Title: Case Studies Add Value to a Diverse Teaching Portfolio in Science Courses
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Let's get down to business

It's the summer of 2000 and Jack is a few years away from retirement. Over the past decade, he had watched his savings balloon as a result of surging stock prices. Caught up in the "irrational exuberance" of the times, Jack decided that stocks couldn't lose, and he invested his entire nest egg of 40 years in the stock of an especially hot prospect-Enron Corporation. After all, the sky was the limit for this company (Figure 1).

At the office, Jack daydreamed about yachts and a condo in the tropics. His evenings were spent with the "talking heads" of cable television finance. These self-styled analysts had become Jack's mentors, and he agreed that going with the flow of 1990s conventional wisdom made sense: "Enron has been on fire for the past five years. Going with what's worked in the past probably will work in the future." "Yeah, why worry about other forms of investment? Enron is HOT, HOT, HOT!"

We all know the ending of this story. Our free-riding investor, along with thousands of others who were invested heavily in Enron stock, saw their retirement savings evaporate during 2001 (Figure 2).

Are science courses, like TV, pushing Enron stock?

The pundits offered Jack a single investment strategy, and it failed him. It's worth considering whether our courses offer students a better outcome. Like an investment portfolio, a teaching portfolio can also be extremely narrow and fail to meet our learning and teaching objectives.

Imagine that teaching and learning styles are like asset classes in a retirement package. We could consider a "knowledge content" category (like stocks) that includes lectures, knowledge gained from labs, in-class discussions and debates, and textbook and primary literature readings. How about a "process skills" category (like bonds) that emphasizes analytical lab skills and the scientific method (asking questions, posing hypotheses, designing and conducting experiments, analyzing and interpreting data, and presenting results), writing in ways that are scientifically meaningful (proposals or manuscripts), quantitative reasoning, critical analysis, collaborating in teams, and oral presentation? We could imagine a third category called "context" (like real estate) that includes field trips, visualization, interdisciplinary thinking, and the way that the progression of course themes tells an overall story. Finally, we recognize a fourth category called "application skills" (like bank savings or money markets), including real-world problem solving, interdisciplinary thinking (again), appreciating how science is really done, understanding the kinds of issues that scientists face, and appreciating how the course matters to students' daily lives and how they could use information and skills to make the world a better place.

Pick up any financial planning book these days and you are likely to come across a concept called asset allocation, which is the practice of distributing dollars across investments both within and among asset classes. Enron Corporation is a nice example of why asset allocation is considered beneficial. Rather than putting all his retirement eggs in one basket, Jack could have purchased the stocks of several different companies. Chances are that one or more of them would have done well while Enron's stock price was heading south, ensuring that Jack's investment experience was not an entirely unpleasant one. Owning more than one stock is only a first cut at diversification, however. Although it does minimize financial risk caused by the failure of a single company, it still exposes Jack to the risks inherent with the stock market, including recessions or depressions when most stocks usually tank. Jack might have been wiser to diversify across asset classes. He could have mixed stocks and bonds, for instance. Better still, he could have added some real estate or money markets to the mix and been fully diversified across four key asset classes.

Why is asset allocation successful as an investment strategy and, I will argue, as a teaching strategy? Asset classes complement one another, such that if one happens to be declining (e.g., stocks), other asset classes (e.g., bonds or real estate) may be rising in value, buoying the entire portfolio and saving it from catastrophe. The U.S. recession from 2000-2003 was a perfect illustration of this point: over this three-year period, U.S. stock values dropped an average of 37% (based on the Dow Jones Wilshire 5000 Index), while real estate and bond values soared (+47% and +33%, respectively, based on the MSCI US REIT and Lehman Aggregate Bond Indices). Investors with equal mixes of stocks, bonds, and real estate would have not only weathered the storm, their portfolios would have increased in value over this period. Similarly, a diverse teaching portfolio has a higher probability of raising overall student learning by successfully engaging students with different learning styles compared to a single approach, such as lecture-only formats (Felder 1993; Felder and Brent 1996).

Designing a course for a group of students with diverse learning styles is similar to selling investment advice. Are we brokerage firms pitching students Enron stock, or do we give them a full range of investment opportunities? It makes good sense that we should meet the diversity of learning styles in our classrooms with a diversity of teaching styles so that we engage all students. But there's more to it than this; indeed, student engagement should be the starting point for any course. Teaching with a diverse portfolio benefits students because it's the real deal. It exposes students to the full range of learning, skills, and problems that scientists face (Allard and Barman 1994). It makes our students' scientific experience genuine and more rigorous. Simply put, it helps them make the transition from science students to scientists.

When I first started teaching as a graduate student, my teaching portfolio was fashioned largely by the same rationale that shaped Jack's investment strategy. As a new teacher, I defaulted to what I knew best from 10 years of training at large undergraduate and graduate universities: lectures and labs. Like Jack, new teachers often reason that going with what's worked in the past (i.e., how they were taught) probably will work in the future. Without much training devoted to the art of teaching and learning, young teachers suspect that there's no need to be distracted by other styles if this one seems to work fine. After all, it worked for us academics, right?

In the beginning, you could say that my lecture and lab teaching asset allocation was similar to a basic 50/50% split between stocks and bonds. However, because many of my lab experiences were of the cookbook variety (i.e., noninquiry or independent investigation based), I'd argue that they were more like lectures (knowledge and content) than hands-on research experiences (process and application), so it's probably more appropriate to characterize my starter teaching portfolio as 100% stock. Think about what that means: I was the teaching equivalent of cable TV pundits pushing Enron stock.

After completing many excellent teaching workshops during the latter years of graduate school, including Preparing Future Faculty (PFF) and the Case Studies in Science workshop at the University at Buffalo, and having taught at Carleton College for seven years, I have shifted from teaching like cable TV pundits to teaching like an investment firm that offers a full range of options to my customers. I have found that case studies, specifically, offer me a powerful diversification tool that allows me to teach across all of the learning styles that matter to me and my students: content knowledge, process skills, context, and application skills. When used in combination with lectures, case studies help me reach many more learning styles and objectives than I can with lectures alone. In some instances, case studies can provide students with the kinds of skills they typically master in labs, thus offering instructors the possibility of turning nonlab classes into more robust scientific experiences. And they make the learning experience real, empowering students to want to become scientists and giving them the practical experience to do so.

Below, I describe how I use case studies in two of my upper-level (sophomore and senior) science courses with labs at Carleton College: ecosystem ecology and plant physiological ecology. I chose these courses because I use the same type of interrupted journal case method in both courses (Herreid 1994; Camill 2000), I have four years of survey data and independent analysis for them, and I use a similar field lab component in both courses, which makes it easier to pool them in the analysis below.

Case studies and learning styles

I structure my ecology courses to provide students with a deep learning experience in the four core learning categories previously mentioned: content, process, context, and application. Each 10-week course is comprised of seven to eight units focusing on major themes in the discipline. Each unit consists of three to four days of lecture to introduce and clarify fundamental concepts. When appropriate, I often use an in-class field trip to the Carleton Arboretum on the first day of a unit so that students have a conceptual image of the concepts they will be learning over the next few days. For example, we may visit a forest to experience trees, leaf litter, and soil carbon before examining terrestrial carbon cycling more abstractly on a chalkboard or from a textbook. The subsequent two to three days of lecture provide students with both content and context. Thus, students visualize the ecosystem in the field before learning about it, gather information about key concepts through lectures and readings, and get a storyline from me that unfolds each unit at an appropriate pace and ties it into the overall progression of course themes. Not a bad start, but we still need to find a way to include the other key learning goals-process and application skills.

In my courses, students gain process and application skills, in addition to more content and context, through case studies and inquiry-based labs. Case studies come at the end of each unit (days four and five) and serve as a capstone experience to show students why the concepts they just learned are critical for understanding contemporary ecological and environmental issues (Table 1).

Table 1

Case studies developed from primary literature for each course.

Ecosystem ecology

Plant physiological ecology

How does acid rain affect soils and ecosystems?

What is the effect of rising CO2 on C uptake?

Using whole-watershed experiments to study the impact of clear-cutting on ecosystem function.

What controls tree lines?

How do species and functional diversity affect ecosystem function?

Competition: A battle to the death for prairie species.

When is wet land a wetland? Validating wetland delineation techniques using measures of wetland ecosystem function.

Succession and shade tolerance.

Can exotic species alter lake trophic dynamics and ecosystem function?

Interactions between C allocation, water, and nutrients during climate change.

Understanding historical changes in ecosystem function: A case study of eutrophication in Chesapeake Bay.

A look at rising atmospheric CO2 and the potential for carbon sinks.

The interrupted journal case method I use is described in detail elsewhere (Herreid 1994; Camill 2000), but I provide a brief synopsis here to illustrate how the kinds of learning involved help fulfill my course goals. Each case opens with students reading an introductory paragraph drawn from the research article to set the context for the issue. For example, in ecosystem ecology, the acid rain case study begins with a discussion by ecologists observing that acid rain continues to be a problem to forest ecosystems despite legislation in the 1990s that sharply reduced the kinds of air pollution that cause acid rain. This is puzzling at first, and it provides an interesting opportunity for students to apply what they learned from the field trip and lectures in the unit called "Geochemical Properties of Soils." After reading the introduction, students are asked to work in teams to pose a research question that addresses the issues raised by the ecologists. They are also asked to state explicit, testable hypotheses and to design field experiments to test them. After a lively discussion about their ideas, including the pros and cons of different experimental methods, students are provided with a set of blank figures from the study (i.e., figures with labeled x- and y-axes but no data) and asked to predict what they expect the data to look like based on their hypotheses. I then provide students with actual data from the study, and we discuss the main trends and how they differed from students' preconceptions. Finally, students are asked to weigh in on the issue based on the evidence from the case study. If they were called to testify before Congress as ecological experts, what would they have to say?

I find this method of case study to be terrific because, in a single in-class activity, students learn content, process skills, context, and application skills. Using a single journal article as the focus of a case study, students are able to practice the scientific method: from issue identification to question formulation, hypothesis testing, experimental design, and data analysis and interpretation. They see how scientists grapple with tough issues and interpret "messy" data that often contain significant statistical uncertainty. And they are able to make value judgments based on the evidence, just like we do in the real world.

The assignment I use for this kind of case study takes process learning one step further to help students develop the craft of scientific writing. Over the term, students are asked to pick one of the seven to eight case studies and to write a manuscript in the style of a journal article based on the analysis they completed. I copyedit manuscripts based on the same criteria I use to review articles for publication (organization, clarity, sophistication of argument, grammar, and style). Importantly, I give students the opportunity to revise and resubmit the manuscript as many times as they wish, and the final manuscript receives the final grade. In the past, I encouraged student groups to submit a joint manuscript for all seven to eight case studies, but because of the challenge in determining individual improvement and the overall work load, I have more recently moved to individual assignments where each student completes a manuscript for a single case study. As part of the case study assessment below, I present information on writing improvement for both approaches. For the analysis of group manuscripts, I developed a rubric for analyzing writing based on Carleton College's Writing Portfolio program. I analyze a group's writing using its first and final case study assignments to assess writing improvement over the course of the term. For the analysis of individual manuscripts, I simply compare mean scores from first, second, and final drafts.

In addition to case studies, I also use inquiry-based laboratory investigations to turn the concepts from lectures and case studies into hands-on research experiences. I use the first six lab sessions to develop a toolbox of advanced skills. Weekly laboratory experiences allow students to test hypotheses using the same sophisticated analytical techniques examined in the case studies. My goal is to help students become proficient in three skills useful to beginning graduate students: (1) learning analytical skills needed to use modern equipment; (2) conducting a pilot study to become comfortable applying these skills in the context of scientific questions; and (3) designing and executing an independent research project, including a research proposal (in the style of a short NSF grant proposal) to investigate a problem of their own choosing. We convene an in-class, NSF-style panel as part of a peer review process where students experience critiquing one another's proposals. They carry out the research and disseminate the results in the format of a journal article and an oral presentation.

Teaching portfolio performance and case studies

Taken as a whole, these activities help me create a diverse teaching portfolio that spans the four teaching/learning-style categories (content, process, context, and application). I present specific learning objectives to students in the syllabus at the beginning of the term (Table 2), and I evaluate whether or not the course has helped students to meet them using course evaluations. Tables 2-4 show the student evaluation questions I use to assess learning goals, teaching methods, and overall course satisfaction, each broken down by teaching/learning-style category.

Table 2

Learning goals and associated teaching/learning-style categories assessed in end-of-course student evaluations (ranked by mean score).

The number of student responses, mean survey score, and significance are also shown.

Learning goal	Teaching / learning-style category	Number of responses	Score*	Significance
Understanding key principles and themes in this course	content	92	1.326 (0.062)	a
Understanding the scientific basis of human alterations to global ecosystems	content	66	1.424 (0.068)	a
Ability to synthesize fine-scale ecological processes to examine the "big picture" of global ecosystem functioning	content	92	1.446 (0.068)	a
Understanding of the kinds of issues that professional ecologists face and the ways that they address these issues	application			

91

1.527 (0.067)

ab

Appreciation for the relevance of ecological issues to your personal life and how to apply biological concepts to real-world issues

application

76

1.553 (0.076)

abc

Analytical skills gained from laboratory methods

process

90

1.667 (0.082)

abcd

Ability to formulate questions and hypotheses, to design field experiments, to make predictions, and to analyze data

process

91

1.835 (0.074)

bcde

Ability to understand how science is a process of learning and to understand how researchers use this process

process

92

1.880 (0.067)

cdef

Ability to write a scientific paper in the format of a journal article: intro/methods/results/discussion

process

81

2.000 (0.091)

def

Ability to write a research proposal (e.g., for a grant)

process

75

2.027 (0.099)

def

Field/lab skills such as experimental design and proper methods of replication

process

74

2.027 (0.100)

def

A practical sense of how the scientific process operates, from research proposal to data collection to analysis to writing to presentation

process

92

2.076 (0.089)

def

Ability to communicate effectively to others through the use of oral presentations, writing, and group collaborations process

process

91

2.088 (0.073)

ef

Higher-order thinking skills, such as the ability to reason logically, to be creative, to critically evaluate information, and to think inductively

process

92

2.207 (0.077)

f

*Mean value of survey response ([+ or -] 1 standard error in parenthesis). Students self-evaluated their learning improvement in each of these areas according to the following 7-point scale: (1) significantly improved, (2) improved, (3) somewhat improved, (4) neutral, (5) somewhat hindered, (6) hindered, (7) significantly hindered.

Significance between goals was determined using one-way ANOVA with post-hoc comparisons (Games-Howell modification of Tukey HSD test, which assumes unequal variance between goals). Goals denoted by different letters are significantly different at the a = 0.05 level.

Several patterns emerge from these evaluations and from my independent assessment of student writing (Tables 2-5). First, mean scores for assessment of learning goals were between one and two, indicating that most students reported "improvement" to "significant improvement" in their learning (Table 2). Similarly, mean scores for teaching methods and overall course satisfaction ranged between one and two (Tables 3-4).

Table 3

Methods of teaching and associated teaching/learning-style categories assessed in end-of-course student evaluations (ranked by mean score).

The number of student responses, mean survey score, and significance are also shown.

Question

Teaching / learning-style category

Number of responses

Score*

Significance

Having more than one style of teaching (lectures, case studies, in-class field trips, and visual information) was more effective for my learning than traditional lecture-only formats.

context

60

1.217 (0.059)

a

The combination used in this course of lectures, visual PowerPoint images, in-class field trips, case studies, online readings, and field-based labs was effective for my learning.

context

59

1.271 (0.063)

ab

The progression of course themes was effective.

context

92

1.446 (0.061)

abc

There are more opportunities for students to think critically in class compared to traditional lecture formats.

process

92

1.576 (0.086)

bc

The case studies helped me apply what I knew about ecology to real-world issues. application

application <TD vAlign=center borderColor=#dff9ff align=mid

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