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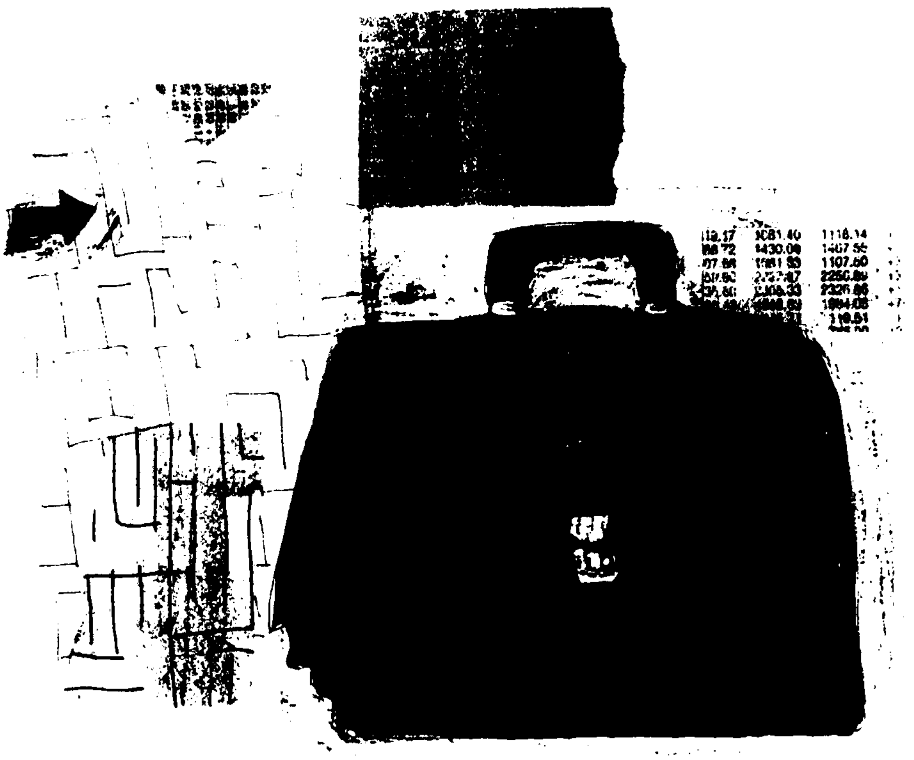
By Philip Camill



Together with lectures and labs, case studies assist students in acquiring content knowledge, process skills, and an understanding of the context and application of science to their daily lives. Cases make the process of scientific learning more genuine and rigorous, bringing alive classroom learning and helping students apply concepts to understand contemporary societal challenges.

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 dol-

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lars 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

FIGURE 1

Price per share of Enron Corporation stock January 1984–August 2000.

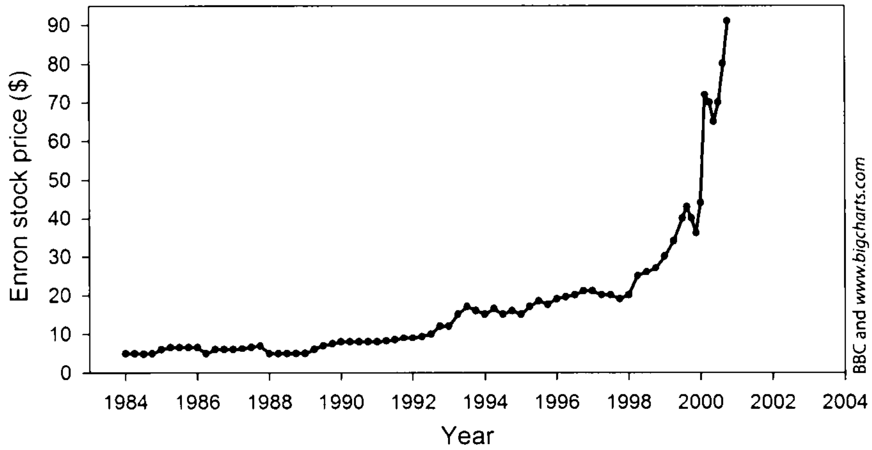
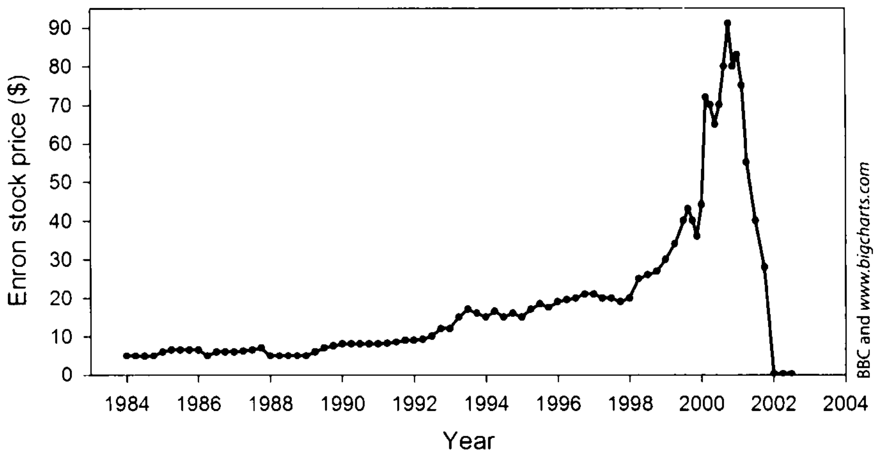


FIGURE 2

Price per share of Enron Corporation stock January 1984–June 2002.



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

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 CO_2 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 CO_2 and the potential for carbon sinks.	

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	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 (± 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 $\alpha = 0.05$ level.

between stocks and bonds. However, because many of my lab experiences were of the cookbook variety (i.e., non-inquiry 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

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	91	1.758 (0.083)	cd
Lab techniques and instruments helped me better understand [ecosystem ecology or plant physiological ecology].	content/process	62	2.016 (0.104)	d
Working in case teams was an effective way to learn.	process	91	2.077 (0.113)	d
I learned more from working with other students than I would have by myself.	process	90	2.133 (0.117)	d
I felt that the opportunity to teach others in my group was effective for my learning.	process	75	2.147 (0.107)	d

*Mean value of survey response (± 1 standard error in parenthesis). Students self-evaluated their learning improvement in each of these areas according to the following 7-point scale: (1) strongly agree, (2) agree, (3) agree somewhat, (4) neutral, (5) somewhat disagree, (6) disagree, (7) strongly disagree.

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

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).

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

TABLE 4

Levels of overall student satisfaction 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†
I would recommend this class to other students.	NA	90	1.222 (0.052)	a
I have enjoyed learning about [ecosystem ecology or plant physiological ecology].	context	90	1.267 (0.054)	ab
#Overall, I felt the instructor was...	NA	75	1.293 (0.059)	ab
I found this course to be relevant to my life.	context, application	90	1.467 (0.069)	b
#Overall, I felt the class was...	NA	74	1.500 (0.070)	b

*Mean value of survey response (± 1 standard error in parenthesis). Students self-evaluated their learning improvement in each of these areas according to the following 7-point scale: (1) strongly agree, (2) agree, (3) agree somewhat, (4) neutral, (5) somewhat disagree, (6) disagree, (7) strongly disagree.

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

#For these questions, student assessment was based on the following 7-point scale: (1) exceptional, (2) excellent, (3) good, (4) average, (5) mediocre, (6) below average, (7) poor.

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.

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).

Interestingly, when the learning goal scores are ranked from most improvement (lowest score) to least improvement (highest score), students reported greatest improvement in content knowledge, followed by application skills, then by process skills (Table 2). One way to interpret this pattern is that students gain most from the parts of these courses that are unique from other science courses at Carleton. Specifically, these two courses provide the greatest exposure to ecosystems and plant physiology at Carleton, so it makes sense that student improvement in content knowledge in these fields will be large if they haven't been exposed to this material before in other courses. Another interpretation is that students value lectures, readings, and discussions for their learning (Carleton students, in general, like engaging stories). A third

TABLE 5

Assessment of writing skills improvement from the case study manuscript assignment.

Method of assessment	Score first assignment*	Score second assignment*	Score final assignment*	Significance of improvement°
(A) Using a writing analysis rubric to assess features present in writing[†]				
Attention to audience and purpose	1.93 (0.07)		3 (0)	$p < 0.0001$
Clarity of prose	1.40 (0.13)		2.67 (0.13)	$p < 0.0001$
Clear organization	1.20 (0.11)		2.60 (0.13)	$p < 0.0001$
Effective use of evidence	1.13 (0.09)		2.67 (0.13)	$p < 0.0001$
Distinctive voice	2.00 (0)		2.87 (0.09)	$p < 0.0001$
Appropriate diction	1.33 (0.13)		2.47 (0.13)	$p < 0.0001$
Control of error	1.33 (0.13)		2.4 (0.13)	$p < 0.0001$
(B) Using manuscript draft grades#	50.6 (3.65)	81.8 (2.08)	95.4 (0.68)	$p < 0.0001$, $p < 0.0001$

*For analysis A, values represent mean value of scoring rubric (± 1 standard error in parenthesis). The following scale was used to assess the seven writing features listed: (1) rarely, (2) usually, (3) consistently. For analysis B, values represent mean assignment grades (± 1 standard error in parenthesis).

°*p* values reported for t-tests comparing mean scores between drafts (assuming unequal variance).

[†]Based on 15 randomly selected groups from ecosystem ecology and plant physiological ecology fall and spring 2001.

#Based on 25 students for the fall 2005 ecosystem ecology course.

interpretation is that case studies allow students to dive into a specific issue and to explore it fully at the level of primary literature. Application skills ranked next highest, indicating that students gained significantly from learning how scientists deal with ecological issues (mean = 1.527) and from learning how relevant these issues are to their daily lives (mean = 1.553). Case studies are the primary vehicle I use to help students apply theory to real-world issues. Finally, students reported less improvement for process skills, which they may have acquired to some extent in other science courses at Carleton (scientific method, writing, higher-order thinking, group collaboration, and oral presentation) (mean score range = 1.667–2.207).

When teaching method questions are ranked by score, context was valued highly, whereas process was valued less highly (Table 3). Diversity of teaching methods, in particular, was singled out as a favorite of students who overwhelmingly agreed that having more than one style of teaching (lectures, case studies, in-class field trips, and visual information) was more effective for learning than traditional lecture-only formats (mean = 1.217). They also agreed strongly that the specific combination of lectures, visual PowerPoint images, in-class field trips, case studies, online readings, and field-based labs was effective for learning (mean = 1.271). Moreover, the majority of students agreed that there were more opportunities for students to think critically in class compared to traditional lecture-only formats (mean = 1.576). Students agreed that case studies were a valuable way to help them apply ecological theory to real-world environmental challenges (mean = 1.758). Although most students agreed that working in teams was an effective way to learn (mean = 2.077), they learned more in groups than by themselves (mean = 2.133), and teaching others in groups was effective for their learning (mean = 2.147), team learning generally ranked lowest. Taken as a whole, these data indicate that students thrive when engaged with a diverse teaching portfolio that includes case studies, rather than the Enron stock model of lecture-only formats.

In terms of overall satisfaction (Table 4), students felt strongly that they enjoyed learning about these particular fields of ecology (mean = 1.267) and that these courses were relevant to their daily life (mean = 1.467). Again, these results highlight a role that case studies can play in the success of a diverse teaching portfolio.

So how did student writing improve as a result of the case study assignments? Although students reported modest improvement in writing on the evaluation (mean = 2.000, Table 2), I believe that their improvement was more substantial than they recognize. Students might have had previous experience writing lab reports, but these two ecology courses were a new opportunity for many students to craft a rigorously analyzed scientific manuscript based on their own analyses. Regardless of the method used to independently assess writing improvement, I found substantial improvement in scientific writing skill after completing the case study manuscript assignment (Table 5). Just examining the mean scores (out of 100%) for 25 individual manuscripts over the course of first drafts (mean = 50.6%), second drafts (mean = 81.8%), and final drafts (mean = 95.4%), it's easy to see both the need for this kind of assignment and students' capacity for improvement. When grading and copyediting these manuscripts, I challenged students with the same degree of scrutiny that I use with the professionally refereed journal manuscripts of my research colleagues. A mean score of 50.6% indicates that the initial work of Carleton upperclassmen isn't comparable to the quality of professional work, *but they are capable of rising to that level* if given instruction on how to do so, a lot of encouragement, and several chances for improvement. Demanding writing assignments associated with case studies and inquiry-based labs are helpful for accomplishing this objective.

Final thoughts

Case studies offer a valuable tool for diversifying the ways that science courses are taught. Students find that cases are an interesting way to examine contemporary issues, and instructors will find them helpful for accomplishing several learning skills at once. Best of all, they are fun to teach because they make the classroom come alive. Just like a balanced retirement portfolio, a balanced teaching portfolio will likely show strong returns and low volatility in student learning over the years. I recommend structuring courses with an appropriate balance of lectures, case studies, labs, and short in-class field trips (when possible). What an "appropriate balance" translates to will be determined foremost by your comfort level and secondarily by the academic culture of your students and institution (many Carleton students would revolt if lectures were eliminated entirely from a course). For me, a 10-week quarter in an upper-level lab course breaks down comfortably to 4–6 in-class field trips, 18 lectures, 6–7 case studies, and 10 afternoon labs (one per week). If you are new to case studies and are interested in incorporating them into your courses, start off with a number that's comfortable to you (maybe a few per term) until the approach becomes second nature. And, remember, a little portfolio rebalancing every once and awhile never hurts.

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