Teaching And Learning Portfolio

by

Rembrandt Haft

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Learning

Research Teaching

This portfolio submitted in partial fulfillment of the requirements for the Delta Certificate in Research, Teaching, and Learning.

Delta Program in Research, Teaching, and Learning
University of Wisconsin-Madison

DELTA
Integrating Research, Teaching, and Learning

C I R T L

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Teaching and Learning Portfolio

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Introduction

During my post-doctoral research at the University of Wisconsin-Madison, I participated in the Delta Program in Research, Teaching and Learning and earned the program's Certificate in Scientific Teaching. The Delta Program (Delta) is part of the National Science Foundation-sponsored Center of the Integration of Research, Teaching, and Learning (CIRTL). Delta and CIRTL focus on improving instruction at the college level through professional development for current and future faculty. Participation in Delta involves broad training in formal and informal teaching methods as well as in educational practices that facilitate the development of an inclusive community of diverse teachers and learners.

The Delta Program is organized around three "pillars" - central concepts that promote good teaching in any context - which are *diversity*, *learning communities*, and *teaching-as-research*. Through my participation in Delta, I came to understanding various ways in which supporting my teaching methods with these pillars can make me a more effective instructor. This Teaching and Learning Portfolio begins with a general statement of my current teaching philosophy, and then provides a narrative, with artifacts as mileposts, to illustrate some of the ways in which I have explored the Delta pillars and put them into practice.

The creation of this portfolio afforded me an opportunity to reflect on my experiences in Delta, and on the Delta pillars, as I finished the requirements for the Delta Certificate in Scientific Teaching. In addition to the Teaching and Learning Portfolio, I completed a variety of courses and activities as components of my Delta Certificate training, which I will note below.

<u>1. Completion of two Delta instructional training courses</u>

- College Classroom Teaching in Science & Engineering: International Students International Faculty (Fall 2011)
- Instructional Materials Development: Designing Materials for STEM Undergraduate Classes (Spring 2012)

<u>2. Participation in the Delta learning community</u>

- Research Mentor Training seminar (Spring 2014)
- Presentation of my Delta Internship teaching-as-research project to colleagues in Delta and at other institutions through CIRTL (Spring 2013)
- Participation in Delta roundtables and Brown Bag Buzz lunch discussions

<u>3. Completion of a teaching-as-research internship (Spring 2013)</u>

In this internship, I worked with instructors of the Microbiology 303 course at the University of Wisconsin-Madison. We introduced active learning pedagogies to a previously lecture-only course, and examined the utility of these methods by analyzing student performance on course exams and by measuring student attitudes related to both lectures and active learning exercises.

<u>4. Presentation and defense of certificate requirements to a committee of educators</u>

Teaching philosophy

Creation and challenges fuel learning

Kamau Kinuthia, who taught my Economics 101 class at South Puget Sound Community College, had a pedagogical style that remains vivid in my memory more than a decade later. After lecturing on a difficult topic, Kamau would pause to let the class digest it for a few moments. Then he would turn and point to a random student, calling, “You! Do you have a question?” If the student said no, Kamau would respond, “well, why NOT? There must be something you want to know, or you wouldn't be here!”

Kamau wanted us to think to the limits of our understanding, and with his help to push those limits. Throughout my education I have benefited most from instructors such as Kamau who encouraged me to find, and move beyond, the limits of my abilities. For myself and the students I have mentored, pushing our limits involves working towards a challenge - some goal that we cannot trivially achieve. As we move towards this goal, we identify important knowledge to apply and skills to master, with the goal giving us a reason to acquire both.

Challenges can give us a "why" for learning, but as an instructor and mentor, I face two critical "how" questions: how do I help students learn to do something new, and how can I tell if they've learned to do it? In theory and in practice, I have found the best answer to both questions is to ask students to create things. The constructivist model of cognitive development holds a central role for creativity in the process of learning. Our brains "learn" by creating novel frameworks internally; these mental frameworks are reinforced when we exercise them as a basis for creation of external artifacts such as posters, computer programs, gardens, or performances. Fundamentally, one has learned if one can now do something that one could not before, be it communicate a concept, create an artifact, or predict the outcome of a series of events.

The products of students' creation are, in turn, what allow educators to evaluate their capabilities and progress. For this purpose, small, frequent tasks play a key role alongside larger challenges. Particularly in laboratory settings, I have found that simple prompts such as “explain this back to me” and “sketch what happens next” provide me useful creative outputs to evaluate.

Bringing the narratives of challenge and creation back together, my aim as an instructor is to help students achieve their goals by guiding them as they gain and retain new abilities through creative work. I consider this an iterative process, in which I must make systematic observations of my own effectiveness to improve my ability. I focus my efforts on what I take to be three primary tasks for an instructor, which I explain further below: fostering an atmosphere for creation, setting the right challenges for students, and remembering why I teach.

Fostering an atmosphere for creation

Accepting a challenge to create something could lead to failure, so as learners, we are at our best when we feel safe enough to participate and take risks. My goal is to build an inclusive learning community where students feel that, whatever their background, beliefs, and interests, so long as they act with respect and consideration towards others, they will be afforded respect and consideration themselves. An open, respectful group also encourages students to communicate and work together, granting them access to a key resource for effective creation: the diverse knowledge and abilities of their classmates. In the lab or outside of it, my mentees do best when I get them to discuss their work with other students rather than relying solely on me.

Students also need opportunities to actively participate during class, which we can facilitate using varied pedagogical methods. In an example from my recent past, I developed an "active learning exercise" for a course at the UW-Madison (Artifact 3 in this portfolio). The in-class project asked students to work by themselves, then in small groups, to create evolutionary histories for biological traits and map them onto a phylogenetic tree. Moving from group to group during the activity, I was excited by the level of student engagement. Students eagerly tackled the assignment, putting critical thought into constructing good phylogenetic maps and working with one another to explore the ambiguities that arise from real data.

Setting the right challenges

When I designed my evolution-mapping exercise, I wanted students to know where to start, but I also wanted them to stretch their cognitive abilities to complete the project. To facilitate this "start-then-stretch" pattern, I broke the project up into a series of smaller tasks using both lower- and higher-level activities from Bloom's taxonomy. I deliberately included ambiguous data so there was no "right answer"; the students had to explain their differing maps to one another as part of the process. The final products - discussions between students and the maps they made - I evaluated by observing and talking with students, so I could give immediate formative feedback. Several students volunteered positive feedback about the activity, and the instructors, who also thought it worked well, decided to integrate it into the course.

In many respects, the exercise illustrated characteristics of a good learning-promoting challenge. The students had to work hard at it, but were able to complete the tasks, while I was able to critically evaluate their efforts. They reinforced their new understandings of evolutionary methods by explaining their maps to one another. Last but not least, they created an artifact that was useful later, since the maps served as study guides for course exams.

Looking ahead to future challenges I may set, I will try to ensure that skills used in my assignments are exercised again and again during the course, so I can look for improvement over time. And ideally, I can guide students to creative efforts that are a source of utility (and perhaps even pride) outside of the course as well. One example of such outside utility that I personally admire is how Bacteriology instructors at the University of Wisconsin-Madison use undergraduate courses as settings to sequence microbial genomes, allowing students to make a concrete contribution to the field.

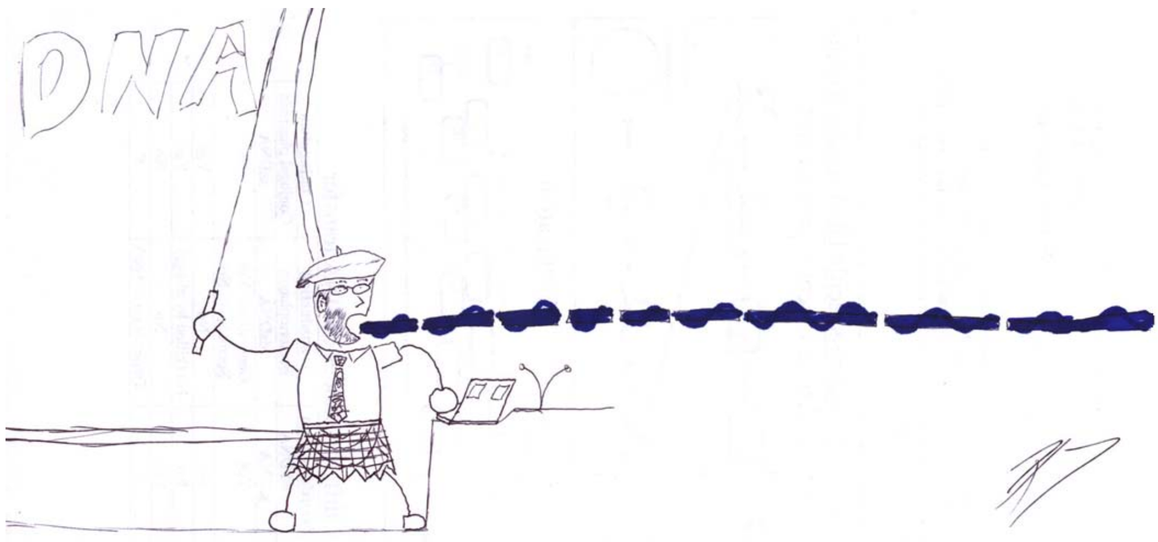
Why I teach

My goal as a mentor is to help students grow and achieve their goals by creating things they could not have created before. This work does good beyond my own limited sphere; by fostering cooperative personal development amongst diverse individuals, I shape a happier, healthier, more productive society. Also, by teaching science as a practice, I give others access to a suite of skills that they can apply beneficially to all sorts of human affairs.

In addition to this broad utility, I teach for the joy of watching people gain strength and ability. I take lasting pride, for example, in the progress of my most recently graduated lab assistant, Mark (some of Mark's work is shown as Artifact Five in this portfolio). Mark started out needing daily guidance from me, but quickly became more independent, designing and setting up his own experiments. His efforts allowed us to publish a peer-reviewed article with himself as first author, and he has since earned his M.S. in Biochemistry. Whatever other students do after leaving my tutelage, I hope they follow Mark's example in using their skills to benefit society while doing things that they love.

Artifact One

Portrait of Rembrandt Haft Lecturing
drawn in 2005 by a student in Microbiology 410
at the University of Washington



Description and Reflection:

Prior to participating in the Delta Program, as a graduate student in Seattle, I gave two lectures in Microbiology 410. I mimicked the usual style for the class: uninterrupted discourse, aided by PowerPoint slides, that filled the entire period. After my second lecture, a student deposited this sketch on the podium, then hastily departed. I took it that I had kept the student's attention, which was true, but years of reflection have changed the meaning of this image for me.

The caricature accurately depicts my role as a talking head armed with a laser pointer. Instead of challenging my students to stretch their boundaries, the primary challenge I laid before them was to follow the unremitting stream of verbiage emanating from the space beneath an unflattering grey beret. Furthermore, I had no way to know what they took away from the lectures. The teaching style I used in these lectures lacked the supportive structure of the Delta pillars: I did not acknowledge the diversity in the classroom, nor use it to the students' advantage; I neither built nor integrated myself into a learning community, having no further interaction with the class after my lectures; and I gathered no data to help improve future instruction.

My desire to become more than the talking head, and to ask more of my students than passivity, inspired me to seek training as an instructor through the University of Wisconsin Delta Program. My work in Delta has provided productive contrasts with my Microbiology 410 experience, particularly the Tree of Life activity (Artifact Three), in which went through a full cycle of providing students with a useful challenge, interacting with them personally, observing their progress, and giving them feedback. The following artifacts in this portfolio illustrate examples of my efforts to understand how Delta pillars promote teaching and learning, to craft active classroom exercises, and to scientifically assess student learning.

Artifact Two

Diversifying Selection Simulation for Introductory Biology

Description and Reflection:

The University of Wisconsin-Madison Biology 151 class is a high-enrollment course in which students are broken into smaller groups, led by TAs, for one session per week. During the Delta course in Instructional Materials Development, I was partnered with two Biology 151 instructors, Dr. Michelle Rondon and Dr. Cindee Giffen, to create a new course activity that could be led by TAs to help students predict the effects of diversifying selection, about which they often exhibited misunderstandings.

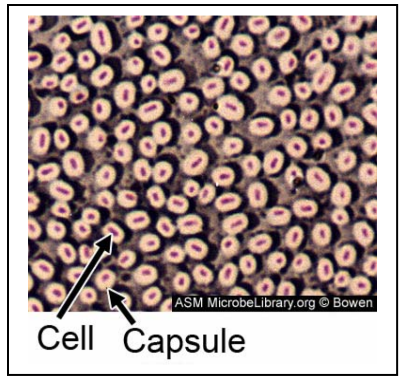
The “Diversifying Selection” exercise that I created is presented as Artifact Two. It starts with a pencil-and-paper simulation of diversifying selection that students perform individually, and then prompts students to analyze the simulated data and discuss how different selective conditions would lead to different ecological outcomes. I designed exercise as a "start-then-stretch" challenge of the sort noted in my teaching philosophy, having students begin with straightforward mathematics before leading them into the more complicated interpretation of their simulated results. To help TAs lead the activity and assess student performance, I also created a "TA notes" version (not shown) that includes talking points, areas of potential student confusion, and examples of acceptable answers to all prompts. This activity was first implemented in Biology 151 in the Spring of 2012. It received positive feedback from TAs and instructors, and use of the exercise in Biology 151 has continued.

This exercise illustrates some of my first (rather faltering) steps in trying to use the Delta pillars to support effective teaching. There was no formal teaching-as-research component, but there was a system by which TAs could provide feedback on the exercise and also relay student feedback. The exercise modestly fosters a learning community in the class by instigating discussions between students about the nature of diversifying selection. The diversity pillar is weak here - student discussions might benefit from diversity in the class, but the discussion material is factual and doesn't leave much room for diverse opinions or interpretations.

The process of creating this simulation was important in my development as an instructor, however, because it gave me some of my first meaningful experiences working in a teaching and learning community of instructors. In designing this activity, I worked closely with Dr. Rondon and Dr. Giffen, as well as other Instructional Materials Development classmates. My fellow instructors gave me multiple rounds of feedback, encouraging me to tweak the focus, pick a different model system, change the format, add graphics, ask tougher questions, and generally make the activity more useful for the students. This productive back-and-forth between myself and my peers set a model for the way in which I hope to design curricular activities in the future. Additionally, while working on the design of this simulation, I made my first forays into resources such as the Multimedia Educational Resource for Learning and Online Teaching, which gave me access to the community of instructors outside the UW-Madison.

Diversifying selection in bacteria

This simulation is designed to show how diversifying selection (also called disruptive selection) can affect a population and thus cause evolution.

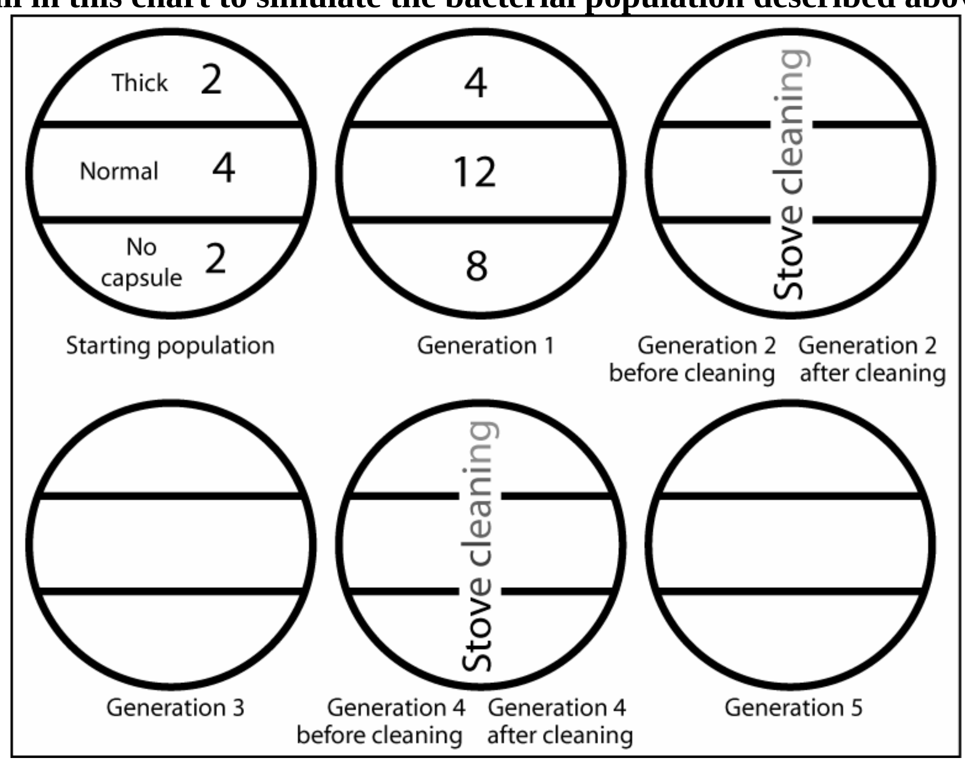


Introduction: Many bacteria protect themselves from chemical harm with a slimy “capsule” made of carbohydrates. The capsule can have variable thickness. Thicker capsules are more protective, but cost the cell more time and energy to produce, limiting its reproductive capacity.

We will simulate the effects of chemical toxins on a population of one species of bacterium in which individuals vary in their ability to produce a capsule. Our scenario is as follows:

1. A group of bacteria are flung across a kitchen onto a stove. Dried-on ramen residue provides ample food for their growth!
2. Most bacteria make a “normal” capsule. A few mutants make a thick capsule, and a few other mutants make no capsule.
3. In each generation, “thick” cells each give rise to one daughter, “normal” cells give rise to two, and “no capsule” cells give rise to three. Cells give rise to identical progeny. Generation 1 is given to illustrate reproduction from the starting population.
4. Occasional cleanings of the stove with detergent (see chart below) kill 80% of “normal” cells, 80% of “no capsule” cells, but none of the “thick” cells (round deaths down). Cleanings occur after generations 2 and 4 (and before generations 3 and 5).

Fill in this chart to simulate the bacterial population described above.



Please turn over the form, and write answers to the prompts on the back!

1. Draw a graph to depict the frequency of genotypes in the starting population.

2. Draw a graph to depict the frequency of genotypes in the final population.

<u>Please discuss these questions with your neighbors, and provide a short answer for each.</u>

3. Compare the graphs you drew above. What about them indicates that the population experienced diversifying selection over time?

4. Which genotype would be favored over time if nobody cleaned the stove?

5. Which genotype would be favored over time if people kept cleaning the stove, but all the bacteria reproduced at the same rate?

Artifact Three

Three Domains of Life Exercise for Introductory Microbiology

Description and Reflection:

Microbiology 303 is an introductory course that serves a variety of majors at the University of Wisconsin-Madison. A key aspect of Microbiology 303 is a comparison of similarities and differences between the three Domains of life (Bacteria, Archaea, and Eukarya). One extension of these comparisons that has traditionally been difficult for students is our ability to use such comparisons to model evolutionary histories of biological structures.

I reasoned that an effective approach to address this difficult topic would be to have students themselves model such evolutionary histories. To this end, I designed a classroom session including mini-lectures, individual student work, and small group discussions. Compared to the "Diversifying Selection" simulation shown above (Artifact Two), this "Three Domains of Life" activity represents a more mature form of curricular development that more effectively integrates the Delta pillar concepts into its function.

Like the Diversifying Selection activity, the Three Domains of Life activity has students work singly to generate a representation of data, then encourages them to discuss their results. But where the former asked only that students consider a concrete mechanism, the Three Domains of Life exercise uses the discussion to reach deeper issues. The data presented in this activity are ambiguous, and different students generate diverse (but equally correct) evolutionary trees based on the data. When they discuss their trees, the conversation quickly shifts from being about the immediate question of "what goes where?" to the more fundamental question of "how do we KNOW what goes where?" This discussion actively uses students' diverse styles of learning and explaining to facilitate deeper understanding, and promotes a respectful, sharing community among the students. Furthermore, this activity had a formal teaching-as-research component: it was part of a larger study on lecture vs. non-lecture pedagogies, which was my Delta Internship project and is presented as Artifact 6 in this portfolio.

This project also allowed me to participate more fully in the teaching and learning community as an aspiring instructor. During the design process I received helpful feedback from Microbiology 303 instructors as well as students in the course. When the activity debuted in the Spring semester of 2013, I came to class sessions to help implement the activities. During the class session I observed students as they worked singly, and joined their later discussions. To my delight, the activity succeeded in meeting my learning goals for the students. I could see and hear them constructing their own understandings of parsimonious evolutionary histories, and in sharing these histories with one another, students influenced each other's understandings and solidified their own reasoning by explaining it out loud. I could also assess students' performance and provide them feedback by talking with students during their work, addressing them individually, and by discussing questions and issues more generally during the post-activity mini-lecture. In the end, I was more comfortable working with the students (and they more comfortable with me) than if I had just visited the course to give a lecture.

Afterwards, the Microbiology 303 instructors told me that they were very pleased with how the session plan and activities had worked. Over the next two weeks, several students gave unsolicited positive feedback to me or the course instructors about the utility of the class period. The effectiveness of the activities was underscored by students' high rate of correct responses on exam questions related to evolutionary histories, even those rated as "very difficult" by course instructors. Due to the positive outcomes associated with the class session, Microbiology 303 instructors have adopted it as a standard part of the course.

Reflecting on the Three Domains of Life activity showed me that I had come a long way towards being an effective instructor since the days of my Microbiology 410 "talking head" lectures (Artifact One). The activity itself allowed me to put key aspects of my teaching philosophy into practice by setting before students the kind of challenge that I believe is most useful to help them grow and to help me evaluate their work. The structure of the activity seemed to work well for stimulating conversations between the students, encouraging them to work together on a difficult problem. Finally, as I walked around the room and conversed with the students, I found an important sort of closure that lecturing did not provide: by the end of the class session I knew that my students had learned something new, and that they were ready to keep stretching their own boundaries should I bring another challenge before them.

Three Domains of Life and Evolutionary History Lesson Plan

Three Domains of Life: Bacteria, Archaea, Eukarya

We have considered bacterial cellular structures and macromolecules in two lectures prior to this session. Now, we will compare structures and macromolecules of the other two biological Domains containing microbes: Archaea and Eukarya. We will consider subcellular structures that are universal to living beings, and others that are specific to certain biological lineages. In the process of the day's work, students will create a document that can be used as a study guide for exam questions on macromolecules, organelles, and the three Domains.

Content/Learning Goals

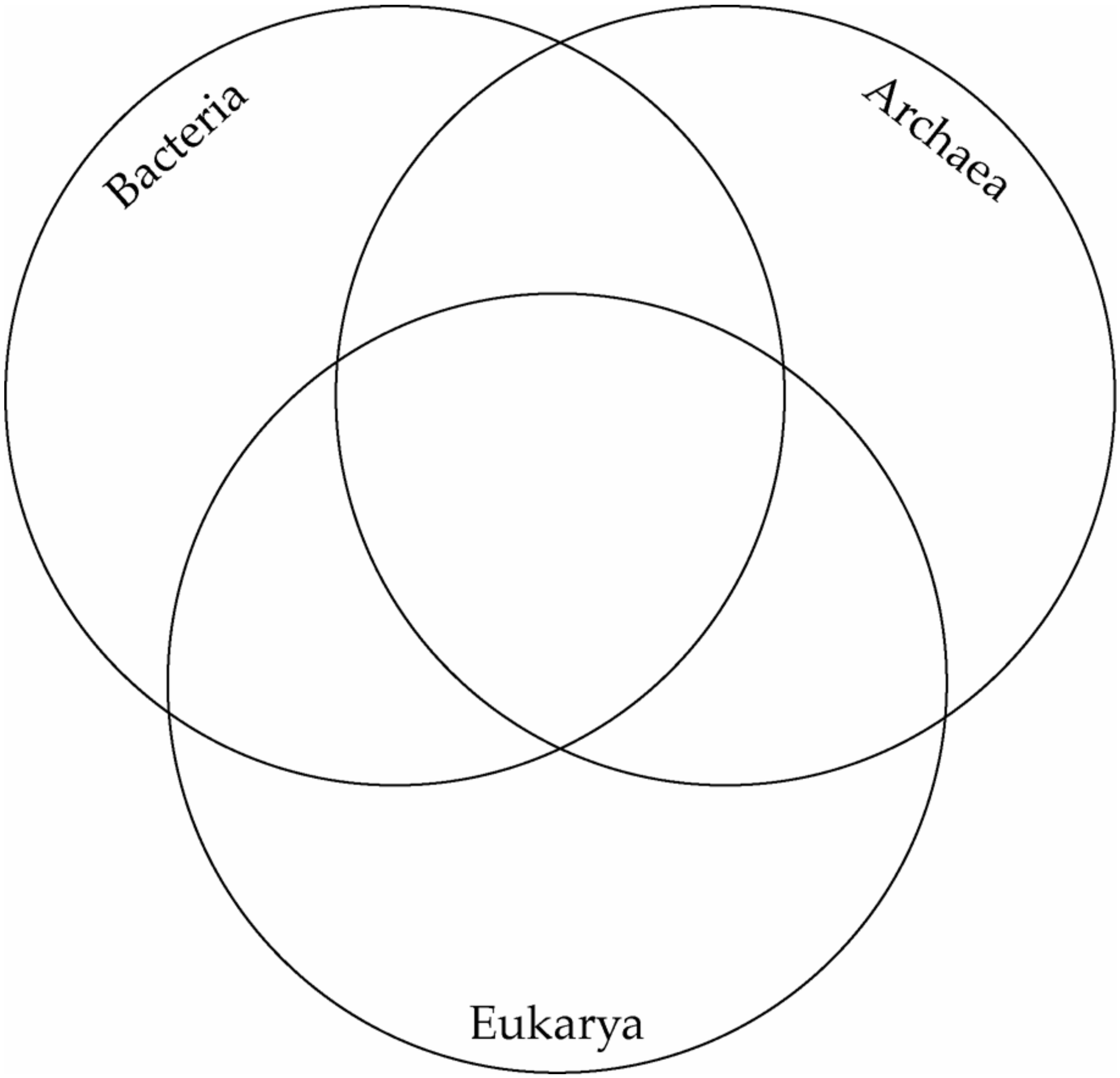
- Compare the macromolecular and structural components present in cells of the three domains of life.
- Describe the macromolecular components of organelles, and compare organelles to bacterial cells in terms of macromolecular contents.
- Distinguish between universal and lineage-specific macromolecules/structures.
- Become familiar with the hypothesis that lineage-specific structures arose later than universal ones.
- Synthesize structural information and phylogeny to map macromolecules/structures onto a model Tree of Life.

Classroom Activities

1. Label subcellular components and macromolecules on a Venn diagram with three circles: "Bacteria", "Archaea", and "Eukarya".
2. Complete a multiple-choice activity to identify which macromolecules are present in bacteria, chloroplasts, and mitochondria.
3. Map the probable origins of structures onto nodes of a model Tree of Life.
4. Mini-lectures by instructor on structures/macromolecules of Archaea and Eukarya.

Teaching Plan

Time	Activity	Topic	Goal
Pre-class	Pre-flight	Organelles and macromolecules	Gain familiarity with structure of subcellular components
0-15	Mini-lecture	Statement of purpose, biology of Archaea and Eukarya	Summarize key content, introduce lineage-specific structures/molecules
15-25	Venn diagram	Subcellular components	Explore differences between lineages, and structure of organelles.
25-30	Mini-lecture	Shared vs. lineage-specific structures	Discuss interpretation of Venn diagram, in terms of the Tree of Life
30-40	Tree of Life mapping	Phylogeny and diversification	Synthesize information to generate hypotheses about origins of structures
40-50	Discuss Trees, answer questions	Trees (ask students for examples of lineage-specific structures), and student-determined questions	Correct misconceptions about the Tree, and clarify issues that remain murky

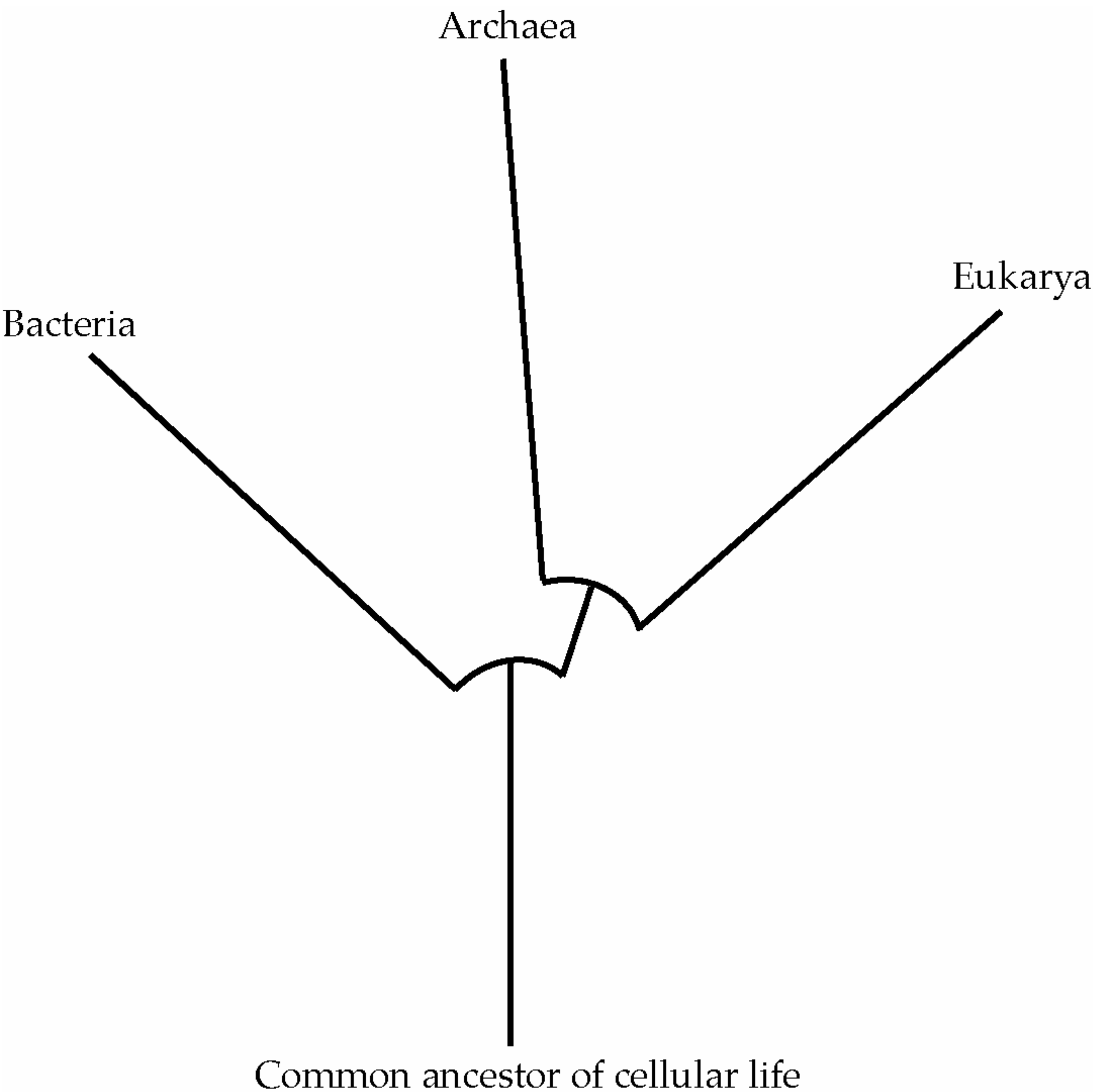


Label the Venn diagram above with at least ten of the following terms, denoting which are universal and which are only present in certain lineages. Then, list three components that are shared by bacteria, chloroplasts, and mitochondria.

DNA	Protein	Lipid bilayer	Mitochondrion	Peptidoglycan
Pilus	Golgi	Nucleus	G-1-P ether lipids	G-3-P ester lipids
Polysaccharides		Cytoskeleton	S Layer	
Isoprenoids (in membranes)			Fatty acids (in membranes)	

Common components of bacteria, chloroplasts, and mitochondria are:

Map the cellular components from your Venn diagram onto the Tree of Life at a branch where they are most likely to have arisen. For each lineage, include at least one structure unique to that lineage.



Artifact Four

A Mentoring Challenge

Description and Reflection:

As a part of the Delta Mentor Training seminar, I wrote a short statement about a challenge I had faced, and continue to face, in mentoring undergraduates - briefly, that research mentees who do not plan to continue in science or medicine after graduation can be hesitant to discuss that fact. The challenge centers around two Delta pillar issues: student diversity (particularly regarding students' goals) and the formation of an inclusive learning community where learners and instructors trust one another.

This document is an example of how I continue to wrestle with implementation of Delta pillars in my own teaching and mentoring. As a mentor, I am in an empowered position, and generally higher in the educational hierarchy than my mentees. Due to this power dynamic, mentees may hesitate to approach me about issues where they think their values or goals and mine do not align. I hope to find better and better ways to convey to my mentees that I value diverse goals and diverse applications of the skills I help them acquire. I want students to build a teaching and learning community where I trust my mentees to be open with me, and they trust me to work with their best interests at heart.

I am still trying to figure out how best to avoid intimidating mentees so that they can be open with me about their future goals. The approach I am trying at present is to use personal examples to reassure students that it is OK to follow various paths during their education and careers. I state explicitly that I am comfortable with the fact that I have had some mentees follow traditional paths in academic research while others left science entirely (such as the student described in the challenge document below). I myself took a hiatus from scientific research to work as a computer technician before graduate school, and can sympathize with students' career uncertainties. By beginning the conversation on future plans in an inclusive and open-ended way, I hope to convey to mentees that the topic is open for discussion and that they need not feel obligated to conform to the usual expectation that they are bound for graduate or medical school.

The Challenge Document:

Recently, I had an undergraduate assistant who worked with me for about a year and a half. He had made good progress in becoming an independent and effective researcher, and I was happy with his work. We met regularly to talk and plan out experiments, and he helped write portions of a paper we submitted recently. Occasionally we sat down for a lunch together to talk about his work outside the lab and his plans for the future. We didn't get together socially outside of the lab setting, but I thought we were getting along well. We had agreed that he would work with me through Spring 2014, then leave the lab for his final semester in college.

At the beginning of the semester, he wrote to tell me that he had decided to stop working in the lab early and would not be here for Spring 2014 after all. He had changed his major suddenly and had to fulfill new course requirements that would leave him no time for research. I felt upset and a bit betrayed, since I was counting on him to continue experiments on his project. I met with him over lunch, outside the lab, to talk about his decision and his future plans. After some gentle prodding, he admitted that he had decided not to go forward in science or medicine, which had been his original plan. He wanted to move into a career coordinating student affairs, which had been a side job for him for several months.

Based on our final conversation, I think he was afraid to be open earlier on about his decision to leave science. I don't mind that he decided to do so. I wouldn't have been mad at him, and I would rather he had told me earlier. How can I not be scary to my mentees, so that they can be open about their plans?

ARTIFACT FIVE

Presentation Materials Generated by a Mentee

Description and Reflection: The following figures were created by Mark DeCanio for a public poster presentation in 2011. I mentored Mark as an undergraduate researcher for two years. Mark quickly achieved increasing independence in the lab, and really became a full member of the research community in his own right. He published a research article as first author, and entered graduate school after leaving the lab.

I helped Mark design the experiments described in the figures below, but he carried out all the data gathering, analysis, and interpretation. He generated the following visualizations of primary data and an explanatory model. And most importantly, he presented and explained his results to his peers on his own.

This artifact is evidence of my participation in an important process: helping induct new members into existing learning communities. I helped Mark learn how to convey his results and their import to the broader learning community of his peers. Furthermore, I encouraged him to find opportunities (such as this poster presentation) that allowed him to participate in that community in his own right. As a mentor, I hope to continue this pattern of helping my mentees earn their own place in the learning communities of their choice and achieve independence.

Selected Figures from Mark DeCanio's poster:

Results

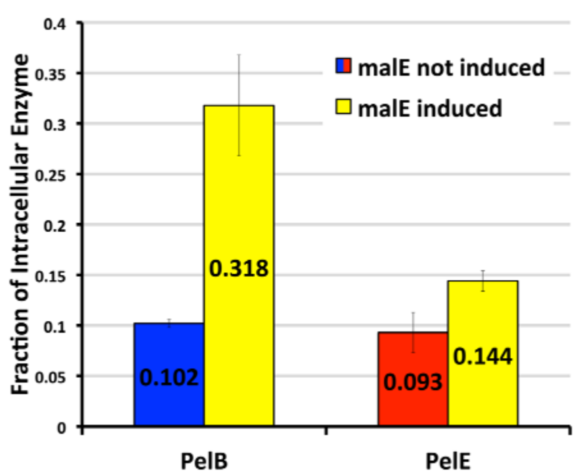


Figure 4: Comparison of PelB and PelE intracellular enzyme fractions with and without the induction of MalE. The MalE competitor caused PelB secretion to be inhibited 3-fold while PelE secretion was only inhibited 1.5-fold. Data represents the average of three trials ± SEM. Statistical analysis at $p < 0.05$ verifies the difference in intracellular enzyme with induced MalE.

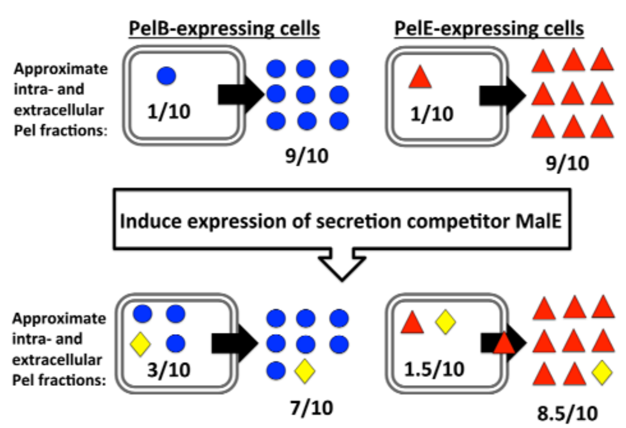


Figure 5: A cellular-level illustration of Figure 4.

Conclusion

- ❖ T2S substrates compete for secretion.
- ❖ PelE is a stronger competitor for secretion than PelB at the 95% confidence interval.

Artifact Six

Internship Project Report

Description and Reflection:

My Delta Internship Project represents my most significant foray into teaching-as-research to date. In this study, I applied the quantitative tools of the sciences to a key pedagogical question: can large lecture courses be improved by the replacement of some lecture periods with other pedagogical tools? Based on my study of an introductory microbiology course at the UW-Madison, I can now use concrete evidence to argue that the answer is "Yes".

For my Internship, I worked with my Internship Mentor Dr. Timothy Paustian and the other Microbiology 303 course instructors, Dr. Michelle Rondon, Dr. Robin Kurtz, and Dr. Jon Roll, to integrate active learning exercises (including the Three Domains of Life exercise shown as Artifact Three) into a course which had previously been lecture-only. To assess the utility of these new exercises, and students perception of their utility, I analyzed student performance on relevant exam questions and measured students' perception of lecture vs. other pedagogical methods using an end-of-semester survey. As the study below describes, students generally performed better on questions related to active learning exercises than they did on questions related to material presented solely in lecture format - though they did not display an awareness of this difference overall.

This project allowed me to tie together the Delta pillars more closely than I had previously. The aim of the course redesign was to better serve a diverse student body by teaching to a variety of learning styles and incorporating activities other than passive listening. During the internship project, I worked as part of a community of teachers and learners in reading relevant literature, designing activities, gathering data, and interpreting the results; I also had a supportive, helpful community to draw on from the fellow members of my Internship Cohort. And I used the course redesign as an opportunity for formal teaching-as-research, making systematic comparisons between different pedagogical methods in a study that have practical relevance for the broader community of college instructors.

As an instructor, I see this internship as a model for how I can use teaching as research to iteratively improve my own teaching while acting as a productive member of a wider community. I will work with my peers to generate hypotheses about what sorts of activities or interventions could improve learning outcomes. Based on these hypotheses, I will implement new pedagogies in a context where I can measure their effectiveness in achieving desired learning outcomes. Finally, I will present and discuss my findings with interested communities of teachers and learners to help improve instruction throughout higher education. Instead of treating education as a one-way transfer of information from myself outwards, as I did in the lecture depicted in Artifact One, I now acknowledge that I can iteratively improve my impact on students by taking in information from a variety of sources, just as I do in the world of research.

Title

Beneficial Effects on Student Learning from the Introduction of Active Learning Exercises to a Microbiology Course for Undergraduates

Abstract

Microbiology 303 has been taught for many years at the University of Wisconsin-Madison as a lecture-only course. We introduced active learning pedagogies to the course, and examined the utility of these methods in promoting student learning of the related subjects. To assess learning, we compared student performance on two sets of exam questions: those on material covered only in lecture, and those related to active learning exercises. Additionally, we assessed student attitudes related to both lectures and active learning exercises using a survey at the end of the course. We observed that student performance on exams was better on active-learning questions than on lecture-only questions, indicating that the active exercises were beneficial to student learning and/or retention of course material. Comparisons of student exam performance between active-learning and lecture-only (prior semester) versions of the course further demonstrated the benefits of active learning. Despite the significant boosts to exam scores resulting from active learning exercises, end-of-semester survey data show that students perceived lectures as having greater utility than active exercises.

Introduction

Incorporating active learning exercises into courses traditionally taught in a lecture-only format has been shown to increase student learning in a variety of disciplines, even when the courses maintain substantial lecture components, as reviewed by Michael (8). A particularly compelling argument for incorporating active learning into lecture-based science courses is put forth by Crouch and Mazur (3), who show large gains in student performance in undergraduate physics using a “peer instruction” course design. Using a mixture of lecture and discovery-based learning, Wilke and Straits (14) found that students in an introductory biology course performed better when tested on material learned during problem-solving sessions than when tested on material covered solely during lecture. With more limited deviations from the lecture-only format, Smith et al. (11) show that even short periods of interaction between students who do not know the answer to a specific question can lead to an increase in student problem-solving ability.

Furthermore, active learning sessions encourage students to incorporate knowledge in a constructivist manner, which aids with long-term retention of the material by individuals (2).

As compared to lectures, active learning sessions can also better serve, and take advantage of, diversity within the class. Active learning involves varied pedagogies that can reach a diverse population of students with differing learning styles (1, 7). Exercises that require peer-to-peer instruction or group work (which include problem-solving, discussion of case studies, and think-pair-share activities) help use the diversity present in the class to broaden students' perspective on the material and encouraging the use of higher-order thinking skills to judge between alternate possibilities. Group work and cooperative activities can also make the course more inclusive by engaging both students whose cultural backgrounds stressed a social construct of learning and students who are most comfortable learning from peers rather than an instructor (9).

In an effort to increase student learning via active learning exercises, we substantially changed the pedagogical approach taken in the University of Wisconsin-Madison Microbiology 303 course. Microbiology 303 is a high-enrollment introductory course for prospective majors (≥ 200 students per semester) in which student performance is assessed using three multiple choice exams. This course has been taught for many years as a lecture-only course. In the revised form of Microbiology 303, first taught in Spring of 2013, two weekly meetings (Monday and Wednesday) were primarily lecture periods (though students were expected to volunteer information or judgments during the lectures), while a third (Friday) mixed short stretches of lecture with active learning exercises. Such exercises mixed individual and group work, including pen-and-paper simulations, problem-solving challenges, think-pair-share discussions, and short writing prompts.

To measure the effectiveness of the revised course, we quantitatively assessed the effects of the new pedagogical arrangement on student exam scores. We also measured student attitudes towards lectures and active learning exercises with an end-of-semester survey. We found that students performed better on exam questions that tested their knowledge of material covered in active learning exercises than on questions related to lecture material. Students' opinions of the utility of the two pedagogical methods were biased towards lecture, however, indicating that as a group they benefited from active exercises without realizing it. This disconnect between perceived gains and exam performance highlights two important concepts in the practice of teaching and the measurement of student learning gains. First, student perceptions of activities' utility in the short term are not necessarily accurate. Second, as instructors, we must work to equip students with effective tools for self-reflection so that they can more accurately gauge what is working to help them learn and retain key knowledge and practices.

Instruments and Methods

Course Design and Study Instruments

Microbiology 303 in the Spring semester of 2013 met on Monday, Wednesday, and Friday mornings for 50 minute sessions. Enrollment was between 200 and 215 students throughout the semester. On Mondays and Wednesdays the full class gathered for lecture presentations, which were divided over the semester between two Instructors. On Fridays, the class was divided into four sections of equal size for active learning exercises led by Instructors or an undergraduate Teaching Assistant. Active learning sessions were similar to the "5E" strategy presented by Tanner (12), in which students are given an engaging background to a topic, allowed to explore and explain parts of it on their own, then guided to key conclusions and evaluated. Each Friday students were given points for turning in a piece of work created during the active learning exercise, to ensure attendance and participation in active learning sessions. Active learning exercises were varied each week and included problem-solving, discussion of case studies, and think-pair-share activities.

To evaluate student learning and retention of course material, the instructors employed three exams spaced evenly during the semester. The exams were similar in length and content to exams used during previous iterations of the course. Exams consisted of 50-60 multiple choice questions evaluated by a Scantron apparatus. Instructors classified each exam question as relating to either a lecture class session or an active learning class session.

Student attitudes towards pedagogical techniques were measured using an anonymous on-line survey at the end of the semester. The survey, shown as Table 1, was designed to investigate students' opinions of the utility of active learning exercises as well as the division of the class into four sections on Fridays. Questions addressing these pedagogical points were paired such that the prompt was stated in two opposing ways to control for any tendencies to fill in the same response to all questions.

Table 1. End-of-semester survey of students' attitudes towards pedagogy.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Prefer not to answer
1. This course as a whole helped me understand the material	☐	☐	☐	☐	☐	☐
2. Being in a smaller group on Fridays contributed to my learning	☐	☐	☐	☐	☐	☐
3. Friday sessions could be at least as useful in one large group	☐	☐	☐	☐	☐	☐
4. Lecture presentations helped me understand the material	☐	☐	☐	☐	☐	☐
5. In-class activities helped me understand the material	☐	☐	☐	☐	☐	☐
6. I understood material better from in-class activities than I did from lectures	☐	☐	☐	☐	☐	☐
7. I would have understood at least as much in an all-lecture format	☐	☐	☐	☐	☐	☐

Results

<u>Active learning exercises increased student learning as evaluated by examination</u>.

We sought to measure the magnitude and direction of effects on student learning that could be attributed to the use of active learning exercises in the course. To provide an objective quantification for these measurements, we compared student performance on exam questions that assessed learning and retention of material that was only given in a lecture format versus those addressing topics from Friday active learning sessions (Figure 1).

The primary tool for evaluating student performance in Microbiology 303 was a series of multiple-choice exams on Scantron forms. Exam questions covered the range of topics presented in the course, and were designed jointly by two course instructors. The instructors divided questions into "lecture-only" or "active-learning" categories. To avoid procedural biases during test-taking, both types of questions were of similar difficulty, were presented in the same formats, and were intermingled on the exams themselves.

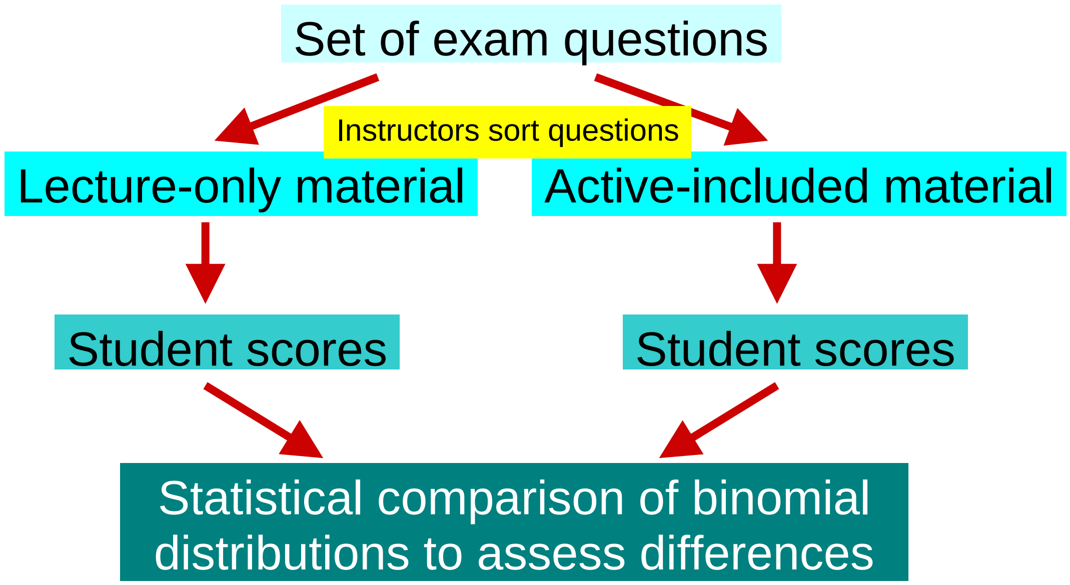


Figure 1: Workflow for assessing the impact of active learning exercises on exam performance within a cohort of students.

After the end of the course we tallied the number of correct and incorrect responses to each exam question. Considering each exam separately, we compared the percentage of correct responses on lecture-only questions and active-learning questions; in each case, students performed better overall on the active-learning questions (Figure 2A). We quantified the magnitude and significance of this difference for each exam using binomial distribution analysis. For this statistical method we considered each student's response to each exam question as analogous to a "coin flip", in that it could have one of two outcomes: it could be correct, or incorrect. While this method did not address the tendency of students to respond to specific "significant distractors" on multiple-choice exams, with a large class such as Microbiology 303, it provided a powerful, objective, and quantitative way to assess the effect of active learning exercises on exam performance.

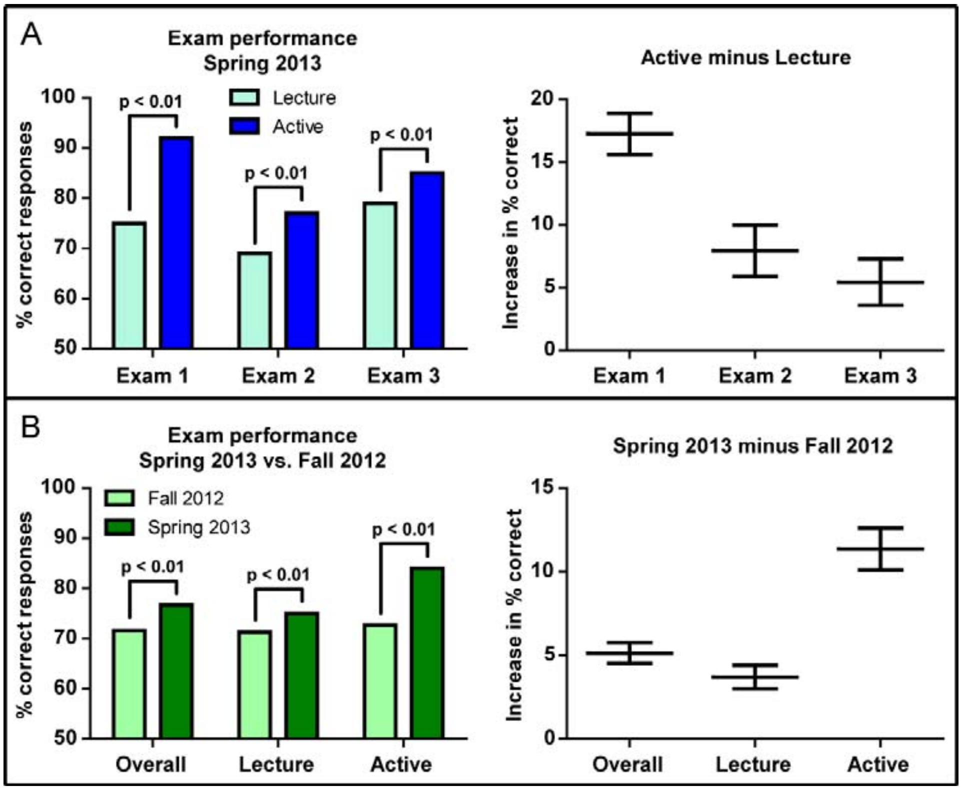


Figure 2: Effects of active learning exercises on student exam performance. *A.* Within-cohort comparison for Spring 2013 course. The percentage of correct answers to lecture-based questions (cyan) and active-based questions (dark blue) for the three course exams are shown at left. Mean increases in correct response rates associated with active learning are shown at right, with error bars bracketing 95% confidence intervals. *B.* Between-cohort comparison for Spring 2013 (lecture and activities) and Fall 2012 (lecture only). The percentage of correct answers in Fall 2012 (mint) and Spring 2013 (dark green) are shown at left for all questions, lecture-based questions (based on Spring 2013 curriculum), and active-based questions (based on Spring 2013 curriculum). Mean increases in correct response rates observed in Spring 2013 are shown at right, with error bars bracketing 95% confidence intervals. Significant differences detected in pairwise binomial distribution analyses are noted by p values above bar graphs.

Binomial distribution analysis indicated that student performance on exam questions related to active learning exercises was significantly better than performance on lecture-only material for each of the three exams given in Spring 2013. In terms of the percentage of correct answers, 95% confidence intervals indicate that student performance on active-learning material was 15%-20% better on the first exam, 6%-10% better on the second exam, and 4%-8% better on the third exam. We concluded from this analysis that Friday active learning sessions were generally beneficial to student learning and retention of course material. The active exercises performed earlier in the semester had greater apparent benefits than those later in the semester, which we discuss further in the Conclusions section.

One alternate interpretation of the observation that students performed better on exam questions related to active-learning topics is that the topics we chose for active exercises happened to be the easiest for students to learn. To test this alternate hypothesis, we compared the performance of students in the Spring 2013 cohort with the performance of students in the Fall 2012 cohort, which was the last cohort to have lecture-only instruction throughout the semester (Figure 2B). If the alternate hypothesis were correct, we would expect to see an equivalent difference in student performance on lecture-based questions and active-based questions in both Spring 2012 and Fall 2013. In contrast, we observed that students in Fall 2012 performed about equally well on the questions that comprised "lecture" and "active" topics in Spring 2013. Furthermore, students in Spring 2013 performed slightly better on topics that were taught using lecture in both semesters (~3% improvement), but much better on topics with related in-class activities in Spring 2013 (~12% improvement). These observations strengthen our conclusion that active learning exercises promoted student learning, and indicate that the greatest learning gains attributable to active learning were on the specific topics addressed by activities.

<u>Students believed lectures were slightly more useful than active exercises</u>.
We hypothesized that students might assign different subjective measures of utility to the traditional lecture periods and the active learning sessions. Active learning sessions differed in two important ways from lecture sessions: the class was subdivided into four groups, and students took part in various activities as noted above. We used an anonymous end-of-course survey to assess student attitudes towards both of these variables, for which the results are presented in Figure 3.

Students expressed positive opinions of the course as a whole and of the pedagogical methods used, with 81% agreeing or strongly agreeing that the course as a whole helped them to understand the material and a majority of students agreeing that both lectures and active learning exercises were useful. Students displayed ambivalence about the division of the class into four subsections for active learning materials, with about half of the class agreeing that smaller sections were useful and half the class agreeing that one large session would have been equally useful.

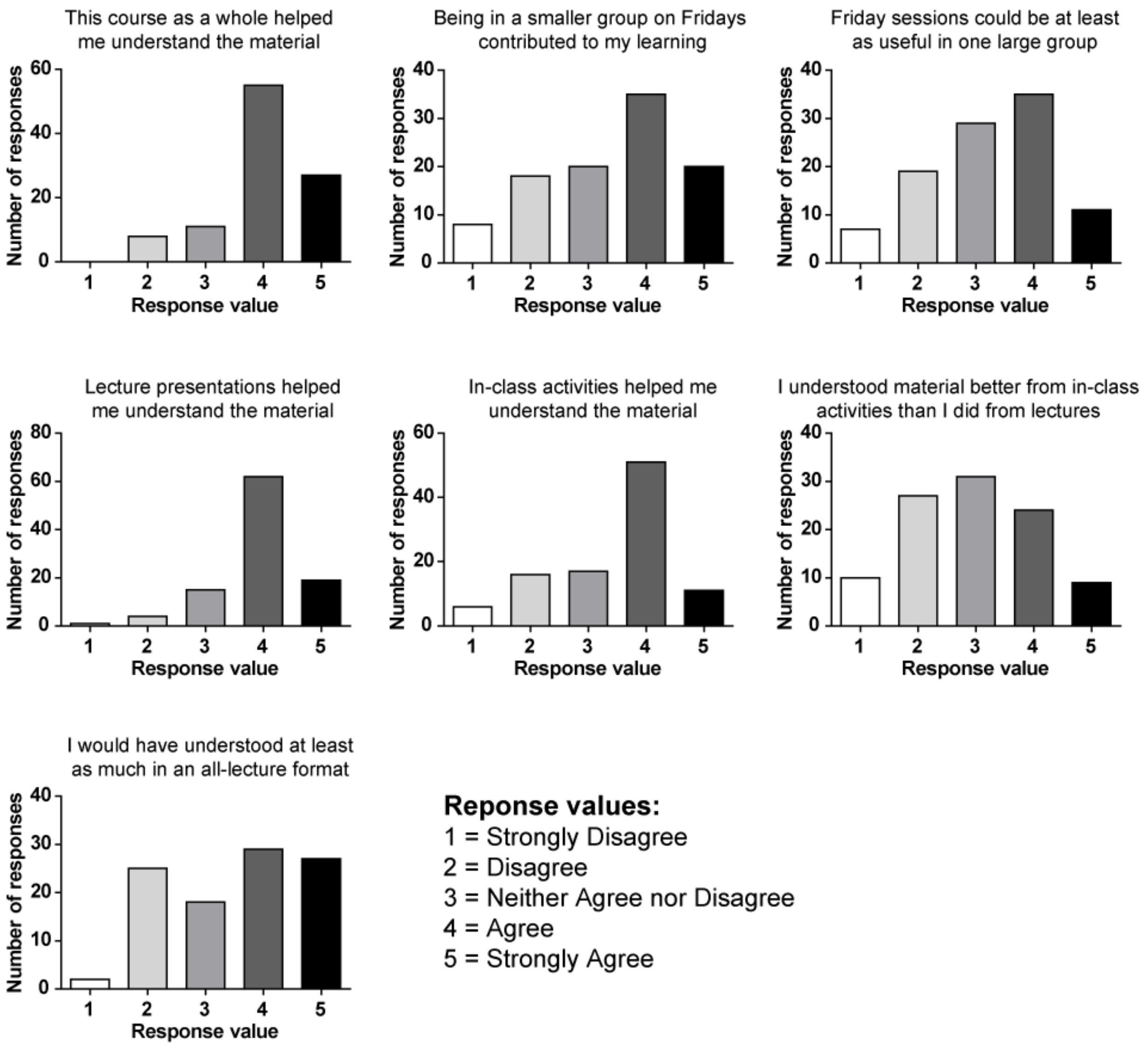


Figure 3: Survey responses. For each graph, bars represent the number of students choosing a given response to the question listed above the graph. Responses ranging from "strongly disagree" to "strongly agree" are coded 1-5 as noted in the key (lower center). A "prefer not to answer" option was given on the survey, but was not chosen by any respondents, so it is not shown here.

Despite their significantly better exam performance when tested on concepts from active exercises, students assigned a higher utility to lecture sessions than active learning sessions. On the end-of-course survey, 80% of students agreed or strongly agreed that lectures were useful, while only 61% agreed or strongly agreed that active exercises were useful. Some students (37%) considered lectures more useful than active exercises, while a slightly smaller number (33%) considered active exercises more useful than lectures. Most students (56%) believed they would have understood at least as much in an all-lecture format. We infer that, while student learning benefited from active learning exercises, as a group students were not consciously aware of these benefits.

Conclusions

This study measured student performance and attitudes, comparing lectures to active learning exercises as pedagogical tools in an introductory Microbiology course. In the semester under study, the student cohort displayed a measurable benefit of active learning exercises, relative to lecture presentations and to the performance of prior students, when evaluated on exams. We conclude that incorporating periodic active learning exercises of varying types is an effective practice for Microbiology 303, and that it may be generally useful in similar courses.

As a group, however, students did not accurately assess the measured benefits of active exercises, reporting lectures to have been superior as a pedagogical method. This disconnect between exam performance and student attitudes is somewhat surprising. Why would students not accurately assess what worked and what did not work to help them learn? The answer to this question likely stems from the interaction between two factors: varying quality of exercises (a study-specific factor), and the more general issue of underdeveloped metacognitive skills in the student body.

Considering the first of these two factors, as noted in Figure 2A, the measured effectiveness of active exercises in terms of increased exam performance declined noticeably from the first to the second exam and again from the second to the third exam. The student survey responses reported in Figure 3 represent a snapshot of student attitudes at the very end of the semester. Students' relatively poor opinion of active exercises relative to lecture may thus in part reflect a decrease in active exercise quality during the semester. One possible explanation for these observations is that active exercises used early in the semester were planned and revised during the Winter break before classes, and received more critical attention that later exercises that were designed during the course with less time for review before use.

Even the relatively less effective exercises used at the end of the semester boosted student performance on exams, however, which suggests that other factors also underlie students' opinion of active exercises. It seems likely that, in general, students did not have the metacognitive tools necessary to accurately assess what methods worked best to help them learn. A lack of appropriate skills for accurate assessment of one's own learning and abilities is a common trait in both college students and the general public (4, 5), and learning self-assessment strategies has been recommended as they are reported to increase student performance at various levels of education (6, 10, 13). In the case of the Microbiology 303 cohort under study, students may have perceived greater utility of lectures by conflating quality and quantity. That is, since two thirds of the course was taught in lecture format, and two thirds of the exam questions were thus derived from lectures, lectures seemed to students more useful overall regardless of their effectiveness on specific topics. Another potential contributing factor in student attitudes is that lectures may have given students a false sense of security relative to active exercises. A student who sits through a lecture and feels like they "get it" may rate the experience as more useful than an activity which challenges the student and highlights areas that they do not actually understand.

Based on the observed benefits of active learning exercises, and the fact that these benefits were not obvious to the students, we conclude with two general recommendations for undergraduate microbiology education. First, we recommend that courses should include active learning exercises, even as an occasional practice, since they increased students' performance on later assessments. Second, our results suggest that undergraduates would benefit from some training in metacognitive self-assessment strategies to better assess what methods of teaching and learning are most effective in promoting their mastery of information and practice.

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