INTERDISCIPLINARY QUANTITATIVE REASONING

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INTERDISCIPLINARY QUANTITATIVE REASONING

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HOLLINS
UNIVERSITY

An intelligent citizen reads a newspaper account of an outbreak of disease in a small community. How can she tell if the number of afflicted looms out of proportion to the expected incidence of disease? A parent must choose whether or not his child will receive a smallpox vaccine. How can he evaluate the benefits and the risks of such an inoculation? An employer asks an employee to develop a profile of the local population to provide a foundation for a marketing campaign. How can the employee assess the significance of distributions of age, race, gender, or other categories in the population?

INTRODUCTION

In order to become effective citizens, workers, parents, advocates—indeed in order to perform a great variety of roles—students must become competent in using and reading quantitative data, in understanding quantitative evidence, and in applying basic quantitative and mathematical skills so that they can solve real-life problems. In fact, as Lynn Steen, past president of the Mathematical Association of America (MAA), notes,

> Quantitatively literate citizens need to know more than formulas and equations. They need a predisposition to look at the world through mathematical eyes, to see the benefits (and risks) of thinking quantitatively about commonplace issues, and to approach complex problems with confidence in the value of careful reasoning. Quantitative literacy empowers people by giving them tools to think for themselves, to ask intelligent questions of experts, and to confront authority confidently. These are skills required to thrive in the modern world.[1]

Quantitative understanding, also called numeracy, is traditionally taught through work in mathematics and statistics courses, but it can often be learned more effectively through work in courses within the student's own major or minor discipline or in the context of courses of interest to the student. "To be useful for the student, numeracy needs to be learned and used in multiple contexts—in history and geography, in economics and biology, in agriculture and culinary arts. Numeracy is not just one among many subjects but an integral part of all subjects."[2]

A program that involves quantitative reasoning across the disciplines gives students an opportunity to learn the broad significance and applicability of quantitative reasoning and mathematical skills in the particular subjects that are meaningful, important, and interesting to them. In this sense, quantitative reasoning across the curriculum becomes a partner with writing across the curriculum. College teachers have too long heard the complaint, "This is not an English course; why should grammar and style count?" The writing across the curriculum movement has sought to address that misunderstanding on the part of students by demonstrating that writing is a skill necessary across disciplines and across jobs, responsibilities, and social roles. Similarly, too many students believe that quantitative reasoning comes into play only in mathematics courses, and that once one fulfills a math requirement, those pesky numbers will disappear. Scholars know better; quantitative reasoning enters into work in fields as diverse as English and biology, history and physics, theatre and statistics.

If those who teach know that students need to become competent in quantitative reasoning, students must gain the motivation to achieve that competence. Offering a student the opportunity to analyze and apply quantitative techniques in the process of studying a subject that the student cares about or expresses an interest in sparks such motivation. The student has the opportunity to see that her understanding of a question that engages her will be deepened by applying quantitative techniques or perhaps that her ability to persuade others to accept her point of view will be strengthened by the use of quantitative evidence carefully presented.

HOLLINS' GENERAL EDUCATION PROGRAM

In the fall of 1998, Hollins began work on a major overhaul of its general education requirements. Under the leadership of the vice president for academic affairs and the Academic Affairs Council, the central curricular body of the university, the Hollins community worked together to develop a new framework to define the intellectual perspectives students should engage during their course of study at Hollins, as well as various skills students should acquire. In particular, our new general education requirements, Education through Skills and Perspectives (ESP), allow for foundational work in the skills areas (writing, oral communication, quantitative reasoning, and information technology) as needed, and then encourage the melding of skills acquisition within courses designed to introduce students to various perspectives (for more details see www.hollins.edu/academics/esp/esp.htm). ESP requires that students complete four credits in each of seven perspectives: Aesthetic Analysis, Creative Expression, Ancient and/or Medieval Worlds, Modern and/or Contemporary Worlds, Scientific Inquiry, Social and Cultural Diversities, and Global Systems. In addition, there is a language requirement. Hollins' faculty approved the ESP program in spring 2001, and all students entering Hollins since fall 2001 are following this program.

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THE QR REQUIREMENTS

Quantitative reasoning is one of the skill areas in our new general education program. We have two requirements in this area.

1. The QR Basic Skills Requirement (q)
The QR Basic Skills Requirement is designed to help students gain an understanding of fundamental mathematical skills they need to be successful in courses that require quantitative reasoning. The basic skills requirement can be satisfied by achieving a satisfactory score on the Quantitative Reasoning Assessment (given to new students each fall) or by successful completion of Mathematics 100 – An Introduction to Quantitative Reasoning. A student who has satisfied the QR basic skills requirement will demonstrate a baseline understanding of such topics as algebra, graphing, geometry, data analysis, and linearity.

Goals of the QR Basic Skills Requirement
- To understand mathematical and statistical reasoning.
- To use appropriate mathematical and/

or statistical tools in summarizing data, making predictions, and establishing cause-and-effect relationships.

In addition to covering what may be considered to be traditional topics in the mathematics curriculum, our introductory QR course has a computer lab every week. Students learn how to use Excel in a variety of ways—to graph data, to analyze data, to explore and model growth, and to learn about loans and financial planning.

2. The QR Applied Skills Requirement (Q)

The QR applied skills requirement is designed to provide students with the opportunity to apply quantitative skills as they solve problems in fields of study in which they show an interest. Students can satisfy the applied skills requirement by passing a course designated as a QR applied course.

Goals of the QR Applied Skills Requirement

- To give students the opportunity to apply mathematical and statistical reasoning in a chosen discipline.
- To involve students in the application of quantitative skills to problems that arise naturally in the discipline, in a way that advances the goals of the course, and in a manner that is not merely a rote application of a procedure.

Each QR applied course must include at least two QR projects. A project might, for example, include data collection, discussion of the data, collaborative work on finding appropriate uses of the data, and use of appropriate technology in presentation and writing. The result of each QR project should be a written assignment that includes a statement of the problem, an explanation of the methods used, and a summary of the results. When appropriate, the written assignment should discuss any limitations encountered and possible improvements to the procedure and/or results.

In the first two years of the program, Hollins had thirty-seven QR applied courses from a variety of disciplines, including history, philosophy, theatre, classics, sociology, political science, economics, humanities (French), biology, chemistry, physics, mathematics, statistics, and computer science. The Hollins program was cited as one of nine exemplary programs in the nation in *Mathematics and Democracy*.[3]

FACULTY DEVELOPMENT

A major boost to the quantitative reasoning program came when Professors of Mathematics Caren Diefenderfer and Patricia Hammer applied for and received an NSF Grant for "A Faculty Development Program for Quantitative Reasoning Across the Curriculum." This grant (NSF/DUE Project 9952807) brought four visiting scholars (Jerry Johnson from the University of Nevada at Reno, Dorothy Wallace from Dartmouth College, Helen Lang from Trinity College in Connecticut, and Lou Gross from the University of Tennessee at Knoxville) to Hollins during the 2000-01 school year. Each scholar gave an evening lecture to the university community and led a faculty workshop to explain how he or she approached quantitative methods in a variety of disciplines.

Professors Diefenderfer and Hammer led two series of four-day workshops in which faculty members discussed the recently published *Mathematics and Democracy*, investigated topics in Hollins' basic QR course (An Introduction to Quantitative Reasoning), shared and critiqued one another's QR project ideas, and presented their QR work in progress. Thus, instructors had the opportunity to test their assignments on a willing audience and to receive feedback on their proposed projects. Twenty faculty members participated in the NSF-funded workshops and their work resulted in twenty-seven QR applied courses.

We were happy with both the number of participants and the variety of disciplines represented (see Appendix C). Anita Solow, VPAA at Randolph-Macon Woman's College from 1998 to 2003, prepared an evaluation of the program and wrote, "The faculty unanimously found the project to have value to them. Although many of the comments were expected, I was impressed by the number of faculty members who explicitly talked about the faculty development benefits to them and their sense of empowerment when it came to quantitative reasoning." As an important side benefit, the workshops provided an opportunity to establish cross-disciplinary connections on campus and to increase discussion of teaching beyond issues related to quantitative reasoning.

After the NSF workshops, faculty members were invited to submit their courses for approval as QR applied courses. The application form is fairly simple and requires instructors to describe the two QR projects so that the reviewers can ascertain that the proposed projects fit the guidelines. From 2001 to 2003, Professors Diefenderfer and Hammer served as the screening committee for these applications. They reviewed the applications, made their recommendations (and occasionally asked faculty members to clarify or revise certain ideas), and sent the applications to the Academic Policy committee for final approval. Currently,

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Professor Diefenderfer works with our director of quantitative reasoning, Professor Phyllis Mellinger (hired in fall 2003), on this review. We hope to establish a QR advisory board to serve as a screening committee to work with the QR director in the future. This would insure broader input from the faculty members teaching QR applied courses and promote less dependence on the mathematics department for program leadership.

Five faculty members who did not participate in the NSF funded workshops are responsible for teaching twelve of the thirty-seven approved QR applied skills courses. This indicates another side benefit of the grant. It generated enthusiasm for the program that has encouraged additional faculty members to participate and thus, the grant lives on.

Participation in the workshops, and indeed in the QR applied program in general, is entirely voluntary for faculty. Professors who find themselves working on too many initiatives already, those who question their own competence to teach quantitative techniques, and those who may have doubts about the validity of teaching QR across the curriculum simply choose not to sign on. On the other hand, a number of those who did not understand what quantitative reasoning might mean or who were uncertain about the program have had the chance to learn about QR and have become enthusiastic supporters of the requirement and of the educational process involved.

SIX APPLIED QUANTITATIVE REASONING PROJECTS

The creativity of the quantitative projects that are now embedded in our curriculum is the major success of the quantitative reasoning program at Hollins. Here we highlight six projects to demonstrate both the variety of disciplines and the meaningful applications that characterize our program. Individual professors developed these six projects during on-campus NSF-funded workshops in January and April/May 2001.

1. American Social History: Professor Ruth Alden Doan

Project: Census of Families in Bristol, Rhode Island, in 1689

In American social history, we focus on themes related to family, work, and community. Assignments on Puritan New England come at the very beginning of the semester, and therefore these assignments introduce students to a number of concepts, skills, and approaches that we draw upon throughout the semester. Goals of the QR project in particular include:

- To encourage students to think about aspects of family life that change over time: structure, function, relationships within the family. This project focuses especially on structure.
- To learn some of the vocabulary used in distinguishing types of families (nuclear, blended, and augmented, for example).
- To expose students to the kinds of data that historians might use and to encourage them to see both how rich and how limited such data might be.
- To exercise certain skills in quantitative reasoning, including finding the mean, median, and mode of a data set, and creating meaningful tables or graphs.

We begin this unit of study by reading and discussing both primary and secondary sources on Puritan New England. The readings do not center on families or on family structure, but rather provide a context for the Bristol census. Thus, for example, students read about and discuss Puritan behavioral norms, the physical shape of a Puritan town, and Puritan spirituality. We then turn to a series of handouts: vocabulary of family structures, the Bristol census itself, and specific questions about the Bristol census.

Quantitative exercises are divided between those done in class and those done as homework. In-class work includes counting the number of households of each size and finding the mean, median, and mode of household sizes. Homework includes counting the number of children per household and determining the mean, median, and mode of these data. Thus we practice together the same kind of work that students are sent off to do individually. In class, we discuss representations of the data. Does a pie chart work for the data? A histogram? Why or why not?

The final product of this project is a five-page paper. Students write about what they have discovered in their mining of the Bristol census. They represent their data in tables or graphs and refer to those representations of the data in their texts. They are also asked to speculate about issues that might be implied rather than proven by the census. Finally, they discuss the limitations of the data. What questions remain that cannot be answered by the available information?

The students expressed a great deal of enthusiasm for this assignment, somewhat to my surprise. Ten out of eleven in the first class I taught worked willingly and enthusiastically. One stated that she was not good at math and that she had math anxiety, and she showed some inclination to withdraw from group participation. (One student confessed after the fact that she was terrified but had chosen not to show it.) All, including the self-professed victim of math anxiety, did more than adequate work in the end.

2. Ancient Art: Professor Christina A. Salowey

Project: A Quantitative Analysis of Doric Temples

Students in ancient art learn the basic elements of Greek architecture by studying both primary source texts and archaeological data. The goals of this specific project are to introduce the textual and material evidence for the Doric temple, to introduce quantitative skills necessary for deeper understanding of ancient Greek architecture, and to show an application of these skills that a working archaeologist would use in the field.

The creativity of the quantitative projects that are now embedded in our curriculum is the major success of the quantitative reasoning program at Hollins.

Does the ancient world measure up? Students in the Ancient Art course examine data from archaeological findings and compare their computations of the ratio of column height to column diameter to see if they match the ideal of Vitruvius.

At first students learn the precise and detailed vocabulary that is necessary to describe specific features of Greek architecture. Vitruvius' *de Architectura* defines in great detail the mathematical relationships between and proportions of the elements of an ideal Doric temple. However, as we look at various temples from 600 to 250 BCE we discover that Vitruvius' ideals are not always met. For example, when we use the existing data and graph the ratio of column height to column diameter during this time period, we discover that the ratio varies a great deal. The graph of these ratios encourages students to raise many questions and also shows that there are significant gaps in the archaeological data, an indication that beckons students and professionals to complete future field work in temple analysis.

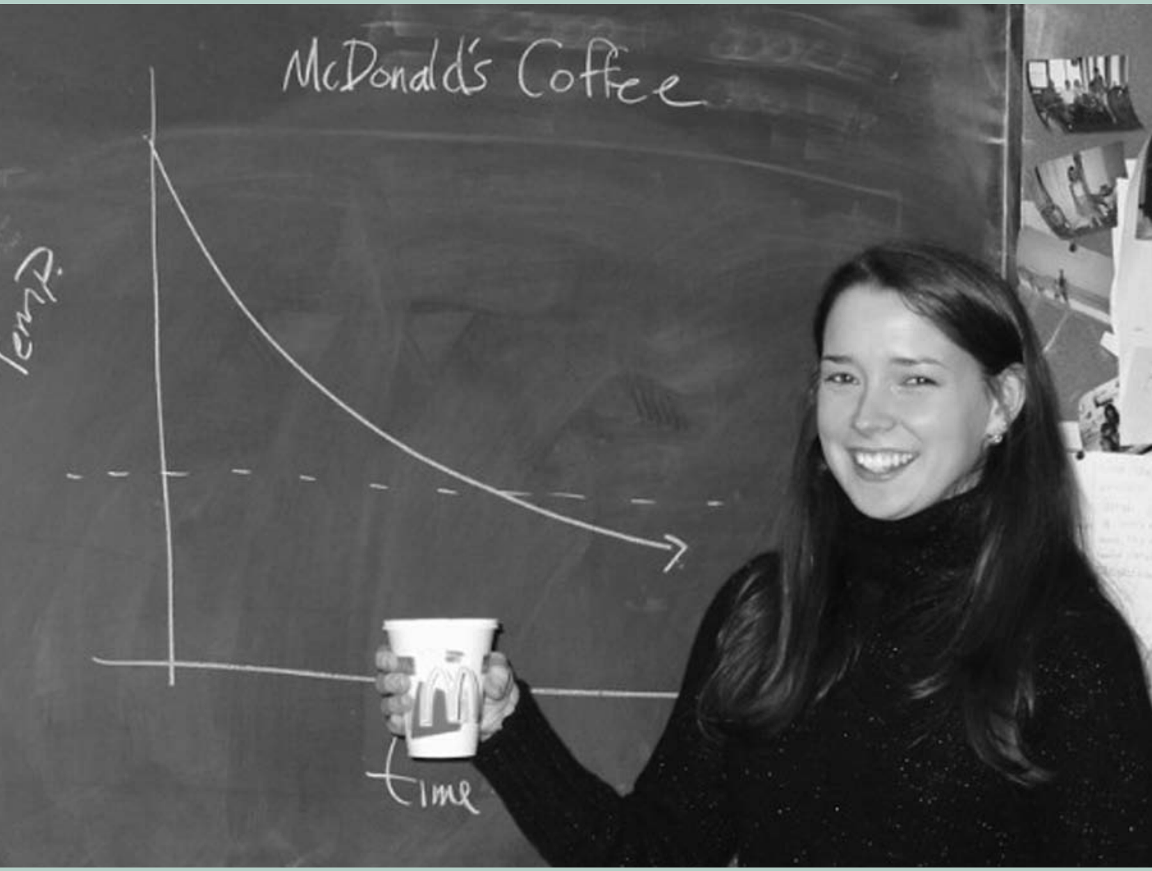
As students become familiar with the ideal proportions of Vitruvius, we observe and measure a terracotta triglyph from Cosa (a temple from sometime between the first century BCE to the first century CE) and reconstruct a temple plan based on this small fragment. Students follow a hexastyle prostyle floor plan and are able to calculate the actual temple dimensions. We then draw a detailed scale diagram that includes the exact number of columns, column width, column height, and distance between columns. In creating this scale diagram we tried to convert all measurements to meters and had each square grid on our graph paper represent one square meter. However, our calculations involved fractions of meters that were cumbersome to deal with and difficult to draw accurately. We quickly discovered that it is much easier to use a module system and assume that each square grid on the graph paper is a square module. The amazing thing about this discovery is that it became clear to us that the ancient Greeks knew and understood this concept. Using the module system makes our drawing process much easier and our result more accurate. It was exciting to experience this intellectual moment of discovery and understanding with my students.

3. Calculus I: Professor Trish Hammer

Project: The McDonald's Coffee Lawsuit—AKA, Newton's Law of Cooling

Students in traditional Calculus I classes spend most of their time with formulas and algebraic manipulations. Calculus Reform of the 1990s emphasizes concepts and applications. I strongly believe that students understand the concepts of calculus by seeing how they apply to real-world problems. The goal of this project is to show students an interesting application of mathematics in a field that most people would describe as nonquantitative: law. Most students have heard about the McDonald's coffee lawsuit. In fact, most have developed a nonmathematical opinion about the case, which is very different from approaching a problem with no background or context. This project allows students to view and analyze a newsworthy problem in a mathematical way. The idea for this project comes from "Coffee to Go."[4]

In class, we discuss several basic differential equations and their solutions. In addition, we have studied Newton's law of cooling and have completed some easy examples that deal with cooling objects and Newton's law of cooling. The problems we work together in class consider only one environment. As students complete this project, they must take the coffee from one



What do the golden arches of McDonald's have to do with a seventeenth-century scientist? Calculus students use Newton's law of cooling to determine if McDonald's is liable in the well-publicized coffee lawsuit.

environment (a person's hands) and move it to a second environment (a cup holder).

Students work together during nonclass times, in groups of two or three, to complete the assignment. I require students to present both the mathematical work and a verbal argument that gives their verdict on whether McDonald's is liable for damages.

In Calculus I, I was very pleased with students' work. Students really get into this project, possibly because many of them have a strong opinion on the case beforehand. One group submitted a letter on law firm stationery stating their opinions. Another group submitted a very elegant mathematical solution, in which they used a single formula to give the temperature of the coffee after so many minutes in the first environment and so many minutes in the second environment. The best solutions always involve some discussion about "if the plaintiff was off by x seconds, then the coffee was above (or below) the industry standard."

Since I have used this assignment for several years, I've learned that I need to stress how I want students to write up their solutions. I tell students that they should think of this as a technical report that includes writing and mathematical calculations. I like the fact that students feel that they have solved a real-world problem when they complete this project.

One of the great things about this project is that even after students complete the mathematics, there is plenty of room for interpretation. What if the coffee is above (or below) the industry standard by 0.3 degrees? Should we round up, round down, or round at all? Is 0.3 degrees worth a million dollars? Is the possibility of being off by 30 seconds a big deal? I get many different and correct interpretations that are based on the same mathematical calculations. It is interesting to see how students use their mathematical work to support their opinions.

4. Ecology: Professor Renee D. Godard

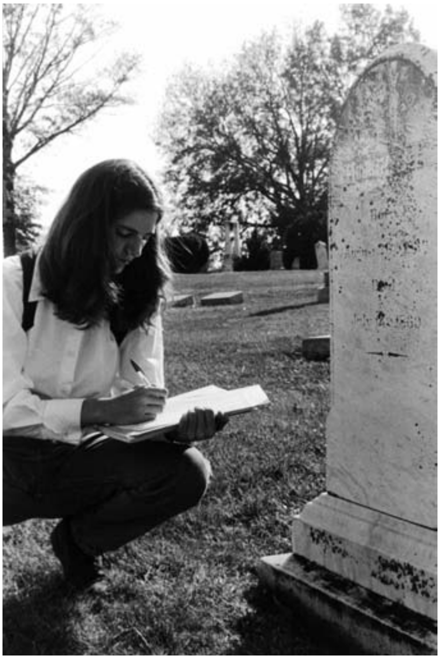
Project: Demography—Life Tables, Survivorship Curves, and Patterns of Fecundity

Population biology covers a myriad of subjects: longevity, mortality, sex ratios, fecundity, and so on. The numbers can be daunting to students, and it is difficult to collect meaningful data in a time period as short as one semester. The purpose of this project is to introduce students to concepts associated with understanding the dynamics of a population in a way that grabs their attention. Focusing on the grave markers of our own species avoids some of the usual pitfalls of population biology.

To prepare for the project, we read the textbook material relevant to population biology. Students also read the materials handed out for the lab, and those materials include background information. By the time this project comes along, the students are fairly comfortable with working with data in Excel, so that part of the project does not have to be introduced. Before we proceed to the project itself, we talk about questions raised by the readings in class and about what we are going to do when we head out to the graveyard.

Working in pairs, the students collect data in the graveyard. In fact, because two lab sections carry out this project during the same semester, we can gather data from two graveyards. Within each lab, the pairs collect their data, and then the whole group comes

Our October graveyard walks are memorable to the students, and examinations of life-history patterns of our own species makes the material come alive.



A grave undertaking? Ecology students gather data in a graveyard in order to explore concepts in population biology.

together—still in the graveyard—to hear summaries of the data. After the collection of data, I pull it all together and hand it back to the students to work with. The summarized data they receive are essentially the beginnings of life tables for the two sexes in the two cohorts. In class, we discuss how the students should complete the life tables (essentially what the variables mean), how to draw survivorship curves (including discussion of the value of semilog graphs), and how they might approach the questions asked.

Of course, the ideal approach to population biology would be to follow a population from birth to death, but most of the inherently interesting species have lifespans that far exceed a semester. However, our October graveyard walks are memorable to the students, and examinations of life-history patterns of our own species makes the material come alive.

This was also a positive experience from a faculty perspective. It gave me the opportunity to bring in current fecundity data and apply it to the survivorship patterns of the earlier group. The project illuminates how patterns of survivorship as well as birth rates and age at first reproduction influence patterns of population. Thus a number of significant points arise out of this project and dramatize important concepts.

5. France Since the Revolution: Professor Andre Spies

Project: A Quantitative Analysis of Napoleon's March to Moscow

Students of history know that Napoleon's march to Moscow, and the retreat of his forces, took place under cold and brutal conditions. In this project students work with a nineteenth-century document that brings the disastrous historical event to life. As they consider such questions as what proportion of those ordered to Moscow survived the march to that city, how many soldiers died per day on each stretch of the march, and, on average, how many yards lay between corpses, students discover and experience the conditions of Napoleon's march and retreat in vivid terms.

Students do not need advance preparation for this assignment; rather, they work through the material together in class. I distribute copies of the map of Napoleon's march and retreat, along with copies of questions to be addressed. Students take turns standing at the board to record the estimates and conclusions of the group. Some students measure distances on the map. Other students wield their calculators to translate numbers and distances into answers to the questions. An essential piece of this group work is that I'm a participant and not an expert. I work through the material with the students rather than preparing it ahead of time, and students see me as a colleague in search of interpretations.

In this project students work with a nineteenth-century document that brings Napoleon's march to Moscow to life.

After the group works through the questions in class, students write papers individually. Their papers must include an explanation of the mathematical processes. Conclusions must be presented both in numerical form and in prose. Students not only analyze the results but also discuss what they have learned through the project. They are asked, in fact, to include adjectives that they would use to describe Napoleon's march.

Students did very good work on this project. Seven out of eight in the first class to tackle it bought into it. Even students who said that they had math phobias succeeded—sometimes did the best work, in fact.

The benefits of the QR component, and of this project, are many. The in-class work loosened up the class and so contributed to improved class dynamics throughout the semester. I became reacquainted with quantitative methods to the point that I am now studying regression analysis, a skill that I hope to use in my own research. For both students and myself, this project proved broadening in the way that the liberal arts are supposed to be.

The QR project changes the ways that students see the study of history. This approach demonstrates to students that professional historians have a variety of interests and skills, that we take interdisciplinary work seriously, and that history professors are not afraid to try some different approaches and different ways of examining material. Similarly, the QR project exemplifies some of the key virtues of the general education program: it shows that many disciplines draw and depend on a number of different skills—even historians can do quantitative work!—and QR provides a model of how the teaching of skills across the curriculum works well.

6. Lighting Design: Professor Laurie Powell-Ward

Project: Creating Even Washes of Light on a Theatrical Stage

In the Lighting Design class students examine the potentials and problems of theatrical lighting through lab exploration with standard industry equipment. Students work with script-based design projects and develop the technical support information that is necessary to produce a stage design. One of the QR projects is designed to allow students to use specific lighting equipment in the Hollins theatre to produce even washes of light on the stage. The specific goals of the project are:

My students have discovered that a theatre design class is not an easy A or a filler course, but one that is intellectually challenging and artistic at the same time.

- To create a light plot that includes three washes for a bare stage.
- To choose correct instrumentation.
- To determine the best placement of instruments for continuity of angle of light.

Students begin by breaking down the stage space (via a ground plan) into sized areas. These sized areas are circles, each of which represents the circular area on the stage that can be illuminated by an individual light. We have a group lab session to become familiar with the instruments and the quality of light they produce. In addition, I work with students to develop vocabulary, introduce the ground plans and section views that we'll be completing, and understand how to use scale measurements.

The assignment requires students to prepare three different washes of light. We complete the first wash together as a group. Students then complete the second and third wash on their own, using the group work as their model. Classes consist of ten students because of limited lab space, and this size makes it easy and fun to work as a group in class on the technical paperwork.

I was pleased with the students' work on this project. At first, many were overwhelmed by the number of steps involved in making decisions. However, part of the exercise is learning how to focus on one step at a time, even though the task seems chaotic. By the end of the project, students were comfortable with the process.

The first time I used this project, I introduced it as our QR project and noticed that many of the students tensed up for a full class period before they relaxed and realized that they were able to understand and complete the task. The next time I teach this class, I will simply introduce this as a lighting project and hope that approach will create less anxiety. In addition, when I assign this project again, I will use a smaller stage space and include a smaller number of lighting areas in order to reduce the frustrations that students experience at the beginning of the task. I will also have the class work on the project in the lighting lab in order to have a three-dimensional reference instead of relying on the two-dimensional paper representation. I plan to continue to use the entire sequence of three assignments, because this was effective and allowed students to master one component at a time as they build on the previous assignment.

While completing this project, my students became aware of the many steps involved in creating a lighting design for stage. They now appreciate the systematic and structured nature of lighting design in the early phases, a process that must occur before the "artsy" work in the theatre space. This project destroys the myth that all lighting instruments are the same and that any one will work fine if you just point it in the right direction. My students have discovered that a theatre design class is not an easy A or a filler course, but one that is intellectually challenging and artistic at the same time. I am pleased that my students now believe that applied QR is not necessarily evil.

This class worked so well that I have recently created QR projects for my Scene Painting course, and it has been approved as one of the QR applied courses. I continue to examine my other design courses and am discovering that quantitative methods are inherent in everything I teach.

Short Descriptions of Additional Projects

Computer Science I: Professors Dan Chrisman and James Allen
Given a very large set of data, what's the quickest way to compute the mean and standard deviation? Students in Computer Science I develop and then analyze both one-pass and two-pass algorithms to determine the best method.

Economics of Health Care: Professor Juergen Fleck
Are lifestyle choices as important in determining a person's health status as access to health care? Students analyze the effects and social costs of particular behaviors, including alcohol consumption, drinking and driving, speeding, inadequate nutrition, lack of exercise, smoking, and drug use.

Human Memory: Professor George Ledger
How can we statistically analyze, describe, and interpret the results of a memory experiment? Students work with the data from the Ledger and Mays (1994) metamemory study. They identify nominal, ordinal and ratio variables. They compute means for all measures by graduating class and create bar charts to describe each. They create scatterplots by class and create new categories based on the distribution of scores. They compute correlations among the variables, using both pair-wise and list-wise deletion of missing data and interpret the results. Throughout the course they are asked to identify the advantages and disadvantages of each re-categorization and analysis and to provide justifications for their decisions and interpretations of the results.

Introduction to Statistics: Professor Julie M. Clark
Students complete three QR projects for this course. In the first project, they practice collecting, organizing, and interpreting data of their own choosing. The second project involves performing a simple linear regression—finding data for two variables that they suspect might be related, and then finding a linear relationship between the variables and calculating the corresponding fit of the model. Students have chosen to study such diverse topics as brain size vs. IQ, diamond prices vs. carat weights, and public school expenditures vs. SAT scores by state. In the third project, students critique a published report of either a statistical significance test or estimated population

value (confidence interval). With all projects, students choose their own topics and find or collect their own data so the projects are meaningful, interesting, and relevant to their individual disciplines.

Methods of Matrices and Linear Algebra: Professor Caren L. Diefenderfer
Linear algebra is an important subject because of its applicability to many disciplines. For each of the QR projects in this course, students may choose one from a list of roughly ten applications. In this way, students can create assignments to match their personal interests. Science students opt for the chemistry, biology, and physics applications; social science students choose the economics, business, and planning topics; computer science students enjoy the computer graphics projects; and other students usually prefer to select applications from a variety of fields. Cryptology (creating and breaking codes), Markov Chains, and the Assignment Problem are three of the all-time favorite projects.

Physical Principles and Analytic Physics: Professor Joseph Ametepe
Edwin Hubble considered the relationship between distance from the Earth and the recession velocity of galaxies, because he hoped this would shed some light on how the universe was formed and what we may expect to happen in the future. Physics students use Hubble's data to find the correlation between distance and recession velocity. In addition, they use these data to make predictions about new galaxies. Students also compare Hubble's law to the regression equation and explain whether the two approaches give consistent or inconsistent information.

Research Methods in Communication: Professors Jane Tumas-Serna and Chris Richter
When is the news truly news and when is it entertainment? Does television news reflect gender biases? Students in this communication studies course address questions like these when they do a content analysis of the TV news. Students record one week of network or network affiliate news programs for ABC, NBC, and CBS. They devise content coding schemes and then code the programs for such things as amount of time devoted to hard, soft, or tabloid news or amount and type of news covered by male and female reporters. Finally, students do statistical analyses to compare the categories across the different stations and to determine their levels of intercoder reliability.

Research Methods in Political Science: Professor Jong O. Ra
Is there a relationship between a voter's (perceived) financial condition and her presidential vote? Students learn how to use a three-way table among three variables (the voter's perception of her own financial condition, the shape of the national economy, and her evaluation of the proposed management of these issues by Bush and Gore in the 2000 presidential election) to answer this question.

Sociology of Health, Illness, and Medicine: Professor Kay R. Broschart
Do nations that spend more money on health care have healthier citizens? Is there a connection between the proportion of women physicians in a medical specialty and their average salaries? Students discover how to analyze data and give informed answers to these questions.

Symbolic Logic: Professor Michael Gettings
Is symbolic logic useful in today's society? Students in Symbolic Logic learn how to apply everyday reasoning processes such as argument, inference, premise, and conclusion as they analyze nonfiction and newspaper articles in ordinary language. Students look at specific excerpts from *Washington Post* editorials and from John Kenneth Galbraith's *The Affluent Society*. Over several years of teaching, Professor Gettings has seen that the textbook examples are often contrived, but articles from other sources have hidden assumptions and prove to be more challenging and beneficial to students' understanding. In-depth understanding also helps students to retain important principles.

The QR requirement at Hollins serves as a cornerstone of the skills aspect of the new general education program and is a model for inspiring more effective teaching and learning.

PEDAGOGY

A change in the general education requirements at any institution affects both students and professors, sometimes in unexpected ways. A reconsideration of general education requirements should cause each professor to reflect on the material contained in a given course topic, how it is presented to the students, and what the students are expected to gain from the educational experience. The implementation of an applied quantitative reasoning requirement in the general education program at Hollins encouraged professors from many different disciplines to recognize that quantitative reasoning was a skill necessary for the mastery of material in courses they were already teaching. Faculty who teach quantitative reasoning material in their courses observe a variety of benefits both to their development as more active, engaged, and creative teachers and to the enhancement of their students' classroom experience.

The NSF-funded seminars were a productive first step for many professors. The introductory readings and interactions with the organizers, Professors Diefenderfer and Hammer, gave the participants ideas about changing their own classes to include quantitative reasoning assignments. The seminars also provided a template for writing a quantitative reasoning assignment. For faculty who teach in fields other than mathematics and the sciences, the creation of an exercise that guides the students step-by-step through a problem-solving process may not be a regular part of their classroom preparation. The peer review of the quantitative reasoning assignments proved instructive for all participants and added to their pedagogical repertoire. The gathering of faculty from several different disciplines had the additional benefit of increasing collegiality among those faculty, generating interest in the goals of courses taught outside of their own disciplines, and raising the level of respect they had for each other's intellect, scholarly ability, and pedagogical technique. The seminars thus expanded the pedagogical horizons of the faculty involved and created a mini-community of exploration and learning that bolsters the educational mission of the university.

Many faculty noted that the techniques they used to present the quantitative reasoning assignments created new

Faculty members re-experience the joys of being a student. During NSF-funded faculty development workshops, we shared and critiqued one another's ideas and enjoyed learning about quantitative projects in an amazing variety of settings.

classroom dynamics. A number of the assignments were multistep procedures involving data collection, calculation, presentation of the results, and interpretation. The step-by-step nature of the assignments alleviated student anxiety about the quantitative component, made the assignments accessible, and had a natural fit with the course material. Group work, especially for data collection, was a common feature, and faculty found that students enjoyed working with each other. Students discovered that they each had different strengths, which contributed to solving a complex problem. Student collaboration added a strong element of fun and excitement to the task, thus removing any stigma that the quantitative reasoning course label might have carried. Instead of being daunted by the in-depth problem solving they were being asked to do, students became engrossed in the work, drawn in by the practical nature, and proud of the results they were able to produce.

The quantitative reasoning exercises developed by many faculty members have the added benefit of coming from real-life examples and data. In Professor Doan's history class, students wrestle with how to deal with the individuals listed in the Bristol census who do not fit into neat family units. In Professor Salowey's classics class, the measurements of extant Doric temples raise many open-ended questions about temples from antiquity: Was Vitruvius' ratio actually the standard, or was it only his imagined ideal? In addition, Professor Salowey's project on the ratio of column height to column diameter shows clearly that professionals need to find and analyze more data from the time period of Vitruvius. In Professor Spies' history class, as students investigate the extraordinary document that records quantitative information about Napoleon's march to Moscow, their analysis conveys a seriousness and weight that make this historic event become real, present, and disastrous. In each of these settings, academic material comes to life when dealing with the messy, complicated, sometimes incomplete real-life data. We have discovered a powerful principle: using data from real situations invites students to explore and even struggle to understand the material so that they own the process of interpretation. Contrived textbook examples are simple and easy, but do little to build confidence or promote deep understanding.

The quantitative reasoning requirement at Hollins serves as a cornerstone of the skills aspect of the new general education program and has proved to be a model for inspiring more effective teaching and learning. The assignments encourage many faculty to move in new pedagogical directions, providing benefits for their students not only in general education but also in the mastery of knowledge and skills essential to their specific fields. The quantitative reasoning program invites students to use all the resources of the academic community, an important hallmark of a successful liberal arts education. Barriers between disciplines begin to fade when a student in a history class thinks about the meaning of numbers reported in statistical documents or when a student in a calculus class notes the importance of the interpretation of a liquid cooling curve in a multimillion-dollar lawsuit. Students will leave this academic environment not only knowing how to read texts and images, but also how to read the important language of numbers and be critical of their interpretations.

ASSESSMENT

We have used several assessment instruments to measure the effectiveness of the Hollins program since we introduced our basic skills quantitative reasoning requirement in the fall of 1998. One measure of effectiveness is to consider final course grades. Of the 363 students who enrolled in Mathematics 100 during the past five years, 85.1% passed the course. Of those who completed the course, 88.5% passed. (Fourteen students withdrew from the course within the approved drop/add period.) The 302 students who enrolled in this course and received a grade earned an average of 2.18 quality points. (On the Hollins scale, a C receives 2 quality points and a C+ would receive 2.3 quality points.)

All entering students complete a quantitative reasoning assessment and students enrolled in the basic skills quantitative reasoning class retake the assessment at the end of the semester. A comparison of these two scores gives us another measure of their progress. Our data from this five-year period show that on average, students improve 13 percent on the assessment after completing the course. (The assessment is based on 50 points and the average score improvement is 6.5 points.) Both of these numerical measures indicate that students who enroll in the course become stronger in analyzing quantitative information.

We have also collected qualitative data. During the 2001-02 year, a campus assessment committee devised student perception surveys to assess the new general education requirements. The data for students in the basic skills quantitative reasoning class show a very high self-assessment of improvement. The percent changes range from +93.9 percent to +140.7 percent on four survey items. Data for students in the applied skills quantitative reasoning classes also show positive student self-assessment, with percent changes of +51 percent to +52 percent.

Hollins has been selected to be a pilot site for an NSF grant, "The Development of Assessment Instruments for the Study of Quantitative Literacy," under the direction of Susan Ganter at Clemson and Jack Bookman at Duke. The purpose of this grant is to develop appropriate assessment instruments for quantitative literacy and to train a small group of professionals to conduct nationwide assessments. Hollins faculty members will help to write the assessment instruments and then test the instruments on campus. This work will occur during 2004.

Since the program is relatively new, we do not yet have feedback from our graduates describing whether skills learned in their QR courses at Hollins have been beneficial to their lives after graduation. A future evaluation will survey alumnae. Hollins faculty members have been invited to give keynote addresses, lead workshops, and present panel discussions at professional meetings. The number and variety of these invitations document the admiration and high esteem that professionals across the country have for the Hollins QR program.

CONCLUSIONS

There are many practical reasons for including courses in quantitative reasoning in an undergraduate curriculum. The skills learned in these courses will help students in both their future academic work and the job market. Prospective employers are often impressed with candidates who have strong quantitative skills. Informed citizens need to know how to make arguments and interpret data they see and hear in the news. Learning how to make appropriate choices when faced with complex issues is an important life skill.

In addition, there are strong academic reasons for preparing students to think quantitatively. Techniques learned in our basic and applied courses give students the confidence to solve problems in new situations. Faculty members at Hollins believe that the project-oriented nature of the applied quantitative reasoning assignments encourages students to approach discovery and interpretation as professionals. In short, students are getting more practice in solving real-life, open-ended problems.

Providing all students with the knowledge, ability, and confidence to solve and understand quantitative issues was the original goal of the Hollins quantitative reasoning program. In designing projects to give students these skills, faculty members have become more conscious and deliberate about creating assignments in all their classes. We have discovered that quantitative perspectives can be found everywhere, in many disciplines and in many classes, not just in the classes that now satisfy our applied quantitative reasoning requirement. Our collective efforts to create projects and assignments that will strengthen the quantitative reasoning abilities of our students are teaching us a great deal about interdisciplinary work. The journey continues to be enlightening for us and for our students.

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[1] *Mathematics and Democracy: The Case for Quantitative Literacy*, edited by Lynn Arthur Steen, prepared by the National Council on Education and the Disciplines, 2001, p. 2.

[2] *Mathematics and Democracy*, p. 6.

[3] *Mathematics and Democracy*, p. 114.

[4] *Instructor's Resource Manual for Calculus from Graphical, Numerical, and Symbolic Points of View, Volume 1*, Saunders College Publishing, 1995, p. 106.

APPENDICES

Appendix A
A History of Quantitative Reasoning at Hollins, 1996–99

For some time, Hollins had recognized weaknesses in the general quantitative skills of its students. In 1996, after a careful reading of the MAA report, *Quantitative Reasoning for College Literacy*, Caren Diefenderfer, associate professor of mathematics, and Ruth Doan, professor of history, submitted a proposal that "Hollins shall institute a Quantitative Reasoning requirement that will draw upon courses across the curriculum and will be supported by a Quantitative Reasoning Center." Support for this proposal gained momentum early in 1998 when Hollins University was required to "demonstrate that its graduates are competent in…oral communication, fundamental mathematical skills, and the basic use of computers" during a reaccreditation study by the Southern Association of Colleges and Schools (SACS). At this time, professor Diefenderfer and Patricia Hammer, associate professor of mathematics at Hollins, secured from faculty and senior administration a commitment to the importance of quantitative reasoning across the curriculum. In spring 1998, Hollins began to develop a QR program similar to that at Wellesley College. The Hollins program not only satisfies the SACS criteria, but also emphasizes quantitative reasoning across the curriculum and gives students the opportunity to learn the broad significance and applicability of quantitative reasoning. A two-part quantitative reasoning requirement consisting of a QR basic skills requirement and a QR applied skills requirement was approved by the faculty in spring 1998, with the basic skills requirement to begin in the fall of 1998 and both the basic and applied skills requirements to be in place by fall 1999. During 1998-99, the mathematics and statistics department under the leadership of Professors Diefenderfer and Hammer worked closely with Hollins faculty to define, identify, and more fully develop the guidelines for QR applied skills courses.

Since the quantitative reasoning requirements outlined in 1998 fit perfectly into the framework of the new ESP program and paralleled the role of writing and oral communication across the curriculum, we decided that instead of following the original timetable and implementing the QR applied skills requirement in the fall of 1999, we should wholeheartedly support this new curriculum and implement the second QR requirement at the same time as the new ESP program. While this delayed the implementation of the QR applied skills requirement for several years, it also gave us time to work with interested faculty members and develop some high-quality projects.

Professors Diefenderfer and Hammer received $3,000 from the Hollins University Sowell Fund for faculty development during the spring semester of 1999. They led a series of workshops to encourage Hollins faculty members to incorporate quantitative reasoning into existing courses. The workshop met four times and had ten participants. These participants worked together to create a Hollins definition of quantitative reasoning (see Appendix B) and wrote guidelines concerning development of QR modules and classification of courses as QR applied. In addition, each participant created one or two QR projects that they used and revised during the subsequent academic year. While these faculty workshops were successful in promoting both camaraderie and the ideas of quantitative reasoning, campus-wide awareness and understanding of quantitative reasoning still fell short. Nine of the ten faculty members who participated in these activities were from science, social science, and mathematics departments.

Professors Diefenderfer and Hammer received another Sowell Grant ($3,000) during 1999-2000 to continue their efforts. Since we wanted to attract faculty members from the humanities and the arts, as well as the sciences and social sciences, we proposed a faculty reading group, with the hope that this format would appeal to a broader cross section of our faculty and that the discussions would help to promote a deeper understanding of quantitative reasoning on our campus. We had approximately twenty faculty members participate, we read *Why Numbers Count—Quantitative Literacy for Tomorrow's America* (published by the College Board, 1997), and we increased the number and variety of represented disciplines. Meanwhile, discussions and deliberations on the new ESP program continued.

Appendix B
The Hollins Definition of Quantitative Reasoning

Quantitative reasoning is the application of mathematical concepts and skills to solve real-world problems. In order to perform effectively as professionals and citizens, students must become competent in reading and using quantitative data, in understanding quantitative evidence, and in applying basic quantitative skills to the solution or real-life problems.

Appendix C
Participants in the 2000–01 NSF-Funded QR Workshops at Hollins

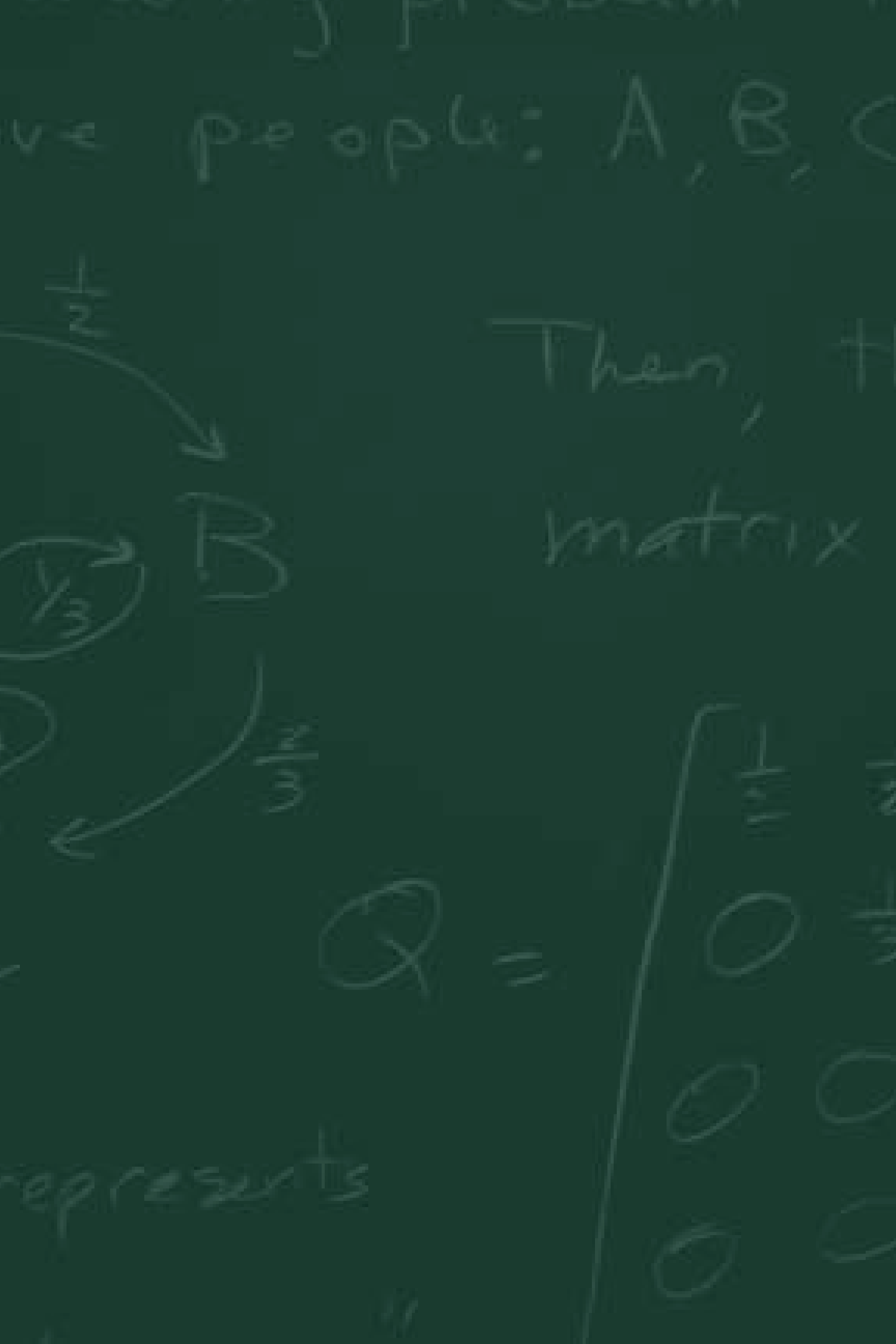
Faculty Member	Department	Q course(s)
Joseph Ametepe	Physics	Physical Principles Analytical Physics
Rebecca Beach	Biology	Genetics*
Sandy Boatman	Chemistry	Biology of Women*
Kay R. Broschart	Sociology	Sociology of Health, Illness, and Medicine Methods of Social Research
Dan Chrisman	Computer Science	Computer Science I
Julie M. Clark	Mathematics and Statistics	Introduction to Statistics Statistical Methods
Dan Derringer	Chemistry	General Chemistry Principles of Chemistry
Caren L. Diefenderfer	Mathematics and Statistics	Methods of Matrices and Linear Algebra
Ruth Alden Doan	History	U.S. Social History
Juergen Fleck	Economics	Economics of Social Issues Economics of Health Care
Sally Garber	Mathematics and Statistics	Intuitive Calculus
Michael Gettings	Philosophy and Religion	Symbolic Logic
Renee D. Godard	Biology	Ecology
Trish Hammer	Mathematics and Statistics	Precalculus Calculus I and II
Nancy Healy	Computer Science	Microcomputers in the Business World*
George Ledger	Psychology	Human Memory
Laurie Powell-Ward	Theatre	Lighting Design
Jong O. Ra	Political Science	Research Methods in Political Science
Christina A. Salowey	Classics/Art	Ancient Art
Andre Spies	History	France Since the Revolution
Robin Taylor	Biology	Plants and People Plant Biology
Jane Tumas-Serna	Communication Studies	Research Methods in Communication

*course is not yet approved

Caren L. Diefenderfer, associate professor of mathematics, earned M.A. and Ph.D. degrees from the University of California–Santa Barbara. Over the years her scholarly interests have focused on approximation theory, graph theory, and computer graphics. Her current work involves combinatorics and the geometry of weaving. Professor Diefenderfer works with the College Board as chief reader and a member of the test development committee for AP calculus. She is the chair-elect of the newly formed Special Interest Group in Quantitative Literacy of the Mathematical Association of America.

Ruth Alden Doan, professor of history, received an M.A. and Ph.D. from the University of North Carolina–Chapel Hill. Professor Doan primarily teaches courses in early America and in social and religious history. She also teaches the survey of U.S. history, seminars on colonial history, the American Revolution, antebellum America, and the American wilderness experience. Her publications include a monograph on Millerism in nineteenth-century American religious history. Currently, she is working on a study of southern evangelicals and narratives of religious experience.

Christina A. Salowey, associate professor of classical studies, has a Ph.D. from Bryn Mawr College, an M.A. from Tufts University, and an M.S. from Rensselaer Polytechnic Institute. Professor Salowey specializes in Greek art and archaeology and religion. She is interested in pedagogical issues and serves on the executive committee of the American School of Classical Studies at Athens. She codirects an archaeological survey in Arcadia, bicycling to all her sites, and continues extensive research on the cult and labors of Herakles.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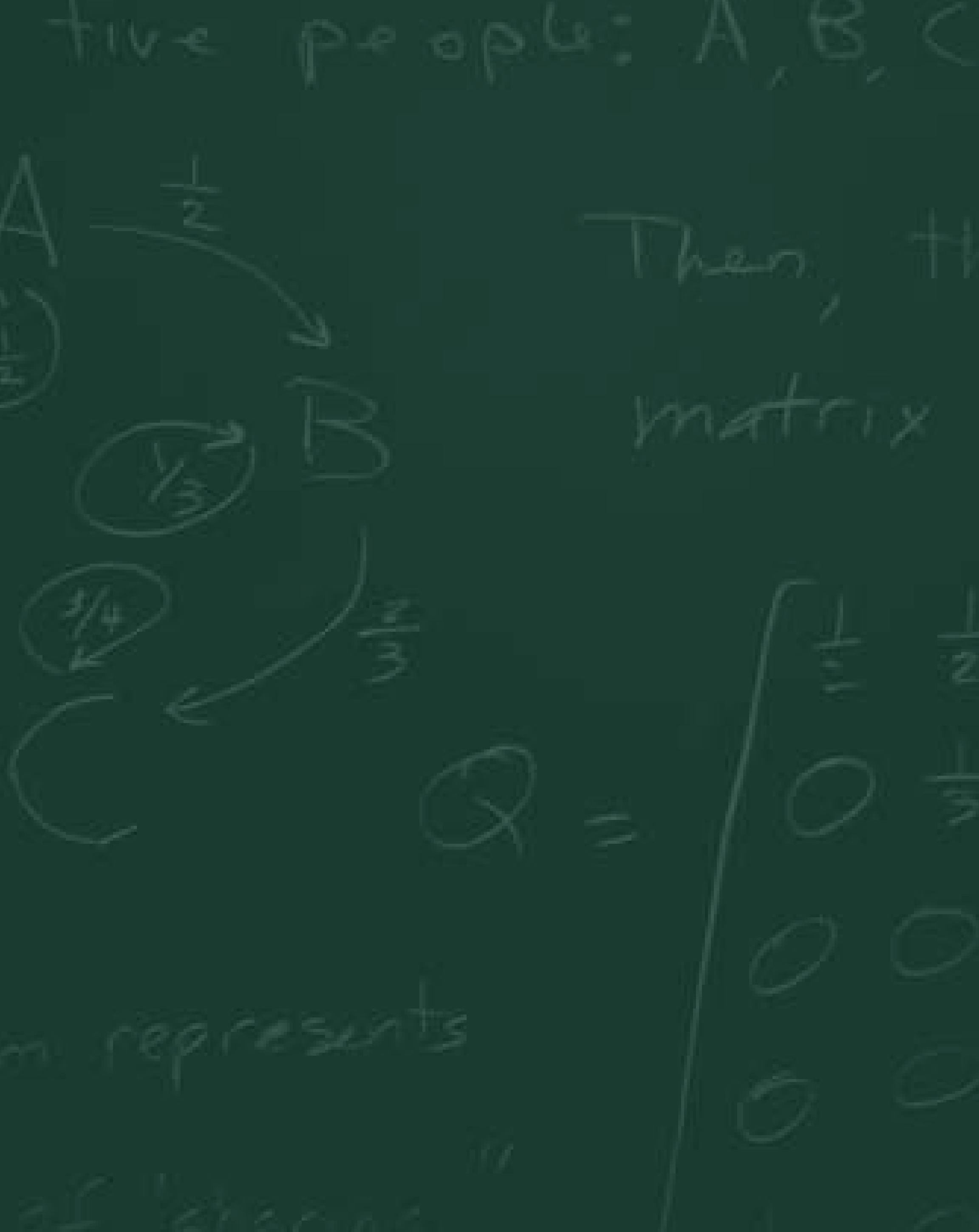

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