

The Leap from Lecture: A Case-Based Approach to Introductory Biology

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Introductory Biology 152 at the UW Madison recently began an entirely case-based approach to teaching plant physiology, ecology, and evolution. Undergraduates work through a series of six cases, each comprised of a specific biological scenario addressing one or more of the three course topics. Students address these cases by conducting in depth research using primary literature and online resources. Ultimately, each student submits a written solution, assessed by their Teaching Assistant (TA). TAs undergo substantive grading calibration at the conclusion of each case. Preliminary analysis suggests that this approach is highly successful at improving students' science writing and critical reasoning skills. Student responses have been largely positive, and, when critical, useful in the further development of our model. This paper provides an overview of this innovative approach to biology education.

Keywords: case-based learning, scientific communication, introductory biology

Introduction

Course Context and Background

Four years ago, our large Introductory Biology course converted one of its three lecture sections to a completely case-based format. In cohorts of 24, students work through six biological cases that cumulatively cover core concepts in evolution, ecology, and plant physiology. Students compose individually written solutions to each case and receive feedback on their writing and their conceptual understanding. Faculty meet with students once per case to promote higher level thinking and more detailed research. All students work with a group to present their findings to one case during the semester and all students complete two take-home midterms that comprise six "mini" cases. These test their ability to apply their research and reasoning skills.

This format has provided many benefits to our course, for students and instructors alike. Foremost among these benefits is the emphasis our approach places on scientific communication. In the case-based portion of the course alone (students also complete several laboratory modules and compose a semester-long independent research paper), each student submits a carefully crafted written solution every two weeks. This consistent practice prevents students from waiting until the very end of term to produce a finished product and inextricably embeds

scientific writing in our curriculum. Such a structure allows us to energetically address the well-recognized need for student practice with research and composition (e.g. Brewer and Smith 2011).

Beyond strengthening students' ability to communicate science in written and oral formats, our course allows students to experience biological content in context. Traditional study practices such as highlighting and rote memorization are not sufficient for mastering either the content base or critical reasoning skills within the discipline of biology. Student-driven, carefully paced methods such as self-testing, self-explanation, and distributed practice are proving much more effective (Dunlosky et al. 2013). By describing specific biological systems in cases that often combine the three broad topics of our course, students are continually forced to evaluate their own understanding and encounter similar material multiple times throughout the semester (rather than studying it once and moving on).

While our ability to evaluate the specific success of this model has so far been limited, preliminary assessments are encouraging. In our first term, we saw the achievement gap between minoritized and non-minoritized students' term papers shrink by half, as compared to students enrolled in the traditional lecture section. Last term, a graduate student coded student case solutions for our final case of the semester, and determined that 95% of

students fully met two of the four learning objectives for the case, and 70% met all four (Lyon 2018). Furthermore, case-study students performed 1.7 – 2.5 pts better (100pt scale) on end of term research presentations and overall laboratory grade compared to students in the lecture sections. We hope to continue to study the specific impacts this model has for our students as we refine our curriculum in future years.

Student Evaluations

Below are a sample of student responses to the Spring 2018 midterm evaluations. We provide both common praise and common concerns, along with our current interpretations of this feedback.

Typical Positive Comments

“Case study sections are great for application of the taught materials. I have learned to research efficiently in the case study section. ... So very effective.”

“Really like the structure of this class. The case based format is much more collaborative and engaging than lecture format.”

“Presenting things as case studies is really useful. It’s much easier to learn.”

“Learning through self-teaching is often quite effective.”

“I enjoy case study because it involves more problem-solving skills than simply remembering the materials.”

“I love the ‘case based’ section of this class. It’s pushing me to write better scientifically and also making me understand more complicated biology topics. Much better than traditional lecture.”

“I think the case studies are an awesome way to let us teach ourselves and discover for ourselves.”

“GREAT! Learning a lot and it’s pretty fun. I don’t dread going to class. ☺”

“Case study is a new method of learning for me. I think that it is effective. It provides real world examples to biological concepts. It requires us to do more research and learn on our own to create a solution.”

“I find this vastly more effective than lectures and memorizing.”

Typical Critical Comments

“Not as effective as if I had taken the lecture. I feel like I am learning a lot about one particular thing within a broad topic but not as much on the broader topic as I would like.”

“I think we could use a little more general biology background that the lectures get. I think it would help with researching the case studies.”

“I haven’t felt like I’m learning a ton of information but it feels good to have learned things and been able to apply them.”

“In general, I feel we learn in depth about specific topics, however I feel like we skip over some concepts.”

“I feel as though a little more guidance is needed.”

“Having a rubric for each case would be very beneficial.”

Evaluation Interpretation

Student dissatisfaction appears to correlate most tightly with student expectations for the course – which suggests that we still have work to do on the front end of the semester to frame our goals and to explain why those goals are what they are. Some expectations are easier to set than others – our goals for student writing, research, and accountability can easily be strengthened. However, since the whole point of these cases is for students to research the solutions themselves, we cannot give them detailed content syllabi or rubrics in advance. In future semesters, we are considering implementing a collaborative rubric building exercise that would ground each case in clear, documented expectations and involve students in setting these expectations. Each case would begin with a blank rubric, which students and TAs would fill in as the case proceeds. The TA could lay out the communication and analysis goals early on in the case. For the content and reasoning portions, students will need to “dig in” to the case a bit before they are able to identify what these might be. By the end of their case work, however, students should be able to summarize the key content, reasoning, and analysis goals for the case. Doing so could preserve students’ open-ended learning experience while solidifying summative expectations before the final product is submitted.

Implementing Case-Based Learning

Instructors interested in adopting this approach may choose to incorporate one case study into an existing curriculum, or, as we did, convert an entire semester’s worth of content. For context, with three instructors (two faculty and a course coordinator) with concurrent duties, we were able to achieve this conversion in 8 months (we began composing cases aligned with course goals in Spring 2014 and implemented a fully case-based version of Introductory Biology 152 in Spring 2015). What follows is not a guide to such a conversion, but can serve as a template for implementing case-based learning at the undergraduate level.

Student Outline

Introduction

Below is an example of a case we often use at the very start of the semester. It is less complex than others, and offers a good introduction to the combination of basic biological reading and specific literature investigations students will need to accomplish during the semester. Following the case you will find a series of Socratic questions that we use to prepare teaching assistants to help individual groups, and which summarize the general approach faculty take when conferencing with students (see Notes for the Instructor for details about these conferences and general case implementation).

Example Case Title: What is Ruining My Father-in-law's Fig Crop?

My father-in-law is spending his retirement in southern California. He loves fresh figs, especially the Calimyrna variety. So, a decade ago, he planted a Calimyrna fig sapling in his front yard. He also planted a caprifig nearby, as, for reasons unknown (to him), its presence was supposed to ensure a bountiful Calimyrna fig crop. His Calimyrna tree has been producing a lot of fruit for the past few years, but most of the figs split and spoil before they fully ripen. Can you identify the likely cause of this problem, as well as a feasible solution?

Overview of Student Research Process

Students start by working with their group to brainstorm a series of questions that need to be answered in order to begin solving this case.

1. What terms will you need to define?
2. Do you suspect any of the factors described in the case impact each other? You will want to frame answerable questions based on these hypotheses.
3. Once you have brainstormed questions, put them in a general series – which ones will you need to answer first? Then begin to use your resources to answer them.

As the group works toward a solution, they must consider the following.

1. How will you organize your information so that it is accessible to all group members?
2. How will you support one another's understanding?
3. What problems/frustrations do you encounter? How did you address these (if at all)?
4. What was most satisfying about your experience tackling this case study?
5. What questions are you still struggling to answer?

At the end of their research time, Work with your group to create an outline of a written solution for this case.

1. What are the necessary elements?
2. How long do you think it will need to be?

Materials

There are very few physical materials needed to successfully implement a case-based approach to Introductory Biology. We decided to invest in a set of 12 very basic laptops for the classroom in the event that students did not have their own for any reason. Access to a computer lab could substitute. We have also found, at an R1 university, that most students do have their own devices – we could comfortably operate with about 6 laptops instead of a dozen. Beyond this, a subscription to TurnItIn or a similar service has been indispensable for catching novice citation errors and more serious cases of plagiarism.

Perhaps the biggest question in our minds, from a course sustainability perspective, is how to continue to generate new cases (and when to re-use old ones). This past semester, we successfully partnered with an on-campus initiative that provides graduate students training in pedagogy and teaching-and-research (the Delta program, part of the CIRT network). As part of completing her internship for this program, a graduate student constructed a novel case on the evolution of the flu virus, implemented it in all 9 of our case sections, and completed an evaluation of student submissions to determine if her learning goals were met. This cooperative model is promising, and we hope to continue and expand upon it in future.

Notes for the Instructor

Preparing to Teach a Case

Before working with the students, the lead faculty member for a case will introduce the background and learning outcomes to our teaching assistants. Content-wise, we identify both broad topic areas we wish to address (water potential, community ecology, niche differentiation, etc.) and the particular elements of the case. For the example case above, our content goals are for students to:

- describe the symbiosis between fig wasps and fig trees
- describe the life cycle of a fig wasp
- describe the process of pollination and how this is relevant to the case
- present clear reasoning linking the above descriptions to conclude that figs split because of over-pollination

We also identify communication goals to be met. These goals typically increase in number and expectation level as the semester proceeds – for our first case, our primary challenge to students is to write concisely about a complex biological system. By the second or third case, we begin to put more emphasis on the incorporation of published literature and proper citations. By the end of term, we expect their writing to possess a narrative polish that guides readers through each facet of a solution with a

strong sense of overall coherence. With these expectations in mind, TAs help focus their students' efforts in class and target their written feedback on student case submissions.

Life Cycle of a Case

Most cases in Introductory Biology 152 run for two weeks, with students meeting twice a week for 75 minute work sessions. Day 1 the case is introduced and students begin initial research. The focus here is usually on the broad picture: defining key terms, brainstorming questions that need to be answered in order to address the case prompt, and compiling relevant resources. Day 2 students are expected to work with their groups to solidify an initial hypothesis regarding the direction of the case. They will present this hypothesis to the lead instructor who visits Day 3 for the case conference. Instructors typically employ a Socratic discussion style to determine what students have learned so far, clarify misconceptions, and establish expectations for the case write-up. Instructors may also give mini lectures on complex material (how to work with isotopic data to assess trophic interactions, the specifics of C3 vs C4 photosynthesis, etc.); in some cases they provide students with a data set that was not in the initial case prompt. Students spend Day 4 completing any final research or data analysis and refining their case solutions. One group presents their solution on Day 5 and the next case is introduced (Figure 1).

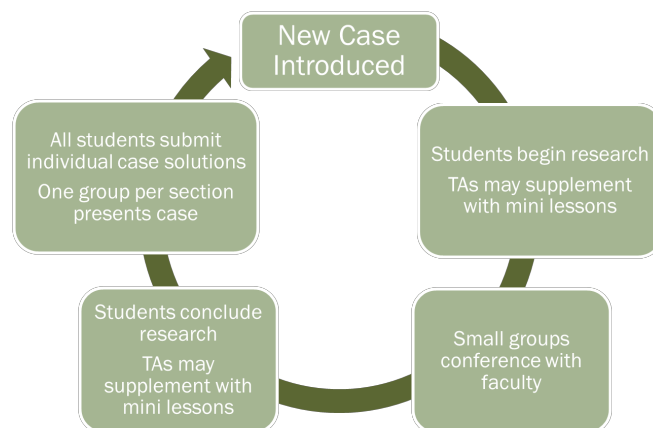


Figure 1. Overview of case implementation.

There are two instructional facilitators in our model – the lead faculty for a given case (this changes case to case) and the case section's teaching assistant (who is always present during case sections and works with the same student cohort throughout the semester). Both focus on asking students questions to help them think through the case. Please see Instructor Notes for a condensed version of the types of questions our TAs and faculty use to structure students' learning experience.

Grading Calibration

When students have all completed their write-ups, we gather as a group and review several samples together. Based on our learning objectives, the particular struggles students faced, and the particular expectations individual TAs set, we agree on a grade range and final criteria for the case as a whole. These sessions allow the TAs to clearly articulate student learning needs and share strategies for addressing them. In other words, our calibration meetings are more than summative assessment, they are part of the living pedagogy of this curricular approach.

Following the calibration meeting, a consensus document is circulated which records the final score and grading rationale for each example solution. Depending on the complexity of the case, the original learning goals, and any emergent learning outcomes, these rationales may take several forms. Three example solutions for the fig case, along with their assessment notes, can be found in Appendix A. While this approach has served us well thus far, we are in the process of developing more robust rubrics in both TA and student modalities to better equip everyone for a successful case experience.

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About the Author

Julie has been a course coordinator with Introductory Biology 151/153-152 for five years. The course is targeted to sophomore level students majoring in the biological sciences.

Appendix A: Example Student Solutions

Below are three solutions submitted by students for the fig case found in the Student Outline. Following each are the meeting notes our TAs generated during grade calibration. Typos and errors in student writing and references have been preserved to give the reader an authentic example of the submissions we receive.

Example Student Solution 1

The fig wasp (*Blastophaga psenes*) and the fig tree (*Ficus carica*) coevolve in a mutualistic relationship. Seeing as the wasp travels between fig trees and burrows into the fig capsules, the wasp acts as a key mode of transportation for fig tree pollen, and the fig itself functions as a protective shell for the wasp queen to lay her eggs (Ware and Compton, 1992). In a given fig, the wasp queen enters the fruit at the ostiole, the apex of the fig, and burrows her way to the core. If the styles within the fig are short enough, the wasp is able to successfully lay her eggs into the female flowers of the fig via her ovipositor (Cruaud et al., 2012). However, if the styles within the fig are long enough, the wasp queen is unable to reach the ovaries of fig and fails to lay her eggs. Meanwhile, as the queen searches about the fig, she deposits the pollen she carried from the fig in which she was born and pollinates the new fig. This pollination process spurs the growth of droplets within the fig; and after a period of time, the syconium of the fig can no longer contain its expanding seeds within and begins to split.

In the current situation, the figs of the calimyrna tree are splitting far too soon. This is most likely due to the over-pollination of the fruits by wasps from the nearby caprifig tree. Due to the short styles in the caprifig, the fig wasps are able to successfully deliver their eggs and thus have a balance of egg laying and flower pollination. However, once the wasps of the caprifig fly to the calimyrna, the styles of the calimyrna are long enough to prevent the laying of the eggs, so the wasp frantically searches about for a place to oviposit and thereby pollinates a large quantity of flowers within the calimyrna fig. This vast over-pollination of the calimyrna fig results in a large quantity of droplets proliferating within the syconium, giving rise to the splitting of the fruit observed.

Since the caprifig's role of acting as source of wasps to pollinate the calimyrna is so crucial to the survival of the calimyrna, a solution to this predicament is not to remove the caprifig tree entirely, but to limit the access of wasps to the calimyrna. This is possible by disposing of a majority of the figs from the caprifig tree and situating the remaining few fruits that contain the fig wasps on the calimyrna tree- this is most easily done by stapling a bag of the Capri figs to the calimyrna tree. This, in turn, allows for a regulated number of wasps to access the calimyrna tree and fulfill their productive role of the mutualistic relationship as well prevent the over-pollination and early onset splitting of the figs.

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Cruaud A, Ronsted N, Chantarasuwan, B, Chou L S, Clement W L, and Couloux, A, et al. 2012. An Extreme Case of Plant-Insect Codiversification: Figs and Fig-Pollinating Wasps. *Systematic Biology*, 61(6), 1029-1047.

Ware A and Compton S. 1992. Breakdown of Pollinator Specificity in an African Fig Tree. *Association for Tropical Biology and Conservation*. 24:544-549.

Meeting Consensus Grade: 85

Content: Some missteps – “seeds” don’t expand, the fruit does. The problem isn’t that one wasp walks around too much in the figs, it’s that too many wasps enter the fig. Doesn’t explain why the caprifig is needed.

Logic: Needs more explicit logic/clearer mechanism when describing the biological system. Needs to draw a clearer connection between the diagnosis and the solution. Needs to establish clearer relationship between the fig trees.

Writing: First and second paragraphs are somewhat redundant. Good citations in first paragraph. Some misspellings.

Example Student Solution 2

Dear Father-in-law,

I am very saddened to hear of your fig problem. The unique flavor of the Calimyrna fig is one that should not go to waste, thus I am here to help your situation. Before we jump into what you should change in your tree setup, allow me to tell you exactly why your figs are splitting and spoiling. To put it simply, the splitting of Calimyrna figs result from over pollination from fig wasps. This happens through the fig wasps reproduction process. When fig wasps reproduce, the female wasps must find a caprifig, which is the fig plant that contains male flowers, and deposits her eggs into the ovary of the flower. For this process to happen successfully, the female wasps must use her ovipositor and insert it into the stigma of the plant and through the style in order to reach the ovary. However, the overpositor is too short to reach the ovary of the caprifig and the female wasps must fly into the ovary herself and lay the eggs there. After this intense process the female wasps then dies inside of the fig. This entire process is what pollinates the Caprifig tree. However that still does not answer the question of why the Calimyrna figs are splitting and spoiling. Well, the process does not end there. The eggs that the female wasps laid then hatch, males first. Once the males hatch they have a goal to fertilize the eggs of the newly born female wasps and they successfully do so. In addition to that, the newborn male wasps also crawl out of the figs and create tunnels that the female wasps can also leave from. The female wasps then embark on a mission to lay there newly fertilized eggs. In order to find a flower to do so in they use their sense of smell. Unfortunately the Calimyrna and Capri fig produce a very similar smell and the wasps cannot decipher between the two, so some wasps end up trying to lay eggs in the Calimyrna which possess the female flower; however, the styles of the Calimyrna are too long for the female wasps to reach the ovary. Thus the female wasps continuously attempts to get the eggs in the correct place of the Calimyrna without success, causing the flower to be pollinated at a higher degree and it eventually becomes over pollinated. Over pollination of the Calimyrna figs causes the drupelets of the fig, which is the fruit of the fig that mainly is made of water, to swell. That swelling leads to excessive pressure build up, and the figs consequently split open, and that split causes the fruit to spoil because it is now exposed to external conditions.

Now what is the best way to solve this problem? Well essentially what needs to happen is that the number of wasps trying to lay eggs in the Calimyrna tree need to be reduced. In order to that the total number of spawning wasps need to be reduced. Thus the Caprifig tree which house those wasps needs to be reduced. So the best solution would be to cull the Caprifig tree each season, so the number of wasps will be reduced; however the cycle of pollination and wasp birth will still continue at a lower level, which will allow the Calimyrna tree to have more figs that are not split and spoiled.

Sincerely,

Your friendly neighborhood fig expert

References

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- Calimyrna Figs - One of the Best Fig Varieties for California. Botanical Journeys Plant Guides. [accessed 2018 Feb 2]. <http://www.botanical-journeys-plant-guides.com/calimyrna-figs.html>

Meeting Consensus Grade: 75

Content: Several substantial inaccuracies (male flowers don't have ovaries, etc.)

Logic: The order in which information is presented is sometimes convoluted, there are many logical gaps (e.g. over pollination does not CAUSE drupelets, pollination does – OVER pollination causes too many drupelets to develop). Feels rambling at times. This improved somewhat toward the end. Solution is correct but doesn't match very well with diagnosis.

Writing: Frequently imprecise (e.g. what do you mean by cull?) and hard to follow. While we appreciate the engagement/creativity, the opening several lines are not necessary. Did not cite internally.

Example Case Solution 3

The relationship between the Blastophaga wasp, the Capri fig tree, and the Calimyrna tree is essential to the production of delicious Calimyrna figs. Within the female flowers of the Caprifig, the female wasp uses her ovipositor to pass her eggs through the short style and into the ovary¹. From here, the male larvae will hatch first, inseminating the female larvae and then burrowing through the syconium of the fig in order to forge a path to the ostiole, from which the mature female wasps can emerge¹. The female pupae will pass through the syconium to the ostiole, picking up pollen from the male flowers along the way. The female emerges from the Caprifig, and travels to the next tree in search of a place to lay her eggs. Whether the tree is a Calimyrna or Capri fig she cannot distinguish -- the two trees emit the same chemical cues. If she enters a Caprifig, she will pollinate the female flowers and oviposit her eggs in their ovaries². If she enters a Calimyrna fig, she will transfer pollen to the female flowers, but be unable to oviposit. The long styles of the Calimyrna flower make it impossible for the wasp's ovipositor to reach the length of the style into the ovary². Frustrated, the wasp continues to try to oviposit her eggs in the ovary, each time failing to do so, but continuing to transfer pollen to the stigma of each flower². The Caprifig trees' close proximity to the Calimyrna trees leads to a large number of female wasps pollinating the Calimyrna figs, resulting in over-pollination and over-fertilization, which produces excessive seed bearing². The excessive number of drupelets increases the water pressure of the syconium causing it to burst, in turn, compromising the syconium by exposing it to the environment and leading to spoilage.

The best solution to preventing over-pollination of the Calimyrna figs is to remove a number of the Caprifigs from the tree. The Caprifigs are a necessary component of the wasps' life cycle, and their removal would sustain the wasps while also eliminating the possibility of over-pollination. Fewer Caprifigs would result in fewer wasps looking to oviposit, which would decrease pollination and result in fewer spoiled Calimyrna figs.

References

- ENN: Environmental News Network -- Know Your Environment. (n.d.). Retrieved February 05, 2018, from https://www.enn.com/top_stories/article/1935
- University of California, Division of Agriculture and Natural Resources. (n.d.). Fig in California. Retrieved February 05, 2018, from <http://fruitandnuteducation.ucdavis.edu/fruitnutproduction/Fig/>

Meeting Consensus Grade: 95

Content: Some questionable details about early wasp life stages, but mostly that is beyond the scope of this case. Good distinguishing between tree types. Good description of the symbiosis. Some confusion about the entry/exit terminology (ostioles vs tunnels).

Logic: Could have used a bit more explanation of the solution.

Writing: Nice concision!

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