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Quantitative Reasoning and Sustainability

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Abstract
Quantitative Reasoning and *Sustainability* have much in common. Both are complex, nuanced concepts with rather long definitions that have evolved over time. Both subjects are "everybody's business" on college campuses, and must be approached in courses across the curriculum, not merely in one course on QR or in one course on Sustainability. The growing, wider presence of both QR and Sustainability on college campuses is due to their applicability in individuals' personal, professional, and public lives. Moreover, QR and Sustainability support and enhance each other in and out of the classroom. Sustainability is an important, authentic, relevant context for lessons in QR, and, at the same time, QR skills are needed to help with benchmarks in sustainability and analyses in examining sustainable options. Please join the efforts of the National Numeracy Network and the Association of American Colleges and Universities, among others, in linking these concepts and enhancing students' learning opportunities in these areas.

Keywords
Sustainability, Quantitative Reasoning, Multidisciplinary Approach

Cover Page Footnote
Corrine Taylor is Director of the Lee Day Gillespie, '49 Quantitative Reasoning Program at Wellesley College and is Past-President of the National Numeracy Network. Since Spring 2011, she has served as a representative of the NNN on the FIPSE-funded initiative "Sustainability Improves Student Learning in STEM." In Fall 2011, she organized a three-part speaker series at Wellesley, "Celebrating QR Connections: Quantitative Reasoning & Sustainability." Her most recent Sustainability project was as an artist on a team creating an architectural ceramic mural celebrating sustainability efforts on the Wellesley College campus. See http://new.wellesley.edu/news/stories/node/26504.

In my teaching and in my everyday life, Quantitative Reasoning and Sustainability have emerged as two similar, important, and mutually supportive themes. If you do not already associate these two ideas on a regular basis, I hope that soon you will, perhaps in depth at one of the upcoming meetings of the National Numeracy Network or the Mathematics Association of America.

Commonalities

Both Quantitative Reasoning (QR) and Sustainability are complex, nuanced topics with multiple audiences that care about them; hence, their definitions have evolved over time and vary from one person to another. Here are definitions and explanations that I like:

> ***Quantitative Reasoning*** (also known as Numeracy or Quantitative Literacy) is a "habit of mind," competency, and comfort in working with numerical data. Individuals with strong QR 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).[1]
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> ***Sustainability*** has been defined variously as the perpetual maintenance of diverse and productive environments upon which all life depends; the reasonable use of resources over an indefinite period of time; or meeting the needs of the present without compromising the ability of future generations to meet their own needs. A sustainable future depends on a workforce of professionals knowledgeable about creating practices, processes, and infrastructure to optimize resource management, and on a community informed about the ethics and influence of human activity on the integrated environmental, economic, and social aspects of sustainability.[2]

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[1] This QR definition is presented with the Association of American Colleges and Universities' (AAC&U's) rubric on evaluating the QR competencies of college students. See http://www.aacu.org/VALUE/rubrics/index_p.cfm. The rubric team's definition combines elements of several prior definitions from leaders in the QR movement, including Deborah Hughes-Hallet, Lynn Steen, and Bernie Madison.

[2] This definition is from the April 2, 2012 "Statement on Education for a Sustainable Future," developed by the Common Language Project Team of the FIPSE-funded project "Sustainability Improves Student Learning in STEM," and published on p. 63 of the second project meeting's guidebook. The three definitions listed in the first sentence come from the following sources: (1)

A second commonality: these subjects are "everybody's business." For over a decade now, helping students develop strong quantitative reasoning skills has been widely acknowledged as being a task too big and too important to be *solely* the purview of Departments of Mathematics. With mathematical modeling, data analysis, and the framing of quantitative arguments being essential in so many academic disciplines – not just in the sciences, engineering, and economics, but also in history, linguistics, art and media studies, etc. – the teaching of QR needs to occur across the disciplines. Additionally, as several early QR leaders have argued, quantitative reasoning needs to be everyone's project, everyone's business,[3] and that requires interdisciplinary communication and coordination.

This same understanding – that sustainability is everybody's business – is emerging now.[4] On college campuses, it is not merely the responsibility of staff in Facilities and Grounds to address issues related to energy conservation, recycling and resource recovery, and purchasing from local vendors or fair-trade vendors when possible, nor is it simply the job of administrators in charge of new or renovated campus buildings to incorporate sustainable designs; rather, it is imperative that students and faculty work on conservation and stewardship in daily practice, too. Moreover, the academic teaching of sustainability cannot be the sole responsibility of Departments of Biology, or even be the sole responsibility of interdisciplinary Programs in Environmental Studies. The current, collaborative, three-year FIPSE-funded initiative "Sustainability Improves Student Learning in STEM" has done much already to ensure coordination and communication across many of the academic fields involved.[5] Sustainability needs to be addressed not only in the STEM areas (science,

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the Renewable Natural Resources Foundation; (2) the National Association of Biology Teachers; and (3) the World Commission on Environment and Development.

[3] A couple of examples of these phrases include Emily Lardner and Gillies Malnarich's MAA PREP 2003 workshop "Quantitative Literacy Across the Curriculum: Everybody's Project" and Judy Moran's 2005 panel presentation at the AAC&U's *General Education and Assessment: Creating Shared Responsibility for Learning across the Curriculum,* "Quantitative Literacy: Everybody's Orphan, Everybody's Business."

[4] Jason Hamilton, Associate Professor of Environmental Studies and Sciences at Ithaca College, was the first speaker in Wellesley College's Fall 2011 "Celebrating QR Connections" series on QR & Sustainability, with a presentation entitled "Sustainability on College Campuses: How It's Everybody's Business."

[5] The "SISL in STEM" initiative is a collaboration of three organizations: Project Kaleidoscope at AAC&U, Mobilizing STEM Education for a Sustainable Future, and the Disciplinary Associations Network for Sustainability. The National Numeracy Network is one of eleven disciplinary societies working on this project to enhance STEM education and an understanding of sustainability in higher education.

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technology, engineering, and mathematics), but also in business and economics, in psychology, in sociology, in philosophy, in the arts, etc. Daniel Sherman described the importance of sustainability well:

> *For sustainability to realize its full transformative potential in higher education and society, it must transcend an association with prescribed practices and even specialized areas of study. Sustainability must become a pedagogical big idea, capable of complementing and connecting avenues of inquiry across the academic disciplines that organize and prioritize teaching and learning on campus. If sustainability is employed as a method of examining the relationship between environmental limits and the human values, decisions, and actions that shape the future, it will transform not only what we do on campus, but also how we think.*[6]

Both QR and Sustainability are important today on college campuses (everybody's business!) because they are critical for individuals' personal, professional, and public lives, as citizens working for the Common Good. In *Mathematics and Democracy: The Case for Quantitative Literacy*, Lynn A. Steen and the Quantitative Literacy Design Team argued for the importance of strong QR skills in personal decision-making, including those choices dealing with finances and health; in professions from social worker to lawyer to journalist to architect; and in being a citizen who can understand data and arguments presented to support or oppose various public policy proposals.[7] The "Big Questions" of Sustainability – how we live our lives, the choices we make, and our obligations to other people and the natural world, as they relate to issues of energy, food, climate change, and the quality of the Earth's water, land, and air[8] – are obviously critically important, in our personal, professional, and public lives, as well. From daily personal decisions of "Paper or plastic?" to broader policy questions about the best ways to invest in public energy, transportation, or housing infrastructure for a sustainable future, we all need to educate ourselves about Sustainability.

Mutual Support

Beyond having many commonalities, QR and Sustainability support each other. How so? As an important, authentic, interesting, and motivating topic, Sustainability is an ideal contextual area in which to teach students (indeed,

[6] From "Sustainability: What's the Big Idea?" 2008.

[7] "The Case for Quantitative Literacy," the opening argument of the book *Mathematics and Democracy*, is available on line at the MAA's site: http://www.maa.org/ql/001-22.pdf.

[8] One of the main goals of the "SISL in STEM" initiative is to prepare students for these real-world issues.

citizens of all ages) QR skills. Virtually all the major concepts in Sustainability require skills in measurement, an understanding of unit conversions, mathematical modeling of patterns of growth and decline, use of ratios in all their forms, an understanding of scaling in one-, two-, and three- dimensions (actually, also scaling in the fourth dimension of time), the ability to use quantitative data in analyses of all kinds, the ability to perform back-of-the-envelope estimations, and the understanding of limits. Analyses of sustainability rely on tables, graphs, and mathematical equations. Addressing Sustainability requires professionals trained with strong skills in quantitative analysis, as well as citizens who can make good environmental, social, and economic decisions based on quantitative evidence. And although we may have an agreed-upon definition of what "Sustainability" means in the general sense, QR is needed to quantify terms and evaluate policy options. Is that sustainable system one that creates 30% less waste or uses 30% less energy than a traditional system? QR can help Sustainability (as statisticians would say) "operationalize the variables" or (as strategic planners would say) "create meaningful benchmarks."

City planner Abigail Emison, AICP (American Institute of Certified Planners) discusses how QR skills are essential when communities decide among various sustainable options. In a town that is planning to provide new medical offices, for example, careful analyses of all the costs and benefits of decisions must be undertaken. Using "green" materials to create a new, energy- and water-efficient medical facility with excellent indoor environmental quality might earn LEED (Leadership in Energy and Environmental Design) gold certification, but what if this new facility were built on what had been pristine farm land and all the clients had to travel by car to get to it? How would that option compare with renovating an old existing building downtown where most of the workers and patients already are? Quantitative skills and holistic cost-benefit analyses are needed in examining and comparing social and environmental consequences that range from carbon emissions to community rehabilitation.[9]

In a similar vein, Scott Neimann, an economist working in Charles River Associates' energy practice, reports on the use of quantitative analyses in examining "the costs and benefits of infrastructure investments in electricity, the value of assets industry investors are buying and selling, and the best ways to establish competitive market mechanisms that provide proper incentives for investment and the efficient supply and consumption of electricity." Their work on renewable energy ranges "from assessing how to accommodate electricity generation from wind and solar sources into a power grid and how to fairly and efficiently allocate the costs associated with doing so, to thinking about how best to design policies and markets that lead to an efficient level of renewable energy

[9] Emison, personal interview, June 6, 2012.

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supply or meet specific policy targets at the lowest cost." Neimann says that QR is important for developing appropriate frameworks for assessing these questions that will stand up to scrutiny in public policy and regulatory forums, as well as for finding ways to quantify expected impacts of market or policy changes in an environment where data availability is sometimes very limited. [10]

The examples above support the importance of QR skills in sustainability-related professions and in public policy decisions. The next example shows how QR and sustainability go hand-in-hand in a classroom exercise that scales up from personal decisions to national policy. In Wellesley College's interdisciplinary introductory Environmental Studies course organized around climate change, estimation exercises abound. Jay Turner, Assistant Professor of Environmental Studies, gives his students a multi-phased project that begins with students calculating their individual carbon footprints. Next, students discuss how they could reduce their personal footprints and then they begin to assess what difference it would make if everyone implemented a particular change, such as switching from incandescent to CFL (compact fluorescent lamp) light-bulbs, regularly inflating their car tires properly, switching from taking airplanes to trains for short-distance travel, or ceasing the consumption of beef. That leads to the second part of the assignment, which is to make a quantitative estimate of one of those potential changes. This is not a pure Fermi-type, quick back-of-the-envelope estimation; rather, Turner has the students work in teams of two or three individuals to find relevant data to incorporate into their analyses. For each potential change, two teams work independently and when they submit their projects, the teams compare their methods and results in exploring the changes that would make the most difference. The final phase of the assignment has students designing several policy options to implement a potential change students analyzed in phase two of the project.[11]

Another professor has taken his teachings about QR and Sustainability to the general public. Thomas W. Murphy, Jr., Associate Professor of Physics at University of California, San Diego, writes his *Do the Math* blog on "energy, growth, and options," to help readers quantify the need for our society to reduce the demand for fossil fuels and migrate to alternative fuel sources. Murphy, a self-described optimist – not a Cassandra – convincingly warns that we ignore sustainability issues at our peril.[12] In journal articles, too, he explores the costs and benefits of changes that people can make at a personal level (e.g., installing a home photovoltaic energy system) and considers their limits with scaling up (e.g.,

[10] Niemann, e-mail correspondence, June 5, 2012.

[11] Turner, e-mail correspondence, June 5, 2012.

[12] Murphy, 2012, *Do the Math* Blog.

"What would it take to get 100% of the US electrical demand from the Sun?").[13] His blog is filled with pertinent QR examples exploring the limits of possible energy sources, helping us to frame our understanding of the need for change.

We need more people like Tom Murphy in this world. Okay, maybe not everyone will obtain the physics background and confidence needed to create their own photovoltaic arrays (they might purchase them instead), so let's suffice it to say we need more citizens with the quantitative skills to read Tom Murphy's blog (I suggest you start here: http://physics.ucsd.edu/do-the-math/post-index/) and other scientific reports on the future of energy, water resources, transportation, food, etc., to act on that information, making good personal decisions, and to help move our public policies and decisions in positive ways to preserve our planet. And we need more faculty members from all the quantitative fields to help students in their classes understand how sustainability and quantitative reasoning matter in the various disciplines, and to convey these ideas to a wider audience, when possible.

Upcoming Events

It seems appropriate that San Diego, home of UCSD's Tom Murphy, is the location selected for the 2013 National Numeracy Network annual meeting. NNN President Caren Diefenderfer recently announced that the meeting, to be held jointly with Association of American Colleges and Universities (AAC&U), October 31 through November 2, 2013, will explore the theme "Engaged STEM and Integrative Learning" and that one of the major topics to be explored under that theme is "Sustainability and QR." I expect that this conference will present a fabulous opportunity for faculty from several disciplines that deal with sustainability – all the natural sciences, geography, psychology, sociology, economics, political science, etc. – to come together to share research and enhance the quantitative components of lessons and projects that deal with sustainability.

The Mathematics Association of America has also recently announced its partnership in "Mathematics of Planet Earth 2013," a year-long program to publicize and promote the role of mathematics in developing a better understanding of dynamic processes affecting Planet Earth. This program "will provide a platform to showcase the essential relevance of mathematics to planetary problems, encourage research to identify and address fundamental questions, coalesce activities currently dispersed among institutions, and create a context for mathematical and interdisciplinary developments that will be necessary to address myriad issues and meet global challenges in the future." The

[13] Murphy, 2008, p. 45.

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MAA section meetings will involve speakers on these topics and the November 2013 issue of The College Mathematics Journal (CMJ) will be devoted to the Mathematics of Planet Earth.[14]

Of course, it is not enough to have a few meetings at which faculty members delve into the topic of QR and Sustainability. We must sustain that effort, too. My hope is that the NNN's Web site can serve as at least one of a variety of active sites for a collection of teaching resources on QR and Sustainability: lesson plans, ideas for quantitative writing assignments and other projects. I also look forward to reading articles in this journal on the intersection of Sustainability and QR education. Please consider this editorial an invitation to join in using Sustainability as a context in which to teach QR.

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