guiding principles that seem necessary.

At the current time, there are two Arkansas QL courses: one with college algebra as a prerequisite and another that is an alternative to that course, which in this article will be referred to as QL1. The QL1 course was developed in 2012 using design principles derived from eight years of experience with the other QL course with a college algebra prerequisite. These design principles are supported by research findings about student learning (National Research Council 2000, 2001; Halpern and Hakel 2003). QL1 has two primary goals: (1) encourage students to develop habits of mind to analyze the quantitative content of everyday occurrences, and (2) increase students’ productive disposition—that is, the habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one’s own efficacy. Productive disposition is one of the strands of mathematical proficiency from the Adding It Up report of the National Research Council (2001) and its absence is a major barrier for QL in many math-phobic students.

Relevant Design Principles for a QL Course

Briefly, the design principles for a QL course are as follows:

- Provide a venue for continued practice beyond the course (and beyond school).
- Quantitative reasoning is a habit of mind, and habits are developed by practice. One or two courses or four years of school can only prepare one for practicing QL. The venue for continued practice in the Arkansas course is media articles.
- Keep the material relevant to students’ everyday contemporary world. According to John Dewey, “School should be less about preparation for life and more about life itself.” Connecting classroom learning to the everyday contemporary world not only can enhance learning in the classroom but can also lead students to adapt their classroom learning to the changing environment of everyday life. Relevance promotes productive disposition, noted above as a primary goal, and keeps material fresh.
- Use multiple contexts to practice quantitative reasoning. According to Halpern and Hakel (2003), “The purpose of formal education is transfer” (38). Halpern and Hakel go on to identify retrieval in multiple contexts as one of the most basic principles for enhancing long-term retention and transfer of learning and indicate that periodically spaced, not massed, practice at retrieval is best.
- Promote appreciation of arithmetical precision and the power of mathematical concepts and processes. This principle is often difficult to apply in a course where
the main goal is to understand contextual situations with quantitative content. Nevertheless, when opportunities arise to make use of mathematical power by developing some algebra, doing so, when needed, shows students the power and utility of mathematics, getting at half of the dual nature of productive disposition.

Help students to structure their quantitative reasoning in resolving problematic situations, including ample doses of critical reading and writing. One way to do this is by using the QL core competencies of interpretation, representation, calculation, analysis/synthesis, assumptions, and communication (Carey 2009; Boersma et al. 2011). Critical reading is the foundation of interpretation, and writing promotes reflection and clear understanding.

Encourage on-the-fly calculations and estimations. If students are able to assess quickly the validity of a quantitative assertion or mentally compute a numerical result, then they will be better able to practice QR in their daily lives. Practice should become reflexive and habitual.

Increase students’ supplies of quantitative benchmarks. Personal quantitative benchmarks are quantities that a student understands. For example, a student may understand a speed of 60 miles per hour (MPH) but not 1200 MPH. Such benchmarks are critical for understanding quantities (e.g., 1200 MPH is 20 times 60 MPH) and being able to determine reasonableness of quantitative assertions or numerical answers to questions. Providing multiple contexts for the use of benchmarks increases the chances that students retain the benchmarks and recognize their utility.

Encourage students to use technology to enhance and expedite understanding. Technology, including personal devices, is omnipresent in students’ everyday lives, so it should be leveraged in service of understanding QL.

Allow student interests to emerge. As reported in How People Learn, “Students are motivated to spend time needed to learn complex problems that they find interesting. Opportunities to use knowledge to create products and benefits for others are particularly motivating for students” (National Resource Council 2000, 77). Again, this promotes productive disposition.

Provide an interactive classroom environment. Interactive classrooms engage students in sense-making activities and promote personal accountability. Successful QL students are able to step outside of their comfort zones and assume responsibility for their work. Further, if we intend for students to use QL outside of the classroom, possibly in discussions of public issues, then the classroom experience should provide preparation for this practice.

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<td>Representation</td>
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Arkansas QL1 Course

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<td>Rational numbers</td>
<td>Habit of mind</td>
</tr>
<tr>
<td>Ratio</td>
<td>Productive disposition</td>
</tr>
<tr>
<td>Linear change</td>
<td>Writing</td>
</tr>
<tr>
<td>Exponential change</td>
<td>Critical reading</td>
</tr>
<tr>
<td>Statistical averages</td>
<td>Argument &amp; evidence</td>
</tr>
<tr>
<td>Statistical spreads</td>
<td>Quantitative benchmarks</td>
</tr>
<tr>
<td>Rates</td>
<td>Contextual accuracy</td>
</tr>
<tr>
<td>Counting</td>
<td>Social constructions</td>
</tr>
<tr>
<td>Probability</td>
<td>Economic constructions</td>
</tr>
<tr>
<td>Mental arithmetic</td>
<td>Comparative analysis</td>
</tr>
<tr>
<td>Measurement &amp; units</td>
<td>Political constructions</td>
</tr>
</tbody>
</table>

1Calculation here is one of the QL core competencies and differs somewhat from the component of the same name as articulated by Joel Best (2008A).
“beyond calculation” we mean to include contributions from the arts, humanities, social sciences, natural sciences, public media, and entertainment—any area of human activity. As a mathematics course, the calculation component is unusual in the sense that it is fragmented, without any obvious unifying concepts. Further, the mathematical concepts and methods in the Arkansas QL1 course do not necessarily include concepts and methods of other QL courses that may be directed at different audiences. The Arkansas QL1 course is directed toward the general education of students in majors other than science, engineering, or business.

Because the mathematics of the QL1 course is largely from the K–12 curriculum, it could be seen as developmental. However, the sophistication of the course is in the “beyond calculation” component—echoing Lynn Steen’s characterization of QL as sophisticated uses of elementary mathematics and statistics.

In table 1, the top rectangle represents the resolution of a canonical QL situation using the AAC&U LEAP Essential Learning Outcomes. One encounters a QL situation—say in a media article about economics—interprets the quantitative content, and produces a mathematical representation—say a linear equation. Then the problem becomes one of calculation. After the calculation and the results are analyzed and assumptions evaluated or noted, the results are communicated. This illustrates the habit of mind we want our students to develop.

One of the major obstacles to developing this habit is a low level of productive disposition—the ability to see calculation as useful and have the confidence and skill to use it to understand the situation. Also, observing and critiquing this process can be difficult, especially since many students are comfortable with their traditionally passive roles in the mathematics classroom.

Some of the items in the beyond calculation component are familiar, but some are not. Neil Lutsky and colleagues (2008) have written extensively about the use of quantitative evidence in argument in student writing at Carleton College. Joel Best (2008B) has noted the importance of statistical benchmarks—broadened here to go beyond statistics—in understanding US social statistics. Economic constructions, such as the various stock indices, appear frequently in the media, and yet they are mysterious to most people.

Political constructions that require QL often arise in disagreements about or differing views of budgetary situations—for example, the expression of the annual federal budget deficit in nominal dollars or as a percent of the gross domestic product. And graduates will frequently encounter comparative analyses, which usually require ad hoc methods. For example, comparing two credit card offers often comes down to individual preferences or expected uses, as the specifics of the offers are not directly comparable.

FINAL THOUGHTS

For quite some time, “quantitative reasoning” has been an accepted learning outcome of college, often without exemplification or clarification and frequently without authentic assessment. As US society has become immersed in quantification and quantitative analyses, specific and intentional QL education efforts have become essential. Over the past decade these efforts have been taking shape, but they remain varied and largely unevaluated. Communities of practice are forming, and research on QL learning is deepening. Professional societies, most notably AAC&U, the National Numeracy Network, and the Mathematical Association of America, lead many of these efforts. Most colleges and universities have created educational responses—courses, cross-curricular programs, or learning centers. Frameworks for QL courses are emerging, presaging standards for evaluation and some coherence, transferability, and expansion of learning. Many of the developments in QL education are described in the NNN journal Numeracy, available at http://scholarcommons.usf.edu/numercy/. Significant progress has marked the decade since the 2004 QL issue of Peer Review, but the educational ground is fertile for better understanding of QL and ways to help students achieve it. Informed participation in US society and individual prosperity depend greatly on those outcomes.

REFERENCES


Improving Success of Students in Introductory Mathematics and Statistics Courses

David F. Brakke, dean of the College of Science and Mathematics, James Madison University
Linda Cabe Halpern, vice provost for university programs, James Madison University

We live in a world of enormous complexity and are surrounded by quantitative problems, awash in numbers and information. This era of “big data” came quickly upon us, forcing us to re-think how we prepare our students to think and reason analytically, for life before and after graduation.

James Madison University (JMU) is a large, public, selective, comprehensive university in Virginia. Our goal is to prepare educated and enlightened citizens who will lead productive and meaningful lives. We believe that we need to enhance quantitative literacy, and to do so in a context of ethical decision making. To that end, a decade ago, we reported in Peer Review on multiple approaches being used to improve quantitative skills at James Madison University (Brakke and Carothers 2004). In that article we addressed first-year advising, support, assessment, curricular changes, minors and majors, and interdisciplinarity. We have continued those efforts and recently expanded them to address specific courses.

Placement for Success and Not for Failure

We cannot overemphasize the importance of placement into mathematics courses while also recognizing the landscape has become more complicated since our article was published. We must start with placement for success, not for failure. Students are entering universities with a wide range of skills and degrees of preparation. We recognize the importance of strong algebra skills regardless of what more advanced topics students were introduced to through IB, AP, and other courses and base our placements mostly on algebra. We have carefully studied the success rates of students in a range of mathematics courses in relation to their SAT and mathematics placement scores. Where necessary we have developed new courses designed to prepare students to be successful and have worked hard to improve advising about mathematics courses.

In other cases, we have begun conversations between the mathematics and statistics faculty and programs relying heavily on them. Examples include an engineering program now beginning its seventh year, working with biological mathematics, mathematics and the physical sciences and data analytics. These conversations may occur across one or more departments and in some cases cross multiple colleges.

Rather than providing an update on all of the areas addressed by Brakke and Carothers (2004) or describe conversations in early stages, we want to report on outcomes for two specific projects that we hope will illustrate ways that focused efforts can achieve very positive results and improve student learning outcomes. In so doing, we will suggest ways to structure collaborative efforts that lead to cooperation, increased understanding across programs, and improved student success.

We believe that we need to enhance quantitative literacy, and to do so in a context of ethical decision making.
INCREASING STUDENT SUCCESS IN TWO GATEWAY MATHEMATICS COURSES

In 2009, as part of the strategic planning process required by the state and coordinated by the State Council of Higher Education in Virginia, JMU undertook a project to increase student success in the two gateway mathematics courses with the largest undergraduate enrollments. These were Math 205, Introductory Calculus I—the three-credit calculus course taken by many students in the College of Business as well as a variety of other majors—and Math 220, Elementary Statistics, which is required by a large number of majors. Over 20 percent of new first-year students take one of these two courses in their first semester. In 2009–2010, the year this project started, the total fall and spring enrollment across these two courses was 3,823 students. In the same year, JMU enrolled 3,952 new first-year students and 669 new transfer students. Even allowing for some retakes and some students taking both courses, it is clear that a very large percentage of our students take at least one of these courses in their first-year. Improving student success in these two courses, therefore, had the potential of having an impact on a very large number of JMU undergraduates, making it a powerful project for improving overall student success.

INVESTIGATING CAUSES FOR STUDENT FAILURE

In the fall of 2009, two task forces, one for each course, were formed to investigate causes of student failure—defined as students completing the course with grades of D, F, or W (withdrawn)—and design possible strategies to increase success. Five years later, the very notable achievements of this project, and its general applicability to a number of undergraduate institutions, have led us to share project details. Before the project began, A, B, and C grades in Math 205 ranged from 62.3 to 71.7 percent and reached 83 percent in 2013–14. For Math 220, the percentages were from 70.8 to 76.0 percent prior to the project and reached 86 percent in 2013–14.

One important aspect of the formation of the task forces is that they included faculty from the departments whose curricula build on the two mathematics courses under review. So, for example, the initial task force examining student success in Elementary Statistics included faculty from biology, health sciences, justice studies, and psychology, as well as a faculty leader from the general education program. This breadth of representation allowed the group to consider not only what students needed to be successful in the gateway mathematics class but also what they needed to retain to be successful in a subsequent class in their major. A similar approach was taken for the one-semester calculus course. Both task forces were promised modest support, but it was clear that JMU could not provide significant new funding. Initial recommendations of both faculty groups and ongoing work on this project fall into three broad areas: student preparation and placement, course augmentations, and alignment.

STUDENT PREPARATION AND PLACEMENT

One immediate finding related to Elementary Statistics was that both our math placement test and preparatory courses were more closely aligned with calculus than statistics. Faculty began working immediately on a new section of our existing math placement test that would focus on the preparation students would need to succeed in a subsequent class in their major. A similar approach was taken for the one-semester calculus course. Both task forces were promised modest support, but it was clear that JMU could not provide significant new funding. Initial recommendations of both faculty groups and ongoing work on this project fall into three broad areas: student preparation and placement, course augmentations, and alignment.

STUDENT PREPARATION AND PLACEMENT

One immediate finding related to Elementary Statistics was that both our math placement test and preparatory courses were more closely aligned with calculus than statistics. Faculty began working immediately on a new section of our existing math placement test that would focus on the preparation students would need to succeed in statistics and also developed a quantitative literacy course that both matches the student learning outcomes of our general education program and provides focused preparation for further study in statistics.

After analyzing data on the relationship between math placement scores and student success in Introductory Calculus, we found that DWF rates were significantly higher for students who did not follow placement advice and took a higher math class than was recommended by their first-year advisors, so the task force recommended much tighter enforcement of placement scores as first-year students registered for classes.

COURSE AUGMENTATION

Mathematics faculty on both task forces also began work on supplemental materials that students could use to develop their skills. Over several sum-
mers, JMU has provided modest summer funding for mathematics and statistics faculty to develop homework questions and problem sets using WeBWorK, an open-source online homework system that is supported by the Mathematical Association of America and the National Science Foundation. Faculty believed the homework system would improve student learning and retention, and that it had the potential to reduce the workload on individual instructors because faculty are assigned to develop homework problems their colleagues could share. They have continued to build the test bank and increase the number of faculty using the homework system.

JMU had existing student support in supplemental instruction, as well as a comprehensive Science and Mathematics Learning Center providing tutoring and homework help for students in both courses. Even so, the group looking at statistics implemented more robust training for student tutors and both task force groups encouraged their colleagues to make greater use of the Supplemental Instruction program.

One of the most creative augmentation efforts has been the development of a one-credit “booster” course for students who do not place into Introductory Calculus, but whose scores fall into a range just below the cut-off point. The course is designed as a self-paced, primarily online supplement taken in the same semester as Introductory Calculus, allowing these students to avoid a three-credit full semester preparatory course. The benefits are many, including the fact that these students are able to move into calculus a semester earlier, and their success in calculus has improved.

ALIGNMENT
Both task force groups recognized divergence across sections of the same course as a problem. Faculty in the calculus group proposed to increase alignment through promoting the WeBWorK homework system and through fostering, in the words of their report, “an environment that promotes open discussion opportunities between faculty who teach Math 205.” Both courses are also making use of peer study leaders.

Statistics faculty implemented a number of specific initiatives designed to improve alignment across sections. These included instituting a Math 220 coordinator in the department, having statistics faculty approve a core list of course content topics to be covered in all sections, and analyzing the grade variance for greater consistency in grading. Because each of these initiatives came from the statistics group and were not mandated, they were widely embraced. The course coordinator worked so well that the same model was adopted by the calculus group.

| TABLE 1. STUDENT PERFORMANCE IN MATH 205 (CALCULUS) AND MATH 220 (STATISTICS) |
| YEAR | MATH 205 | MATH 220 |
| YEAR | ACTUAL\(^1\) | TARGET | THRESHOLD | ACTUAL\(^1\) | TARGET | THRESHOLD\(^4\) |
| 2000–01 | 62.3% | — | — | 73.4% | — | — |
| 2001–02 | 71.4% | — | — | 74.7% | — | — |
| 2002–03 | 66.4% | — | — | 73.9% | — | — |
| 2003–04 | 65.9% | — | — | 71.8% | — | — |
| 2004–05 | 63.0% | — | — | 70.8% | — | — |
| 2005–06 | 64.2% | — | — | 71.6% | — | — |
| 2006–07 | 69.1% | — | — | 72.5% | — | — |
| 2007–08 | 71.1% | — | — | 76.0% | — | — |
| 2008–09 | 71.7% | 70.7%\(^2\) | 67.7% | 76.4% | 75.0%\(^2\) | 72.0% |
| 2009–10 | 70.2% | 70.7% | 67.7% | 79.8% | 75.0%\(^2\) | 72.0% |
| 2010–11 | 76.0% | 70.7% | 67.7% | 79.1% | 75.0% | 72.0% |
| 2011–12 | 80.0% | 71.7% | 68.7% | 84.3% | 76.0% | 73.0% |
| 2012–13 | 80.2% | 72.7% | 69.7% | 85.5% | 77.0% | 74.0% |
| 2013–14\(^3\) | 83.0% | 73.7% | 70.7% | 86.0% | 78.0% | 75.0% |
| 2014–15 | — | 74.7% | 71.7% | — | 79.0% | 76.0% |
| 2015–16 | — | 75.7% | 72.7% | — | 80.0% | 77.0% |

\(^1\) Uses the annual course enrollment data file. Numerator consists of all students earning an A, B, or C grade. The denominator consists of all grades received with the exception of Audit, Incomplete, Pass and Fail.

\(^2\) Cumulative percentage of 06–07, 07–08, and 08–09 academic years.

\(^3\) A conservative estimate as of 7-18-14 that compares summer/spring terms from 2012–13 annual course enrollment with summer/spring terms from term course enrollment data for 2013–14.

\(^4\) The minimum level at which the improvement would be considered successful.
Another move undertaken across the department of mathematics and statistics was an effort to align faculty enthusiasm and commitment with their course schedules and teaching assignments. This move also more clearly defined the roles of faculty in teaching not only Math 205 and Math 220 but also other courses.

RESULTS
The results to these combined efforts have been stunning. As one faculty member noted at the beginning of the process, JMU started with success rates that many departments around the country would be proud to match. The current success rates (grades of A, B, or C) of 83 percent in Introductory Calculus and over 85 percent in Elementary Statistics exceed the targets we set by a great deal, and represent an extraordinary achievement by a dedicated group of faculty. Equally notable is the scale at which this has been achieved—in 2013–14 there were ninety-eight sections enrolling over 3,800 students during the fall and spring semesters. While reporting the major gains in student success, we need to emphasize that there was no change in course content or rigor of the courses. One of the instructions to the task forces from the very start was that they not back away from content, but instead focus on ways students can be more successful.

Because the project to increase student success in these two math courses was undertaken as part of a state-level strategic planning process, it started with specific targets by which the improvement would be considered successful. Table 1 lists actual student performance in these courses beginning in 2000, and compares those results with the established targets and thresholds. In each course, large increases in student success followed the implementation of the improvement strategies described in this article.

Mathematics and statistics faculty are proud of the success of these efforts, and are continuing to seek ongoing improvement. For 2014–2015, they have expanded the use of the one-credit booster course and are considering the model for other more specialized introductory math courses. They continue to expand the problem sets used in WeBWork. We may reach a point where the university’s goal will be to maintain our level of student success in these courses rather than continued improvement in success rates, but we hope to see further progress in the near future. *

ACKNOWLEDGMENTS
We would like to acknowledge the leadership of our colleagues in the department of mathematics and statistics. The task force promoting student success in Math 205 was led by Debra Polignone Warne, professor of mathematics; the task force promoting success in Math 220 was led by Hasan Hamdan, professor of mathematics, and Kane Nashimoto, associate professor of mathematics. David Carothers, mathematics department head, has supported their efforts throughout the process.

REFERENCES
Quality Collaborative to Assess Quantitative Reasoning: Adapting the LEAP VALUE Rubric and the DQP

Jennifer Berg, assistant professor of mathematics, Fitchburg State University
Lisa M. Grimm, assistant professor and graduate program chair of biology, Fitchburg State University
Danielle Wigmore, associate professor of exercise and sports science, Fitchburg State University
Christopher K. Cratsley, director of assessment, Fitchburg State University
Ruth C. Slotnick, former director of articulation and learning assessment, Mount Wachusett Community College; director of assessment, Bridgewater State University
Susan Taylor, professor and chair of computer information systems, Mount Wachusett Community College

Quantitative skills have been consistently highlighted as among the critical outcomes of a strong undergraduate education. The Association of American Colleges and Universities’ (AAC&U) Liberal Education and America’s Promise (LEAP) initiative identifies quantitative literacy as one of six “Intellectual and Practical Skills” within its broader list of Essential Learning Outcomes (ELOs) for a liberal education (National Leadership Council for LEAP 2007). More recently, the Lumina Foundation Degree Qualifications Profile (DQP) has included Quantitative Fluency as one of the proficiencies within the “Intellectual Skills” area in both the original version and DQP 2.0 (Lumina Foundation 2011, 2014). Furthermore, AAC&U has surveyed employers across the nation, finding that 55 percent believe colleges and universities should place more emphasis on students’ ability to work with numbers and understand statistics, and 81 percent believe more emphasis should be placed on the ability to analyze and solve complex problems (Hart Research Associates 2013).

While the extent to which employers considered analyzing and solving complex problems as related to quantitative literacy or fluency is unclear, this emphasis from employers suggests that our institutions should prioritize the ability to apply quantitative skills to solving problems—quantitative reasoning. The combination of understanding abstract principles and processes of mathematics, and quantitative reasoning as the practice of applying those principles and processes in real-world contexts, sometimes referred to as “the two maths,” must be a critical area of emphasis within higher education (Steen 2004).

In 2012, Fitchburg State University (Fitchburg State) and Mount Wachusett Community College (MWCC) were selected to form a two- and four-year dyad as part of AAC&U’s nine-state Quality Collaboratives (QC) project. There was substantial overlap between MWCC’s Quantitative Reasoning and Scientific Modes of Inquiry learning outcome, Fitchburg State’s Problem Solving through Quantitative Reasoning outcome, the LEAP Quantitative Literacy ELO, and the DQP Quantitative Fluency competency, so we selected quantitative reasoning (QR) as one of four areas of focus (along with civic engagement, information literacy, and written communication) for our project. The AAC&U Quality Collaboratives initiative, funded by Lumina Foundation and the William and Flora Hewlett Foundation, has supported efforts to develop practices and strategies for assessing DQP proficiencies as the basis for transfer between two- and four-year institutions.

Our project has brought together four teams of faculty and staff Assessment Scholars—one for each focus area—with equal representation from each campus to perform the following work: develop rubrics for assessing each of the four learning outcome...
areas, pilot those rubrics in the assessment of student artifacts, develop strategies for engaging faculty in the assessment process, and consider how the assessment data could be used to inform student transfer policies. Through this process, the QR team reaffirmed our institutional commitments to having students from both institutions engage in the application of quantitative skills to complex problems, while grappling with the challenges of designing appropriate assessments in comparable ways across our two campuses.

MODIFYING THE QUANTITATIVE LITERACY LEAP VALUE RUBRIC

The QR team began their work by sharing the two institutions’ previous rubrics and seeing how they compared to the AAC&U LEAP Valid Assessment of Undergraduate Education (VALUE) rubric for quantitative literacy (http://www.aacu.org/value/rubrics/quantitative-literacy) and the DQP Quantitative Fluency competency. Fitchburg State faculty had recently created a modified LEAP VALUE rubric for assessing problem solving through quantitative reasoning in our general education curriculum. The Quantitative Reasoning and Scientific Modes of Inquiry rubric in use by MWCC was also discussed. The team agreed that the LEAP VALUE rubric was a good starting point, but wanted to incorporate elements from both institutions’ rubrics as well as clarify the categories within the rubric: the rubric criteria. Modifications to the LEAP VALUE rubric included changes to criteria names, reordering the criteria to match what we imagined the flow of student work would display, and removing the Communication criterion from the rubric, as we felt it was duplicating the criterion we eventually labeled Judgment/Conclusions (table 1). In addition, a criterion was added (from the Fitchburg State rubric) addressing students’ ability to apply content knowledge or methods and/or results to a new situation. The team members felt that this criterion spoke to an important feature of quantitative reasoning that was absent in the LEAP VALUE rubric. A clearer distinction was made between students’ ability to describe patterns in data (Interpretation/Description) and to make inferences based on the data (Judgments/Conclusions). Modifications in language to the rubric criteria, or the performance descriptors therein, were made in order to reflect how the team members felt we would use the rubric on our students’ work.

TABLE 1. COMPARING THE QC QUANTITATIVE REASONING RUBRIC TO THE UNMODIFIED LEAP VALUE RUBRIC

<table>
<thead>
<tr>
<th>MODIFIED LEAP VALUE CRITERIA</th>
<th>ORIGINAL LEAP VALUE CRITERIA</th>
<th>CHANGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation</td>
<td>Calculation</td>
<td>Appears as the third criterion in the VALUE rubric, but has been moved to the first criterion in our rubric with minor changes in the performance descriptors.</td>
</tr>
<tr>
<td>Representation</td>
<td>Representation</td>
<td>The description in italics was changed slightly and the performance descriptors were also modified slightly.</td>
</tr>
<tr>
<td>• To math—The ability to convert relevant information into various mathematical forms (e.g., equations, graphs, diagrams, tables)</td>
<td>• Ability to convert relevant information into various mathematical forms (e.g., equations, graphs, diagrams, tables)</td>
<td></td>
</tr>
<tr>
<td>Interpretation/Description</td>
<td>Interpretation</td>
<td>Appears as the first criterion in the VALUE rubric, but moved down to third criterion on modified rubric. Minor changes were made to the performance descriptors.</td>
</tr>
<tr>
<td>• From math —The ability to explain information presented in mathematical forms (e.g., equations, graphs, diagrams, tables, words)</td>
<td>• Ability to explain information presented in mathematical forms (e.g., equations, graphs, diagrams, tables, words)</td>
<td></td>
</tr>
<tr>
<td>Judgments/Conclusions</td>
<td>Application/Analysis</td>
<td>The name of this criterion was changed, and minor changes were made to the performance descriptors.</td>
</tr>
<tr>
<td>• Ability to make judgments and draw appropriate conclusions based on the quantitative analysis of data, while recognizing the limits of this analysis</td>
<td>• Ability to make judgments and draw appropriate conclusions based on the quantitative analysis of data, while recognizing the limits of this analysis</td>
<td></td>
</tr>
<tr>
<td>Applies content knowledge, methods and/or results to new situations</td>
<td>Communication</td>
<td>This criterion is a new one, replacing Communication. At the capstone level students make accurate and comprehensive conclusions about a new situation using information previously learned in another context.</td>
</tr>
<tr>
<td>Assumptions</td>
<td>Assumptions</td>
<td>This criterion is unchanged, but it was moved so that it is the last criterion.</td>
</tr>
<tr>
<td>• Ability to make and evaluate important assumptions in estimation, modeling, and data analysis</td>
<td>• Ability to make and evaluate important assumptions in estimation, modeling, and data analysis</td>
<td></td>
</tr>
</tbody>
</table>
These efforts led to a working draft of the rubric, which we used to evaluate student work for a variety of courses selected from both institutions. This assessment resulted in additional minor modifications to the rubric, and, most importantly allowed us to norm as a group. The success of this project rested in the wide range of experience in our group, which included representatives from both institutions—adjunct faculty, full-time faculty (some tenured, some not), a lab technician, and a campus administrator. While we all had similar conceptions of QR, we also brought different disciplinary perspectives to the table, and those nuances shaped our work, both with the development and application of the rubric to evaluate student work. Our collaborative model encouraged us to consider a broad definition of QR that encompasses the criteria of the LEAP VALUE rubric as well as a student’s ability to extend and apply their reasoning to new situations.

COMPARING THE RUBRIC TO THE DQP QUANTITATIVE FLUENCY COMPETENCY

Entering the second year of the project, the QR team was charged with comparing the modified rubric to the DQP competencies for quantitative fluency. The DQP provides reference points for learning outcomes at the associate’s, bachelor’s and master’s level, demonstrating a progression of learning as a student advances through the levels. The intent of this task was to determine areas of overlap or disparity between the modified rubric and the DQP, and to craft DQP-like statements that could comprehensively reflect our expectations of a quantitatively fluent person at the associate level (table 2).

Our main criticism of the DQP 1.0 competency (Lumina Foundation 2011) was that it focused entirely on a student’s ability to perform and explain calculations. Lacking was any expectation of representation or description of data, making judgments or drawing conclusions based on the quantitative analysis of data, applying concepts to new situations, or stating assumptions. These are important skills that students should be practicing at the two-year mark and refining at the four-year mark. Our team developed a revised DQP-like statement (table 2) that was better aligned with our modified QR rubric and more accurately reflected our expectations of a quantitatively fluent person at the associate level, which is often the point of transfer to the four-year institution.

Since our first review of the DQP, Lumina published a revised version, DQP 2.0 (Lumina Foundation 2014). The quantitative fluency statement in the DQP 2.0 improves upon the original DQP statement in several ways. First, it expands the qualification to include “creates and explains graphs or other visual depictions of trends” (Lumina Foundation 2014). There is now also an expectation of “accurate interpretations of quantitative information” (Lumina Foundation 2014). However, while students are expected to interpret quantitative information, they are not necessarily expected to draw conclusions from it. Furthermore, the skills of applying concepts to new situations or stating/discussing assumptions are still absent. While the revised DQP statement is an improvement upon the original, it does not go far enough, in our judgment, in terms of emphasizing the quantitative skills and abilities at the associate level needed to tackle complex problems. Reviewing and revising the DQP allowed us to reaffirm our commitment to the quantitative problem-solving skills reflected in our modified QR rubric.

ASSESSING STUDENT ARTIFACTS WITH THE MODIFIED QR RUBRIC

In the first year of the Fitchburg State/MWCC dyad, multiple student artifacts from both institutions were collected and assessed by the QR team, and included artifacts from two statistics courses, an environmental science exam, and a chemistry exam. In the second year of the project, the QR team focused on collecting artifacts from high-demand fields and disciplines and on locating assignment prompts that explicitly required students to engage in the more difficult rubric areas such as Application and

<table>
<thead>
<tr>
<th>DQP 1.0</th>
<th>DQP 2.0</th>
<th>MWCC/FITCHBURG STATE QC DYAD’S DQP-LIKE STATEMENTS FOR THE ASSOCIATES LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presents accurate calculations, and symbolic operations, and explains how such calculations and operations are used in either his or her specific field of study or in interpreting social and economic trends.</td>
<td>Presents accurate interpretations of quantitative information on political, economic, health-related, or technological topics and explains how both calculations and symbolic operations are used in those offerings.</td>
<td>Students interpret descriptions of situations and use the interpretations to develop appropriate quantitative solution strategies.</td>
</tr>
<tr>
<td>Creates and explains graphs or other visual depictions of trends, relationships, or changes in status.</td>
<td>Within these solutions, student should make effective choices in which calculation to complete, successfully complete those calculations, and connect information into mathematical forms.</td>
<td>Students then draw conclusions from results of quantitative analysis, including in novel situations, and reflect on any assumptions they made in completing their work.</td>
</tr>
</tbody>
</table>

TABLE 2. COMPARING THE DQP REFERENCE POINTS TO THE MWCC/FITCHBURG STATE QC DYAD’S DQP-LIKE STATEMENTS FOR THE ASSOCIATES LEVEL |
Assumptions. In total, three sets of student artifacts were collected in year two: a biology lab report from MWCC, a biology lab report from Fitchburg State, and a nutrition analysis assignment from Fitchburg State. For both years of the project, each artifact was independently scored for each rubric criterion (1–4 or NA) by at least two assessors using our Quantitative Reasoning rubric in the TK20 assessment management system.

In each set of first-year artifacts, there were only one or two rubric criteria that could be scored by assessors because many of them were not observable in the student artifacts. The most consistently missing criteria were Judgments/Conclusions, Application of Knowledge, and Statement of Assumptions. In all four sets of artifacts, greater than 60 percent of the artifacts did not demonstrate these quantitative reasoning categories, with Application and Assumptions being absent in 100 percent of the artifacts. Demonstration of the remaining rubric criteria of Calculation, Representation, and Interpretation/Description was highly variable and depended upon the nature of the assignment.

In the second-year collection, there was substantial improvement in the number of artifacts that showed evidence of Interpretation/Description, with 88–98 percent of artifacts being scorable for this criterion (table 3). However, in the categories of Application and Assumptions, there was still little to no evidence to score these criteria. There were no obvious trends or patterns illustrating areas of student weakness in the mean scores in the criteria of Calculation, Representation, Interpretation/Description, and Judgments/Conclusions. Each assignment’s mean scores achieved milestone proficiency (>2) for each criterion that could be scored.

In order to open up discussion on these data, the QR team used a modified “ATLAS: Looking at Data” protocol (School Reform Initiative 2007). In this protocol, participants were asked to make purely descriptive statements about what they saw in the data tables and then make claims about what these data suggest (i.e., making sense of the data in as many ways as possible), often times using the descriptions from the first phase as evidence in support of these interpretations. The conversation then moved into three layers of implications: those for the classroom practice, for assessment practice, and finally for transfer policies between our institutions. This approach allowed interpretations to flow into meaningful conversations and reflections about how material is taught, how we assess student learning, and how we develop and think of transfer issues related to assessment.

Looking more closely at the data through the lens of our institutional assessment practice we noticed some common issues. When using the rubric in both the first- and second-year of the project it was a challenge to find one assignment that would provide evidence of student learning on all (or even most) of the criteria on the rubric. Our discussions revealed that although the second-year assignments improved upon this problem by providing opportunities for students to engage in the application of content to new situations and to identify any assumptions made, students did not demonstrate these skills because they were not explicitly prompted to do so in the assignments.

What emerged from this data analysis was the need to have more carefully constructed assignment prompts that explicitly require these higher order tasks. However, the team also found that assignments that addressed the Analysis, Judgment, and Assumptions portion of the rubric were often project-based assignments in which the student did not explicitly show the method of calculation, as it was often calculated by a piece of software. In this the QR team uncovered a challenge common for those who assess QR: how to assess both calculation skills and conceptual understanding when looking at a completed piece of student work. The team continued to emphasize a shared commitment to the quantitative problem-solving skills reflected in the rubric, while recognizing the challenges of soliciting appropriate assignments of these types from faculty.

### Table 3. The Mean Scores of Student Artifacts That Showed Evidence of a QR Criterion*

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>BIO 109 LABS (N=24)</th>
<th>RESPIRATION LABS (N=20)</th>
<th>NUTRITION ANALYSES (N=18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation</td>
<td>NA</td>
<td>3.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Representation</td>
<td>2.4</td>
<td>2.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Interpretation/Description</td>
<td>2.4</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Judgments/Conclusions</td>
<td>2.3</td>
<td>NA</td>
<td>2.0</td>
</tr>
<tr>
<td>Applies to new situations</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Assumptions</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Mean scores (on a scale of 1–4) for three different assessments of QR. NA indicates 94–100 percent of assessors did not provide a score for that criterion. All other criteria were scored by at least 80 percent of assessors.
teria of Application and Assumptions were not assessable in any of the work we had reviewed. As a result of this discovery, the QR team turned to lab reports that would allow most, if not all, of the rubric criteria to be assessed within the same assignment.

To this end, a sample lab report assignment was annotated to communicate to faculty what an appropriate prompt might look like and how to apply the QR rubric to student work. Annotations were provided throughout the assignment to identify where the various rubric criteria were being assessed. For example, when the students were prompted to “create a table that shows the subject descriptive data,” the annotation noted this as a method to assess the Representation criterion. Construction of the table reflects the Representation criterion because “the table requires students to determine that they must first calculate average values for the two groups, and then to organize the relevant information into a clear table with appropriate labels.” In this way the annotated lab report assignment provides a guideline for using the modified QR rubric. Additionally, faculty may choose to use it to develop assignments that align with the QR rubric. The QR team also developed an e-mail template to be used when requesting student work from faculty for assessment. The e-mail explains the purpose of the assessments, describes what appropriate assignments should include, and inquires about the type of feedback the faculty member would like to receive from the assessments.

As the dyad moved into the third year of work, we shifted our attention to assignment design. We brought new faculty members into the project and turned to another protocol to help focus conversations about assignment prompts, a modified Charette that was developed by the National Institute for Learning Outcomes Assessment (School Reform Initiative 2007). First, using both the Lumina DQP 2.0 and the modified QR rubric, participants gave each other feedback to determine if each of the selected assignment prompts matched the performance criteria. Second, they addressed the role their assignment plays in the course and were asked to reflect on the assignment’s strengths and weaknesses to locate what parts were working well and what parts needed attention.

After this, each member of the group had the opportunity to have their assignment discussed (using the Charette protocol). Participants gave the assignment designer feedback on how well the assignment was suited to assessing student work and learning on the DQP proficiencies, and on how the assignment might appear from a student’s perspective. At the end of the sessions each faculty member had feedback on the assignment from numerous perspectives. This feedback will be used to further revise the assignment prompts over the summer with the goal of having assignments that effectively measure the criteria of the QR rubric. As we move forward with shared methods for QR assessment on our campuses, we are continuing to focus on collaborative faculty professional development in the area of assignment design to ensure we can assess the higher order quantitative problem solving skills we have stressed through our rubric.

CONCLUSIONS AND IMPLICATIONS FOR TRANSFER

Our work developing common rubrics, stating shared goals for quantitative reasoning expressed as DQP-like statements, and creating a culture of collaborative faculty professional development in the area of assignment design provides a strong foundation for setting expectations for transfer students. Each institution is undergoing a review of its own general education curriculum, and the initial discussions have been informed by the work of our Assessment Scholars. The two institutions are also planning shared professional development days in the future to ensure ongoing alignment of our assignments and student learning expectations. While the LEAP quantitative literacy ELO, VALUE rubric, and DQP Quantitative Fluency competency each provided a necessary tool to frame our cross-institutional discussions, they alone were not sufficient to allow the two institutions to develop our shared vision for Quantitative Reasoning.

By bringing faculty and staff from our two institutions together with a focus on student learning, we expanded our understanding of quantitative reasoning beyond the mechanical translation and computation of mathematical information to embrace an expectation that students will make judgments about the processes and assumptions involved in translation and computation, draw conclusions about what knowledge has been gained from those processes, and be able to apply those processes effectively in novel situations. By emphasizing these student learning outcomes, we hope to better prepare students for successful transfer from MWCC to Fitchburg State and for careers in which they will increasingly need to apply quantitative skills to analyze and solve complex problems.

REFERENCES


Quantitative Literacy VALUE Rubric

The VALUE rubrics were developed by teams of faculty experts representing colleges and universities across the United States through a process that examined many existing campus rubrics and related documents for each learning outcome and incorporated additional feedback from faculty. The rubrics articulate fundamental criteria for each learning outcome, with performance descriptors demonstrating progressively more sophisticated levels of attainment. The rubrics are intended for institutional-level use in evaluating and discussing student learning, not for grading. The core expectations articulated in all 15 of the VALUE rubrics can and should be translated into the language of individual campuses, disciplines, and even courses. The utility of the VALUE rubrics is to position learning at all undergraduate levels within a basic framework of expectations such that evidence of learning can be shared nationally through a common dialog and understanding of student success.

<table>
<thead>
<tr>
<th>CAPSTONE</th>
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<tbody>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

**INTERPRETATION**
- Ability to explain information presented in mathematical forms (e.g., equations, graphs, diagrams, tables, words)
- Provides accurate explanations of information presented in mathematical forms. Makes appropriate inferences based on that information. For example, accurately explains the trend data shown in a graph and makes reasonable predictions regarding what the data suggest about future events.

**REPRESENTATION**
- Ability to convert relevant information into various mathematical forms (e.g., equations, graphs, diagrams, tables, words)
- Skillfully converts relevant information into an insightful mathematical portrayal in a way that contributes to a further or deeper understanding.

**CALCULATION**
- Calculations attempted are essentially all successful and sufficiently comprehensive to solve the problem. Calculations are also presented elegantly (clearly, concisely, etc.)

**APPLICATION / ANALYSIS**
- Ability to make judgments and draw appropriate conclusions based on the quantitative analysis of data, while recognizing the limits of this analysis
- Uses the quantitative analysis of data as the basis for deep and thoughtful judgments, drawing insightful, carefully qualified conclusions from this work.

**ASSUMPTIONS**
- Ability to make and evaluate important assumptions in estimation, modeling, and data analysis
- Explicitly describes assumptions and provides compelling rationale for why each assumption is appropriate. Shows awareness that confidence in final conclusions is limited by the accuracy of the assumptions.

**COMMUNICATION**
- Expressing quantitative evidence in support of the argument or purpose of the work (in terms of what evidence is used and how it is formatted, presented, and contextualized)
- Uses quantitative information in connection with the argument or purpose of the work, presents it in an effective format, and explicated it with consistently high quality.
**DEFINITION**

Quantitative Literacy (QL)—also known as Numeracy or Quantitative Reasoning (QR)—is a “habit of mind,” competency, and comfort in working with numerical data. Individuals with strong QL skills possess the ability to reason and solve quantitative problems from a wide array of authentic contexts and everyday life situations. They understand and can create sophisticated arguments supported by quantitative evidence and they can clearly communicate those arguments in a variety of formats (using words, tables, graphs, mathematical equations, etc., as appropriate).

Download this and other VALUE Rubrics at www.aacu.org/value/rubrics.

<table>
<thead>
<tr>
<th>MILESTONES</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides accurate explanations of information presented in mathematical forms. For instance, accurately explains the trend data shown in a graph.</td>
<td>Provides somewhat accurate explanations of information presented in mathematical forms, but occasionally makes minor errors related to computations or units. For instance, accurately explains trend data shown in a graph, but may miscalculate the slope of the trend line.</td>
<td>Attempts to explain information presented in mathematical forms, but draws incorrect conclusions about what the information means. For example, attempts to explain the trend data shown in a graph, but will frequently misinterpret the nature of that trend, perhaps by confusing positive and negative trends.</td>
<td></td>
</tr>
<tr>
<td>Competently converts relevant information into an appropriate and desired mathematical portrayal.</td>
<td>Completes conversion of information but resulting mathematical portrayal is only partially appropriate or accurate.</td>
<td>Completes conversion of information but resulting mathematical portrayal is inappropriate or inaccurate.</td>
<td></td>
</tr>
<tr>
<td>Calculations attempted are essentially all successful and sufficiently comprehensive to solve the problem.</td>
<td>Calculations attempted are either unsuccessful or represent only a portion of the calculations required to comprehensively solve the problem.</td>
<td>Calculations are attempted but are both unsuccessful and are not comprehensive.</td>
<td></td>
</tr>
<tr>
<td>Uses the quantitative analysis of data as the basis for competent judgments, drawing reasonable and appropriately qualified conclusions from this work.</td>
<td>Uses the quantitative analysis of data as the basis for workmanlike (without inspiration or nuance, ordinary) judgments, drawing plausible conclusions from this work.</td>
<td>Uses the quantitative analysis of data as the basis for tentative, basic judgments, although is hesitant or uncertain about drawing conclusions from this work.</td>
<td></td>
</tr>
<tr>
<td>Explicitly describes assumptions and provides compelling rationale for why assumptions are appropriate.</td>
<td>Explicitly describes assumptions.</td>
<td>Attempts to describe assumptions.</td>
<td></td>
</tr>
<tr>
<td>Uses quantitative information in connection with the argument or purpose of the work, though data may be presented in a less than completely effective format or some parts of the explication may be uneven.</td>
<td>Uses quantitative information, but does not effectively connect it to the argument or purpose of the work.</td>
<td>Presents an argument for which quantitative evidence is pertinent, but does not provide adequate explicit numerical support. (May use quasi-quantitative words such as “many,” “few,” “increasing,” “small,” and the like in place of actual quantities.)</td>
<td></td>
</tr>
</tbody>
</table>
ne of my earliest memories from my experiences with math is from when I was in second grade. We were counting by twos as a class and my teacher singled me out for not knowing them—I was just saying random numbers. I remember he laughed and the entire class also erupted in laughter. From then on I knew I would never be good at math."

This is a quote from a student’s math autobiography in a recent quantitative reasoning course at Seattle University. While the details of students’ mathematical histories vary from person to person, a traumatic mathematical experience from childhood that has had persistent negative effects is common amongst students enrolled in this course.

It is apparent that if we are to effectively teach quantitative reasoning, one of our fundamental goals needs to be to help our students reduce their mathematical anxiety and improve their attitudes toward math. Ashcraft (2002) confirms that students with high levels of math anxiety are likely to avoid math whenever possible. As a result, people with math anxiety perform poorly on mathematical tasks not only as a direct consequence of anxiety, but also as a consequence of the fact that their anxiety has led them to avoid learning math and quantitative reasoning skills in the first place. If we are to effectively teach students math, we must reduce the students’ math aversion. There are a number of techniques that can be used to address this issue. Here, we will focus on one in particular: service learning.

Since 2010, the first author has regularly taught quantitative reasoning with a service-learning component. As part of this course, university students are required to tutor elementary school students who struggle with math.

They primarily tutor elementary school students who struggle with math.

Before their service-learning experience begins, tutors are provided training that helps them to develop basic cultural competencies (such as avoiding making judgments regarding the children’s academic abilities based on their ethnic background or economic status) while emphasizing that a positive attitude is of utmost importance when working with young learners. They see firsthand that having a poor attitude themselves will translate into low motivation and interest on the part of the children they are working with. So our tutors often employ a “fake it ‘til you make it” strategy, manufacturing an infectious mathematical enthusiasm. It is common for students to express the following sentiment.

“I was pretty surprised that this quarter I’ve been feeling so much more positive toward math and I can’t help but think that tutoring played a major role in that.”

During their service-learning experience, many university tutors see themselves in the children they are working with. This third-person perspective on math anxiety and avoidance helps tutors work through their own aversions and boosts their confidence. In his final tutoring reflection, a tutor commented on this insight:

“I have been able to better understand the traditional troubles surrounding math, why and how these troubles occur and how they can create an irreversible (or practically irreversible) hatred of math.”

The tutor quoted above seems to recognize that, while most math-anxious people in our society never get past their fears and ‘hatred of math,’ it is possible to turn these attitudes around. Indeed, in our ongoing research into the effects of this course, we
are seeing a statistically significant increase in students’ confidence in their mathematical abilities and a positive shift in their attitudes towards math, as measured by the Fennema-Sherman Scales (Fennema and Sherman 1976).

Now that we have a glimpse into the benefits of a quantitative reasoning course with service learning in particular, we will take a brief look at the history, rationale, and benefits of service learning in general.

AN OVERVIEW OF SERVICE LEARNING

Over the past two decades higher education in the United States has witnessed a dramatic growth in the use of service learning as a pedagogy to enhance students’ academic learning and civic engagement while simultaneously working with the larger community to address unmet social needs.

A few facts regarding service learning in the United States highlight this growth:

- More than 1,100 institutions are now members of the Campus Compact, a national organization formed to support the growth of service learning and community engagement in higher education and 91 percent of those institutions offer service-learning courses (Campus Compact 2012).
- Service learning has been identified as a high-impact practice and one of only four practices that have a positive impact on retention of students in higher education (the other three are study abroad, undergraduate research, and living–learning communities) (Kuh 2008).
- A growing number of departments and universities are requiring students to complete service learning experiences as a requirement for graduation (Butin 2010).
- Students are increasingly recognizing the importance of contributing to the larger community as a core component of their education (Clayton, Bringle & Hatcher 2013).

Service learning is not just a recent phenomenon or an educational fad; it has a rich history rooted in the transformative, progressive educational and social ideals of reformers such as John Dewey and Jane Addams. One reason for the recent continuing growth of service learning is that most students like it. They appreciate the way in which service learning allows them to explore connections between the theoretical realm of the classroom and the practical needs of the community. It provides them with the opportunity to test facts and skills learned in the classroom, refine their problem-solving abilities, and work collaboratively with diverse groups of people.

A growing body of research (Clayton, Bringle, and Hatcher 2013; Eyler and Giles 1999) indicates that participation in well-designed service learning can result in a wide array of positive outcomes for students, including

- **cognitive growth** (intellectual development, critical thinking, problem solving, and application of knowledge and skills across settings)
- **academic learning** (higher essay exam grades, deeper understanding of subject matter, student self-reports of greater learning)
- **civic learning** (enhanced civic knowledge, skills, and values)
- **personal development** (self-efficacy, identity, moral development, spiritual growth, and career development)
- **intercultural competence** (building cross-group relationships, disrupting stereotypes, gaining awareness of community resources and problems, increased sense of teaching efficacy with diverse youth)

OUR STUDENTS’ SERVICE-LEARNING EXPERIENCES

In order to achieve the desired outcomes for students and the community, faculty must intentionally design service-learning courses to focus on those goals. Both research and the experiences of knowledgeable service-learning faculty indicate that successful service-learning courses share certain common characteristics. We describe these characteristics and consider how they emerge in our own quantitative reasoning course with service learning.

**Meaningful Service**—students engage in personally relevant service activities, students see their actions as having positive consequences

It is common for students in the quantitative reasoning course with service learning to express the belief that they are making a difference in the children’s lives, both mathematically and on a more personal level. One reflection essay described such an experience:

“I remember a student came up to me and just spilled his life story about how he only lived with his mom and sisters...I remember him saying, ‘I like having you around.’ And I feel like since then, I had a little reality check and needed to remind myself that just being there to talk with him makes a big difference.”

At the end of her reflection, this student expressed an interest in continuing her tutoring after the quarter was over. Each time this class is taught, about half of the students report that they plan to continue volunteering beyond the end of the academic term because they feel like their service is important.

In 2010, when Seattle University began to implement various math and science outreach programs (including our service-learning course), the percentage of fourth graders at our local elementary school proficient in math as measured by their performance on the Measurements of Student Progress test was 33 percent. By the 2011–12 academic year, 59 percent of the fourth graders achieved proficiency, and in 2012–13, 60 percent reached this level.
Sufficient Duration and Intensity—the service lasts long enough to achieve learning and community goals and is seen by students as a significant aspect of the course

Through reading the reflections of the students in the quantitative reasoning course throughout the quarter, it is clear that many students’ attitudes undergo a transformation. One student had this to say about her experience:

“If I’m being completely honest, I was pretty skeptical about the service-learning part of this class. My first reaction was, how could I possibly tutor anyone in math?! I’ll probably need a tutor, but I could never BE a tutor. Even though it’s kids and it’s counting and addition, etc., I don’t speak math. I can’t explain numbers to anyone. I was pretty nervous, but I figured if I stayed positive and pretended to be confident, I could do it… So far I have really enjoyed working with the kids. The anxiety of screwing up or not being able to help has gone way down. I’ve found that I can usually (though sometimes it’s harder than others) answer questions, and it’s not the end of the world if I can’t. I am excited to see the kids grow and progress in the short time I will be working with them.”

Change in attitudes doesn’t happen overnight, both for the university students and for the children they are working with. Several months of consistent tutoring are needed for them to build relationships and to build their own confidence in their mathematical abilities. While eight weeks is enough time to build an impactful service relationship, it is certainly a limitation of this course for the learning of both the tutors and the children that they do not have a longer period of time to work together.

As mentioned above, many students elect to continue tutoring beyond the end of the quarter to deepen their relationships with the children and teachers they work with. Our Center for Service and Community Engagement does an excellent job facilitating placements for those who decide to continue their service. The students’ willingness to volunteer their time, together with the institutional support for volunteering in the community, lessens the issues surrounding the short duration of the course.

Strong Connections between the Curriculum and Service Activities—transparent links between course content and service allow students to make explicit connections

What is unusual about the service-learning experience that our students have is that it is not designed primarily to reinforce the specific mathematical topics that are taught in the course. In the quantitative reasoning course, students learn about voting theory, financial math, and statistics, among other things. When they tutor, however, they often help kids with basic arithmetic.

Instead, the tutoring experience is designed to increase students’ interaction with mathematical ideas and to help them see how much more sophisticated their mathematical abilities have become. Tutoring invites students to think about basic mathematical algorithms that they have long taken for granted in a different way. The curriculum that is used in Seattle Public Schools employs nontraditional techniques and algorithms for teaching basic arithmetic. Here is one student’s reflection on the curriculum:

“Tutoring has helped me understand arithmetic better because the kids at Bailey Gatzert have numerous ways to learn it. There are fact triangles, math boxes, and dice games—fun yet functional ways to learn and practice math.”

Students in the service-learning course often find themselves wondering if the way the kids are taught to perform a computation today is equivalent to the way they were taught as kids. In effect, students become more curious about math and feel like they are capable of getting to the bottom of these issues and understanding simple concepts at a deeper level.

Student Voices—students are provided with opportunities to play a role in designing projects and make meaningful decisions regarding their implementation

Because of the logistical issues with connecting students with math classes or after school programs, they have less of a voice in their placement than would be ideal. In some cases, however, a student will come into the course having already developed a relationship with a group of students at a local elementary, junior high, high school, or community college through another service-learning course or volunteering opportunity. In these cases, we are usually able to place students back in their established tutoring site, as long as they can guarantee that they will be tutoring math as a part of their service.

In the future, we may consider expanding the placement options for our students. This would afford them the opportunity to work with more advanced students if they feel like they would benefit more from that experience.

Community Voices—community partners share decision making with faculty related to identifying outcomes and implementing programs

Seattle University math faculty work closely with our Center for Service and Community Engagement and local schools to match tutors with placements at specific school sites. Tutors are only placed in schools where there has been an expressed request from the community. Teachers at a local elementary school, Bailey Gatzert, requested tutors to help provide the following types of support:

- more adults in the classroom in order to allow teachers time to address individual student needs;
- small group and one-on-one tutoring on essential math skills and concepts;
- college students to act as role models, to plant seeds in the minds of the young students suggesting that they, too, can go to college; and
additional relationships with caring adults.

After the tutoring sessions at Bailey Gatzert were completed, here is what several teachers have said about the involvement of Seattle University service-learning students:

“The service learning students I worked with quickly became a valuable part of our classroom community, they built positive relationships with my students and always went above and beyond.”

“Honestly, I don’t know what we would do without the math service-learning students. I remember back to when we didn’t have them and it was so much harder in the classrooms. The contributions they have made have been amazing.”

“The service-learning students have become a critical piece to help keep our classroom running smoothly. With their help we are able to do more station activities, allowing for more small-group settings to cater to individual student needs. This has contributed a lot to our students’ improvement on standardized tests.”

Diversity—in the populations involved and the types of experiences students gain

At Bailey Gatzert, the primary placement site for tutors, 96 percent of kindergarteners qualify for free or reduced-price lunch and most students are immigrants from East Africa or Southeast Asia. Since most Seattle University tutors are white and from middle-class backgrounds, the opportunity to work with Bailey Gatzert students can expand the tutors’ understanding and appreciation of human diversity.

Critical Reflection—students participate in regular, structured oral and written activities that involve them in critically examining all aspects of their experiences in order to integrate classroom and community learning

Every two or three weeks, students write a short reflection essay about their tutoring experience. They are prompted to make connections between the experiences of the children they are working with and their own experiences with math. They are also asked to reflect on what skills they have developed as part of their tutoring.

In addition, we have short discussions in class every few weeks where students can compare experiences. At the end of each quarter, about half of the class is asked to participate in a focus group. This is a valuable reflection experience for some students in the course.

CONCLUSION

“Tutoring has been surprisingly amazing. I never thought I would enjoy it as much as I do. I certainly didn’t think delving back into my traumatic elementary math experiences could be so rewarding… I think I might be discovering my own love for math!”

This student quote sums up many of the benefits of a quantitative reasoning course with service learning. Students who enroll in quantitative reasoning courses in college often have a history of math anxiety and negative attitudes about math. Well-designed service learning can be an effective avenue for improving mathematical attitudes, achieving both our educational and our psychological goals for this population of students. Moreover, students have the opportunity to have a positive impact in their community by becoming mentors and tutors for children who face similar mathematical challenges.

Looking ahead, we plan to continue to offer our quantitative reasoning course with service learning at Seattle University, while making improvements to its structure. In the future, we may include more placement site options for students to choose from. We also aim to deepen student reflection on their experiences by including more in-class discussions, as suggested by the students in recent course evaluations.

Some of our colleagues plan to incorporate service learning into more advanced math courses during the next academic year. We are excited about this possibility and will be curious to see what types of benefits emerge both for our students and for the community in other service-learning experiences.

REFERENCES


The Quantitative Skills Center at Pomona College: Year One Review

Travis Brown, director, Quantitative Skills Center, Pomona College

Pomona College is a liberal arts college located in Claremont, California. It is a founding member of the Claremont Colleges (along with Claremont McKenna College, Harvey Mudd College, Pitzer College, and Scripps College), and approximately 1,500 undergraduates are proud to call themselves Pomona “Sagehens.”

Pomona has a diverse student population, but as is the case at many colleges and universities across the country, students from underrepresented backgrounds—African American and Hispanic students in particular—do not pursue degrees in the natural sciences (particularly math, physics, and chemistry) and mathematics in the same proportion as white and Asian students. Our approach to liberal arts education fosters exploration and discovery, and our hope is that all students find their true passion. However many students who experience struggles in quantitatively heavy gateway courses may reconsider their initial love of chemistry, physics, economics, or mathematics and pursue an alternate path. Retaining students in science and mathematics requires a comprehensive approach to teaching, advising, mentoring, and supplemental instruction.

CREATING OUR QUANTITATIVE SKILLS CENTER

The Quantitative Skills Center (QSC) was created to support the needs of future and present science and mathematics majors, improve the quantitative reasoning skills of all Pomona students, and promote quantitative literacy as a goal for all Pomona graduates. The center was born out of an effort to address those quantitative skills most crucial to success in “gateway” courses, and as happens at small liberal arts colleges, it was not a quick birth. Faculty discussions about the center can be traced back to the early 2000s, but a 2009 white paper written by a team of faculty and deans established a more concrete plan. The broad strokes of the paper described a learning center with a full-time director, dedicated space, a focus on peer tutoring, and support for faculty-led department-level supplemental instruction programs. Other activities included in the initial scope of the center included software support (SPSS, Excel, LaTeX, etc) for students, training for departmental mentors (a group of department-based peer tutors that hold group drop-in homework help sessions), and support for upper-division courses.

The initial funding for the center was generously provided by the Arthur Vining Davis Foundation, which awarded $250,000 in 2012 to provide enough funding to cover two years of operating expenses for the center. I was hired in January 2013, and the center’s invaluable administrative assistant, faculty steering committee, numerous student mentors/fellows, and I have created an academic support program and center that, for the most part, meets the objectives of the 2009 white paper. Has everything worked according to plan? Of course not (I will mention some of those lessons learned below), but overall our first year was successful.

While much of what Pomona College needed to institute a new academic learning center was in place, the details of how that would actually be implemented were up to me. I would not say that I had a blank slate, but I was certainly given the freedom to respond to student concerns. Much of my first semester was spent just trying to meet students and get to know the campus. I introduced myself in classrooms, at cohort program meetings, and at club meetings. My goal was to quickly build relationships, first with students and second with faculty and administrators, so that
I could hear open and honest feedback about why students—particularly students of color—were arriving on campus with the goal of becoming a scientist but not persisting to graduation with that dream intact. We didn’t build something and just expect students to participate. I attribute a large part of our initial success to taking the time to generate student buy-in before setting up a new support center.

**QSC IMPLEMENTATION**

The presence of our writing center and college writing program was, and continues to be, a large influence on how we have structured the QSC. The writing center has a long history of working with students on their written communication skills, and the deep institutional memory has helped create a campus culture in which getting help with writing is, according to students, “just what you do.” My goal was to create the same type of campus culture for help with math or science, but the nature of the disciplines has made this more difficult than expected. Having your writing reviewed is a requisite of the writing process itself. Having someone help you with calculus or organic chemistry is not typical for these fields. Students typically only seek help when they fail to meet an objective (usually the correct answer on a quiz or exam), and taking the necessary actions to fix it (seeking help) can be very challenging. Getting students to use the QSC’s resources before they are too far behind in their coursework has been a challenge, but we’ve made some strides in that direction.

After a semester of fact finding, the summer of 2013 was spent developing the tutoring program and working with our information technology services team to create a simple online system for students to sign up to meet with a tutor. I cannot stress enough how important it is to establish a low a barrier of entry for academic support services. Our goal was to create a system in which a student did not have to contact a faculty member or administrator in order to receive tutoring, and our online scheduler only requires a commitment from the student that they will meet their tutor at the appointed time and location. Approximately 99 percent of the study sessions that have been reserved in the past year were fulfilled, and students report great satisfaction with the online reservation system.

In the fall of 2013, we began offering individual and small-group study sessions. At this time we did not have a dedicated space, so we operated as a virtual center and used various classrooms and computer labs across campus as meeting rooms. Our initial pool of tutors, or “fellows,” was inherited from a previous tutoring program that the dean of students’ office ran for many years. We added to this small group of fellows as the semester wore on, and ended up with thirty-two QSC fellows by the winter break.

**QSC FELLOWS**

Our fellows are the cornerstone of the QSC, and I can’t say enough about the hard work and dedication they have shown this past year. Fellows are all top-performing students who have shown an interest in tutoring and have been recommended by faculty. I try to be as accommodating and flexible with their time as possible, and typically a fellow will work between two and six hours a week, with their study session times mostly set by them (our hours are 6pm–11pm, Saturday–Thursday). Fellows are paid and I guarantee the number of hours they work. But no fellow books 100 percent of their hours (although several were above 75 percent), so there are times when I am basically paying fellows to get their own work done (which is the case with many campus jobs). This system has worked well for our fellows, who are busy students themselves, and it also allows a small school like Pomona to leverage our talented students in multiple ways. For instance, many of my fellows also are employed by departments as mentors, and for certain upper-division courses there may really only be one or two students on campus qualified to tutor.

In our first year we provided course-based tutoring (although our fellows were not required to sit in on any classes or meet with the professor—this will be changing for next year) for courses in mathematics, physics, computer science, biology, chemistry, economics, and statistics. We expected to cover introductory courses but it came as a surprise to us how many students needed help with upper-division math, physics, and computer science courses. As needed, we hired fellows and added study sessions to the calendar. Overall we booked about 30 percent of the total number of offered study session hours, with our most popular subjects being biology (50 percent of offered sessions booked) and statistics (60 percent of sessions booked).

Statistics can be a challenging topic to tutor because it comes up in many different ways in many different courses. But we decided to hire a graduate student to be our “stats specialist,” and she became one of our most utilized fellows in the fall (also this past spring). The initial fear was that students seeking help with their senior theses would be coming to the QSC instead of their faculty mentor, and while we did end up working with a few seniors, the vast majority of our stats specialist’s time was spent helping students with in-class assignments, group projects, and lab reports.

**A SPACE OF OUR OWN**

Spring 2014 saw us move into a new dedicated space, centrally located on the second floor of our Smith Campus Center (upstairs from the writing center). Having a
dedicated space for all of the study sessions has finally made the center “real,” and some students have started making it their own private study space. During the day, before study sessions begin, the center is available for any student who needs a quiet place to study. The QSC features three study rooms, a central lounge area, my office, and space for our administrative assistant.

Logistically, our spring semester went much more smoothly than the fall, and we saw our numbers increase slightly. We booked about 350 total study session hours from about 130 students (up from about 120 in the fall). I can only estimate how many students utilized the QSC because in addition to our individual sessions (all reserved online and recorded), we also offered drop-in sessions that were not tracked online. Unfortunately, our fellows didn’t always take attendance, which will change in the coming year.

Other challenges had to do with connecting with students about workshops and other events. Direct emails to students are not always effective, and posting flyers around campus wasn’t drawing students to the center either. Often group student meetings can attract students by offering food, but every student at Pomona has a meal plan, so that strategy didn’t work for us. Eventually we settled on day-of-the-event e-mails and Facebook posts combined with word of mouth (text your friends!) as useful ways of bringing students in for one-off workshops (e.g., Study Skills for the Sciences, Basics of Excel). But we found that the most successful approach to reach students was to work directly with faculty teaching courses we covered, and to directly work with the new retention programs we have developed in the last year. My work with several of our new initiatives to retain underrepresented students in the sciences has been an exciting development for the center.

**COHORT PROGRAMS**

All of us who work with underrepresented students (particularly in the sciences, but not limited to them, of course) have heard a similar story. A student arrives to campus; let’s say our student is an African American woman. She was valedictorian, number one in her high school. Her plan is to become a doctor and major in biology. Maybe she is the first in her family to go to college, but maybe she isn’t. In any case, she starts out her first college semester taking biology, chemistry, calculus, a writing course, and why not, a language class, too. Things are going along fine (she thinks) until about five weeks into the semester when the first round of exams hit. Low grades in biology and chemistry appear, and our student doesn’t know how to deal with them. She’s never gotten below a B on anything, and now she just pulled two failing grades. She starts to experience feelings of stereotype threat; maybe some pangs of imposter syndrome cause her to question whether or not she should be trying to pursue a science degree at all.

Because we know where this is headed, many of our schools have instituted programs designed to create a different story for our student by giving her the mentoring, advising, and academic support she will need to persist and succeed. At Pomona College we have two new cohort-based science retention programs, the Howard Hughes Medical Institute-funded High Achievement Program (HAP) and the home-grown Pomona Science Scholars (PSS). Students in both programs are from backgrounds traditionally underrepresented in the sciences and have shown a high degree of potential as science majors.

The twenty students in the programs just completed their first year in the college and have used QSC services at a higher rate than other first-year students. In the center’s first year, I did not hire dedicated fellows just for cohort students (the goal was to simply encourage the HAP and PSS students to use the QSC services), but for the coming year I will hire QSC fellows to hold hours specifically for students in PSS, HAP, and our new Pomona Scholars of Math.

**CONCLUSION**

With two semesters under our belt, I can’t say that we have solved all of the quantitative issues for students at Pomona, but we are off to an excellent start. We still have much to do—assessment, program development, and connection with more departments that use quantitative reasoning (psychology, for example) are three major endeavors for next year. We also will begin to focus on study skills and time management (for all students) as well as continuing our work with underrepresented students in the sciences. I have begun working with an increasing number of students who are dealing with feelings of stereotype threat or imposter syndrome combined with feelings of inadequacy because they have, many for the first time, experienced failure. How the QSC will play a role in working with students struggling in this particular way is yet to be fully fleshed out. Finally, we have plans to begin a campus conversation about quantitative skills versus quantitative reasoning. As many schools begin to shift from QS to QR, we will have to determine what that means for our campus and how the QSC fits into the conversation. Being very good at hammering a nail (QS) is not the same as building a house (QR).

I hope this look back at the development of a new learning center over one year has been interesting and informative. If your campus is beginning to formulate its own quantitative support center, feel free to contact me.
Toward a Numerate Citizenry: A Progress Report

Nathan Grawe, associate professor of economics, Carleton College

The modern quantitative literacy (QL) movement finds its seeds in the 1959 Crowther Report on QL in UK secondary schools (in which the synonym “numeracy” was coined). Early years of the movement were marked by predictable debate over how to conceptualize QL and its relationship to mathematics, but the late 1980s and early 1990s provided articulation of QL as the ability to apply quantitative evidence to arguments in broad contexts of personal and public life. Twenty-five years on, what has been accomplished and what remains to be done?

Most in higher education recognize that innumeracy is a problem requiring attention. With a growing number of national statements like QL’s inclusion among the AAC&U’s Essential Learning Outcomes and curricular reforms on individual campuses, it is quickly becoming unacceptable to proclaim, “I just don’t do numbers.” These institutional reforms have been accompanied by a wide range of course and assignment revisions that have bubbled up to full-blown curricular reforms such as state requirements or the Carnegie Foundation’s Quantway initiative, which has developed a QL curriculum for two-year colleges. And while innovation in high school curricula can be slowed by regulations, the twenty-fold growth in AP statistics examinees since 1997 to almost 170,000 per year suggests that change is afoot even in K–12 (Rodriguez 2012).

While curricular reform must ultimately be local to meet the particular institutional circumstances, the work is made infinitely easier by the development of an overlapping set of professional networks. The Mathematical Association of America’s special interest group on QL (SIGMAA-QL), the National Numeracy Network (NNN), and Project Kaleidoscope (PKAL) host professional development workshops, run conferences, archive examples of QL-rich assignments and courses, and nurture cross-pollination of ideas. The 2007 inception of the journal Numeracy has further provided a venue for scholars to engage in extended conversation about QL and its advancement.

Despite this progress, Steen’s 2001 warning remains disturbingly current: “Unfortunately, despite years of study and life experience in an environment immersed in data, many educated adults remain functionally innumerate.” The 2012 Program for International Student Assessment (PISA) test of mathematical literacy reported that fewer than 10 percent of American students exhibit strong (level 5 or 6) QL skill (National Center for Education Statistics 2012), a result largely unchanged from 2003.

As with any assessment tool, the PISA is imperfect and some may question whether it accurately captures the concept of QL. While the last twenty-five years have seen the development of several multiple-choice exams (notably at James Madison University and Bowdoin College) and rubric-based assessments for application to open-ended student work (notably at AAC&U and at Carleton College), far too little is known about the efficacy of the many curricular experiments noted above. To be sure, the power of any educational intervention will vary from context to context, and I am not advocating for a single measure. Still, the foundational observation of the QL movement is that consideration of quantitative evidence invaluably enhances our ability to understand many issues. It would seem obvious then that we should be eager to collect assessment data to ensure that efforts to improve QL curricula lead to demonstrable student learning gains.

We must continue to push forward both on our campuses and, through administrators’ support of faculty involvement, in national organizations such as SIGMAA-QL, the NNN, and PKAL. With sustained engagement, we will be able to capitalize on the progress of the last twenty-five years and ensure a numerate citizenry for the twenty-first century.

REFERENCES
AAC&U is the leading national association concerned with the quality, vitality, and public standing of undergraduate liberal education. Its members are committed to extending the advantages of a liberal education to all students, regardless of academic specialization or intended career. Founded in 1915, AAC&U now comprises more than 1,300 member institutions—including accredited public and private colleges, community colleges, research universities, and comprehensive universities of every type and size.

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