SUCCESSFUL INTERDISCIPLINARY TEACHING:
Making One Plus One Equal One

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ABSTRACT

Interdisciplinary courses are widely commended to help students acquire the mental agility and critical thinking skills needed for success in the modern world, but mathematics is seldom one of the interdisciplinary players. This paper uses evaluation data from ten mathematics and humanities courses developed as part of the Mathematics Across the Curriculum project at Dartmouth College to show that interdisciplinary mathematics and humanities courses did more than help students achieve an interdisciplinary perspective. By involving students actively in learning interesting mathematics, they were more successful than more conventional courses in promoting positive attitudes about mathematics. Connecting student outcomes with faculty strategies in developing and teaching these courses yields guidelines for developing successful interdisciplinary mathematics courses.

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Introduction

In the last decade, the call for an interdisciplinary perspective has risen from a suggestion to an exhortation. From all quarters, colleges are urged to breach barriers between departments by developing more interdisciplinary courses and programs. Reviewing the 1997 *Handbook of the Undergraduate Curriculum,* Klein (1998, p. 4) writes, "For the most of this century, the dominant trend in higher education was the growth of specialization and the proliferation of programs and courses. At present, we are in the midst of a historic reversal of this trend, and interdisciplinarity is at the heart of it." The need for interdisciplinary teaching and learning is a leit-motif in Rhodes' (2001) prescription for the college of the future. If the sciences led the way in specializing, they now especially feel the need to reintegrate knowledge. In *Shaping the Future* (1996), the Advisory Committee to the National Science Foundation repeatedly commends interdisciplinary learning as a strategy for keeping the United States' workforce competitive.

The driving rationale is that success in the contemporary world demands an acrobatic intellect capable of constant readjustment. Interdisciplinary approaches, it is reasoned, exercise the mental muscles needed for this kind of thinking. Recent literature catalogues the benefits believed to accrue from interdisciplinary courses. These courses will show students how to address complex issues and help them think more critically (Newell, 1994; Davis, 1995; Klein, 1998; Rhodes 2001). They will encourage faculty to be pedagogically adventurous, promote the synthesis of knowledge, and help to draw the campus community closer together (Austin and Baldwin, 1991; Davis, 1995, Rhodes 2001). In mathematics and the sciences, they will increase student interest by relating those fields to other accessible and engaging questions, and they will increase student numbers by attracting students from outside the traditional mathematics and science majors (National Science Foundation, 1996; Ganter and Kinder, 2000).

This is a tall order for any pedagogical strategy, especially one that goes against the structural grain of most universities. Apart from the organizational challenges of apportioning faculty time and rewards among departments (itself no small consideration), the pedagogical value of interdisciplinary courses remains moot. In interviews about interdisciplinary teaching, Dartmouth College faculty from all disciplinary corners described their own scholarly work as highly interdisciplinary, but in the next breath many voiced reservations about the value of interdisciplinary courses for their students, especially at the introductory level. A physicist who felt graduate school was the appropriate location said, "We have to get through this essential material before [students] even have anything to think *with*." A humanist agreed: "The student has to have some grounding already in a discipline."

In this skeptical environment, mathematics has historically been the discipline least likely to succeed. Elementary and high schools that integrate all other subjects still teach math as a standalone offering. Interdisciplinary courses at the college level often connect disciplines where communication is already close, a matter more of overcoming dialectical differences than of learning a new language. Courses linking English, history, philosophy, and drama are common. Math and physics are also a frequent (and usually successful) pairing, but as one student insisted, "Physics **is** math." But interdisciplinary mathematics beyond "math applications for science" courses are viewed suspiciously by mathematicians, who cannot believe such courses could be rigorous enough to teach real math, and by humanists, many of whom have made math-avoidance a lifelong endeavor. Dartmouth's decision to link these two ends of the curricular spectrum in interdisciplinary mathematics and humanities courses was largely unprecedented.

The Dartmouth Project

The determination to make mathematics and humanities courses a cornerstone of the large, multi-year National Science Foundation-funded Mathematics Across the Curriculum project was serendipitous. Responding to the NSF's call to promote broader mathematical competence, the project's goals were to make mathematics accessible, interesting and relevant to students in all disciplines. Coincidentally, the project's Principal Investigator, Dorothy Wallace, along with an artist, had just created "Pattern," a course that used pattern in art to generate interest in and to illustrate elementary group theory. Wallace was convinced that other humanities could provide topics that would similarly motivate students by showing the relevance of mathematics to their other interests and by allowing them use more familiar non-mathematical material as a springboard into math. Her belief was supported by the regnant constructivist educational theory which asserts, put simply, that students are stimulated to learn when they are actively engaged, with others, in addressing material with personal relevance and that they learn most easily by building on what they already know (Bransford, Brown, & Cocking, 2000; Phillips 2000; LaRochelle, Bednarz , & Garrison 1998). The goals of the mathematics and humanities courses thus incorporated all the interdisciplinary goals noted earlier, with a constructivist twist. While improving analytic abilities and learning real math (and other real stuff) were clear goals, faculty also believed that making students receptive to studying more math in the future—a job that often involved undoing old fears and broadening constrained perspectives—was also a valid goal.

Over five project years, fourteen faculty members (half mathematicians, half humanists) created nine new courses connecting mathematics with literature, cultural history, music, art, architecture, drama, and philosophy.[1] Course developers expected the usual challenges of creating interdisciplinary courses to be magnified for them: greater substantive differences between the two kinds of content were accompanied by equally sizable pedagogical and linguistic differences. They also knew that they ran the risk of being seen as (and, in truth, of becoming) examples of "marshmallow math"—soft, sweet and toothless. But there was one wrinkle they didn't anticipate. They imagined that these courses would attract mostly students who were anxious about mathematics. In fact, perhaps because they were labeled "mathematics **and** humanities" courses (not "math for humanists" or "humanistic math"), when opened to an unrestricted population, they drew as many competent mathematics students as fearful ones—and few in between. (Three of ten course iterations were presented as first-year writing seminars, drawing only strong math students.) A population bimodally distributed between strong mathematics students hungry for new perspectives on a favorite subject and apprehensive ones hoping for a soft landing on their quantitative requirement posed yet another challenge for instructors. What math could engage both? In her paper in this volume, Wallace discusses how instructors selected interesting mathematical topics and made them accessible to a varied audience.

[1] Descriptions of these courses, and syllabi and materials for most, can be found at the MATC website http://www.math.dartmouth.edu/~matc/

Each faculty pair had complete independence in course development, and the resulting variations on the theme provided an excellent laboratory for evaluating the effectiveness of different approaches. Not all were unqualified successes, especially early in the project. However, since it's often easier to identify strategies that don't work than to tease out the components of success, less successful efforts were particularly instructive. Student data from 75 in-depth interviews with randomly selected students in nine course iterations and from 134 matched pre-post mathematics attitude surveys from the last four (and most "mature") courses offered[2] were linked with pedagogical strategies documented through faculty interviews, observation of planning sessions and classroom observation. Here is what we learned.

Student Results

The critical questions in evaluation are always, "compared to what?" and "for whom?" Nearly half the population in the surveyed math and humanities courses was math-phobes (necessarily non-science majors), who saw these courses as alternatives to introductory calculus for meeting the College's quantitative requirement.[3] The remainder was about equally divided between math or science majors eager to discover any new angle on a subject they enjoyed and strong mathematics students whose interests and majors directed them away from science and the calculus. For this latter group, mathematics and humanities courses offered interesting and challenging math without a calculus prerequisite.

Survey data show that in sustaining desirable attitudes about mathematics, the mathematics and humanities courses compare favorably to the introductory calculus course (the most prominent option for non-science majors, whether weak or strong in mathematics) and to two highly successful mathematics applications for science courses (which draw mostly science majors). Table 1 below compares the three types of courses along five indices constructed from the 35-item, 5-point Likert-scaled survey. The "Overall Index," constructed by dividing an individual's total post-survey score by the total pre-survey score, provides a gross measure of change in his/her attitudes about mathematics over the interval of a course. Indices greater than 1.00 show an overall gain in desirable attitudes; those less than 1.00 show an overall loss. The "Ability," "Interest," "Personal Growth" and "Utility" indices are similarly constructed from the four scales derived through factor analysis from the survey data and reference, respectively, students' perception of their mathematics ability, their interest in math, their belief in its importance for their personal growth, and in its usefulness in their professional lives.

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[2] Six of the ten mathematics and humanities course were offered in the first two years of the project, Winter 1996 - Spring 1997, before the mathematics survey was in final form.

[3] About three-quarters of the entering class take calculus at some level.

Table 1. Mean index scores by type of course for science, social science, humanities, and undecided majors.

	INDEX	MATH AND HUMANITIES	INTRO. TO CALCULUS	MATH'L APPLICAT'N FOR SCIENCE
SCIENCE MAJORS[4]	*Number*	*(N = 34)*	*(N = 99)*	*(N = 49)*
	Overall ††	1.04	.91	1.01
	Ability ††	1.07	.93	1.02
	Interest ††	1.01	.88	1.00
	Personal growth††	1.07	.91	1.03
	Utility††	1.06	.90	.99
SOCIAL SCIENCE MAJORS	*Number*	*(N = 34)*	*(N = 38)*	*(N < 10)*
	Overall **	1.01	.92	
	Ability *	1.01	.92	
	Interest	1.00	.91	
	Personal growth *	1.03	.92	
	Utility	1.00	.95	
HUMANITIES MAJORS	*Number*	*(N = 24)*	*(N = 20)*	*(N < 10)*
	Overall	.97	.91	
	Ability*	.99	.86	
	Interest	.93	.85	
	Personal growth	.99	1.01	
	Utility	.98	.89	
UNDECIDED ABOUT MAJOR	*Number*	*(N = 29)*	*(N = 127)*	*(N <10)*
	Overall **	1.01	.92	
	Ability *	1.02	.96	
	Interest **	1.00	.87	
	Personal growth **	1.02	.90	
	Utility **	1.05	.92	

†† $p < .01$ using one -way ANOVA

* $p < .05$ using Student's t-test for independent samples

** $p < .01$ using Student's t-test for independent samples

For students in **all** majors the mathematics and humanities courses were more effective in sustaining and increasing desirable attitudes about mathematics than was the standard first-year

[4] For science majors, both the mathematics and humanities courses and the mathematical applications courses were significantly different from the introductory calculus courses, but they were not different not from each other.

calculus course or the lively advanced applications courses. While there is no substitute for calculus for students who need it, mathematics and humanities courses offer students who do not require calculus to pursue their intellectual interests—or those who simply want to try a new kind of mathematics—an alternative that nurtures their mathematical interests. This is particularly significant viewed against the inexorable decline in math participation in United States colleges.

Well and good, the skeptic might respond, but did they learn any math? Positive attitudes framed in the absence of rigorous mathematical effort are fragile at best. The answer to this, of course, is complicated. Few would equate math learning with exam performance. Faculty and students consistently report that unless math knowledge is reinforced and conceptually deepened by subsequent use, most evaporates shortly after the test. Math grudgingly learned or believed to be irrelevant disappears even faster, although distaste for the subject may linger. On the other hand, one could argue—indeed, interviewed students do so argue—for the value of the problem-solving skills developed in learning math, even if little math content is retained. While students in interdisciplinary courses spend only half their time on math (and expectably would learn "less"), their reduced exposure is offset by the fact that learning math which is intellectually engaging and relevant to their other interests encourages diligence and enhances retention. The engine of mathematics learning requires both hard work and intrinsic motivation; neither is adequate alone. Interview data suggest that the motivation-infused mix on which interdisciplinary courses run is as productive as the work-enriched fuel of many mathematics courses.

Survey results offer a broad-based but superficial understanding of **how** students responded to the courses. In interviews students detail their experiences, giving substance and depth to survey data. Even the most successful courses did not persuade all students that an unconventional approach to mathematics is worthwhile. As one dissatisfied student explained, "In terms of my perception of what math is—numerical equations and actual problems with concrete right and wrong answers—that was definitely not part of the class. There weren't concrete right and wrong answers. It was theorization and ideas." Some students never achieved the desired connection between the disciplines. Despite their shortcomings, the interdisciplinary courses resulted in stronger gains in student attitudes than the other courses surveyed. In the exemplary quotes below, students explain **why** these courses were effective.

Revealing how mathematics is embedded in other fields helps students understand the mathematics better. Whether a math concept is embodied in a painting or used as an element in plot development, seeing it instantiated provides a new avenue to comprehension. As one student explained, "Compared to [other] math courses, it's more interesting because it's not just like they give you a formula and then you give them an answer. It has some kind of applications; something you can hang onto. Some of the math in there, I hadn't seen much of at all. For instance, when we looked at infinity, infinite cardinals and things like that, I had no exposure to that whatsoever. So I felt that I would be able to understand those rather obtuse ideas better in the context of the science fiction stories, so I could see, not exactly practical applications, but just some sort of a demonstration of what they meant."

Interesting applications and different, non-calculus math stimulate student interest in mathematics. For many college students, calculus **is** higher-level math. Mathematics and humanities students were excited to discover whole new worlds of mathematics. Repeatedly, they prefaced their revelations with, "I used to think of math as cut and dried, but now...." One reported enthusiastically, "We just leapt ahead, and talked about things like the transfinite numbers, and the set theory things that I had never really heard about before." Students who came to these courses weary of a subject valued more for its challenge than for its content found their interest resuscitated. As another remarked, "This course renewed my passion for math." For another, the interdisciplinary course changed her perception of math "from black-and-white to color." Still another student concluded, "I think the reason a lot of people shy away from math or science is because it's not a tangible subject that you can relate to different aspects of your life. Which [these courses show] is very false."

Different pedagogical approaches increase student confidence. Hands-on exercises were common: students kept star journals, composed music, wrote stories, created art. These alternate entries to mathematics offered students who had not succeeded in conventional courses a second chance. "The great thing about [this] course was that it did give me confidence about math again. I learned that it's always connected and that I can do it, that I can succeed in math." Student comfort rose when faculty members functioned as a clever but inexpert "model students" because, as one student explained, "you don't feel like you're just working with an expert." Perhaps most important, the interdisciplinary dialogue between professors included students in genuine scholarly discourse. This student related, "The two of them challenged each other, which was really nice, and they weren't afraid to contradict each other, or to add things to each other's lectures, or to cut one another off. They weren't inhibited by formality. The collaborative environment they tried to foster with the students was really nice. It felt more like a partnership than 'we'll tell you stuff and you learn it.'"

The interdisciplinary approach brings an exciting new perspective. In discovering the intersection between two subjects, students developed stronger analytic abilities and achieved a broader perspective. Consider these responses to the question, "Please tell me something you learned in the course."

"...to see the world through a more mathematical eye, take a second look at the world."

"...to look at things from two different angles, and see how different aspects of a subject can fit into another subject that you would never relate before."

"...how to think more broadly, and look at things in a less than mainstream way, kind of off the beaten path, and just take a different approach to ordinary things."

"...the interdisciplinary approach—just knowing how to integrate material that doesn't necessarily at the beginning seem like it would fit together. And learning that when someone says, 'Can you do these two things?' and you say, 'No' you probably can. You just need to figure out how. "

Designing and Teaching Interdisciplinary Courses

A genuinely interdisciplinary perspective, essential to the success of these courses, is realized only as an emergent attribute of conflating their separate parts. The ordinary metaphor for interdisciplinarity, that of bridging different domains, fails to convey adequately their property of intersection. Perhaps Piaget's (or Whitehead's) concept of a hierarchical structure in which higher levels subsume and "explain" lower levels evokes a more appropriate image. Thus, if to link in an interdisciplinary way is to achieve a level of abstraction unifying both disciplinary perspectives, the challenge to co-instructors grounded in distinctively-framed worldviews can be considerable. So fundamental a shift holds a number of direct implications for teaching in such courses. Correlating student results with faculty teaching methods documented in pre- and post-course faculty interviews, observations of planning sessions and in classroom presentation provides guidelines for designing and teaching successful interdisciplinary mathematics courses.

Think differently. Making the interdisciplinary connection the armature of the course (instead of an epiphenomenon) requires approaching one's own discipline differently. Course planning needs to begin by establishing a productive point of intersection (like the concept of time, or pattern) and then choosing material—typically not standard introductory topics—to elucidate it. Interdisciplinary teaching is not an exercise in parallel play: teams who proceeded by coordinating existing topics or lectures had notably less positive student outcomes than those who began afresh. Needless to say, this is a lot of work. As one math collaborator remarked, "I think that doing this was much more work than doing two [regular courses]." (He went on to add that he would happily do it again!) For math professors, the time required to grade written work was also a revelation. The first time around, most instructors felt that they had underestimated the time required to do a job they deemed satisfactory.

Think deeply. Successful course developers exposed disciplinary linguistic and epistemological differences during the planning process, defining more sharply for themselves the contours of the relationship between the two disciplines. For a mathematician, it happened this way: "What we realized in talking to one another is that each of us has our own language that we think is English—and it's not English. It's jargon. And so we find ourselves having to explain to one another things that we each take for granted, and don't even realize we take for granted." Faculty pairs who did not tackle epistemological issues head-on were less able to negotiate the intermediate territory. As one student remarked, "The two [disciplines] just never came together. They were coherent, but they were coherent as separate entities."

Talk about pedagogy. This should emerge naturally from deep thinking (above), since different ways of knowing imply different ways of learning. Bringing pedagogical issues out into the open not only clarifies epistemological differences, it anticipates potential moments of classroom awkwardness, helping to smooth the transition from the intimacy of teaching alone to the exposure of teaching collaboratively. Trust between collaborators is critical—one described it as "like a marriage"—and it's easier to achieve if potentially divisive issues are aired and resolved in the planning stage. Whether collaborators knew one another beforehand was less important to smooth functioning than the openness of pre-course discussions.

Be committed. Faculty need to acquire the same level of knowledge in the other discipline that they expect of their students. Not only does this generate more productive and informed interdisciplinary discussions, it's a matter of voting with your feet. What message do we send to students about the value of interdisciplinary learning if we're not willing to do any ourselves? (When acting as the model student, you don't want to be the one who didn't do the homework!) As students note in interviews, "If we can learn it in ten weeks, why can't they?"

Be transparent. Like teachers, students have a clear idea of how a course should proceed. Interdisciplinary courses break many of the rules, and they can leave students bewildered about their direction and purpose. Sharing the goals of the course and the strategies you'll use to achieve them is not cheating; it reassures students and makes them partners in the enterprise. Modeling interdisciplinary thinking in the classroom—and identifying it as such—is important for introducing students to the analytic practice of finding patterns and connections where they are not obvious. Then be sure students are required in their homework to make connections on their own.

Be sparing. Don't overload the syllabus. This is a temptation in any new course, doubly so when two disciplines are involved. Much of the work of interdisciplinary courses takes place in the conceptual space between the two, so it's especially important to resist the impulse toward all-inclusiveness.

Teach math. Despite the range of student abilities and backgrounds represented, almost every student wanted to learn mathematics. Few who feared math were there to avoid it; most were there to surmount their fear. Courses that failed to challenge students, presenting math that was too easy or stressing the humanities portion at the expense of the math, left even math-phobes unsatisfied—and confirmed their conviction that real math must, after all, be too much for them.

For Faculty: "A great experience"

Despite the hard work, faculty uniformly and enthusiastically endorsed these courses.[5] The most common first response was that they were "fun." It was "fun" to work with students they would not usually encounter and "gratifying" to see them truly engaged. "They were very excited; we could see the light bulbs going on." Talking about pedagogy and learning from one another's teaching was "very exhilarating" for novice and experienced faculty. Most important, faculty found deep personal satisfaction in the opportunity to be scholars together, exploring new fields and acquiring a fresh perspective on their own. Working with colleagues in other fields was "stimulating intellectually," "very exciting," "humbling in a very good sense." As one summarized, "In present academia everyone rushes around and there's little time to talk about what one is doing. Here a very interesting dialogue is going on, and I liked that enormously."

At this point it is well to recall that these results were achieved under the most favorable conditions. Nobody was drafted for this job; faculty members who developed interdisciplinary courses had a desire to do so. Because these courses were created as part of a well-funded project, faculty was given the equivalent of one course in free time to develop them. Their enthusiasm undoubtedly reflects pleasure at simply being given adequate time to accomplish what they set out to do, as well as satisfaction with the experience itself. Like any enterprise, courses like these are likely to be more successful when faculty has the resources they need to develop and teach them.

The Dartmouth experiment suggests that interdisciplinary mathematics courses are worth the investment. They can fill a gap in the curriculum, offering a fresh start for the mathematically timid and a lagniappe, a bonus of unexpected applications and insights, for mathematically

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[5] Only one member of one team did not value the experience highly.

adventurous students. But students are not the only beneficiaries. As they explored new material with new colleagues and many new students, faculty found the intellectual and pedagogical challenges of these courses immensely rewarding.

REFERENCES

-Austin, A. A., Baldwin, R. G., 1991, *Faculty Collaboration: Enhancing the Quality of Scholarship and Teaching,* ASHE-ERIC Higher Education Report No. 7. Washington, D.C.: The George Washington School of Education and Human Development.

-Bransford, J. D., Brown, A. L., Cocking, R. R. (eds.) 2000, *How People Learn: Brain, Mind, Experience, and School,* Washington, D.C.: National Academy Press.

-Davis, J. R., 1995, *Interdisciplinary Courses and Team Teaching,* Phoenix, AZ: American Council on Education and The Oryx Press.

-Ganter, S. L., Kinder, J. S. (eds.), 2000, "Targeting institutional change: quality undergraduate science education for all students" (Conference Executive Summary), *Targeting Curricular Change: Reform in Undergraduate Education in Science, Math, Engineering, and Technology,* pp. 1-17, Washington, D.C.: American Association of Higher Education.

-Klein, J. T., 1998, "The discourse of interdisciplinarity", *Liberal Education* **84** , vol. 3, 4 - 11.

-LaRochelle, M., Bednarz , N. Garrison, J. (eds.), 1998, *Constructivism and Education,* Cambridge: University Press.

-National Science Foundation, 1996, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology,* (NSF96-139). Arlington, VA: NSF.

-Newell, W. H., 1994, "Designing interdisciplinary courses", in *Interdisciplinary Studies Today,* J. Klein, W. Doty (eds.), San Francisco: Jossey-Bass Publishers, pp. 35-51.

-Phillips, D. C. (ed.), 2000, "Editor's preface", *Constructivism in Education: Opinions and Second Opinions on Controversial Issues,* Ninety-ninth Yearbook of the National Society for the Study of Education, Chicago: University of Chicago Press, pp. vii-ix.

-Rhodes, Frank H. T., 2001, *The Creation of the Future,* Ithaca and London: Cornell University Press.