Chapter 13

Vignette #2: Making a Switch to In-Class Activities in the Biochemistry Classroom

Emily J. Ragan*

Department of Chemistry, Metropolitan State University of Denver, Denver, Colorado 80217, United States

***E-mail: eragan@msudenver.edu.**

Active learning strategies aim to increase student critical thinking and engagement. In this article I describe my biochemistry classroom switch from lecture-only to half lecture and half in-class activities, inspired by Process Oriented Guided Inquiry Learning (POGIL). Students in a first semester biochemistry course maintained the same ACS exam scores at the end of the course, continued to rate the course and its instruction highly, and class attendance significantly increased after the change in pedagogy. This format was also implemented in a second semester biochemistry course during a course redesign. The flexibility of in-class activities allowed an iterative addition of a bioinformatics themed course-based undergraduate research experience (CURE). The Biochemistry II students report learning practical skills that are likely to benefit them in the future.

Introduction: Transition to Half Lecture and Half In-Class Activities

Five years ago, after teaching in a primarily lecture-only format, I transitioned to a classroom structure of half lecture and half in-class activities. This switch was inspired by attending an intermediate-level workshop on Process Oriented Guided Inquiry Learning (POGIL). I continue to teach in this format because I see students make connections in the classroom, can more easily discern challenging areas for students, and I appreciate the flexibility of multiple teaching strategies.

My experience with using in-class activities is that it requires an equivalent effort to lecturing but uses different skills due to the need to facilitate group work and develop activities that meet the learning objectives I use. Through facilitating in-class activities, I am more excited and engaged in the classroom and can more easily introduce new lecture innovations. For example, I recently introduced a course-based undergraduate research experience (CURE) during the first half of the semester in Biochemistry II.

Bussey et al.; Biochemistry Education: From Theory to Practice
ACS Symposium Series; American Chemical Society: Washington, DC, 2019.

Evidence-Based Active Learning with a Focus on Biochemistry

The Case against Straight Lecture

Student success depends on active engagement, making connections between new content and prior knowledge, and developing sufficient understanding to apply material to new content areas (*1–5*). While lecture remains popular, there is increasing evidence that a lecture-only classroom has limited capacity to elicit skills that we want our students to develop, including accurate figure analysis, successful extraction of information from written passages, and an ability to make connections beyond specific examples (*6–8*). In addition, student attention lapses with increasing frequency during lecture. While inattention can be reduced by engaging practices such as demonstrations and real-time formative assessments such as classroom polling, these practices do not typically challenge students to transfer knowledge broadly (*9*). We hope students will retain key concepts for use in future courses and in their careers, but my experience in the biochemistry classroom shows I cannot assume that students will always successfully remember and apply general chemistry and organic chemistry concepts. Students also struggle with transfer of knowledge from the classroom to other domains. Hence, there is a call for educators in biochemistry and related fields to work collaboratively to improve our teaching and to rethink how we spend our valuable in-class time with our students (*1*, *10*).

Active Learning Pedagogies

Active learning pedagogies, which include POGIL, problem-based learning (PBL), and peer-led team learning (PLTL), aim to create opportunities for students to engage with the course material in a supportive environment where they can take advantage of interacting with their peers while under the guidance of an experienced instructor (*4*). Active learning was an important element of a highly-structured course design that decreased the achievement gap in introductory biology (*5*); another study looking at an introductory biology course found gains were especially pronounced among students in the lower end of the grade distribution (*11*). Over eighty percent of biochemistry students in a large class reported in-class POGIL activities helped them learn (*12*). Group work may lead to learning gains due to increased peer and student-teacher interactions, and structured small groups and varied active learning strategies are proposed to promote equity and inclusion (*13*). It also provides an opportunity to target specific biochemistry concepts, as Mary Kopecki-Fjetland details in the chapter entitled "Introducing Active Learning to Improve Student Performance on Threshold Concepts in Biochemistry (*14*)."

A recent study found increased course motivation in students taking biochemistry in a small group and discussion format (*15*). Other research has shown value in using significant amounts of class time for students to interpret textbook figures, first independently and then in groups (*8*). The skills that are important for the acquisition of new knowledge include visual literacy, reading and understanding biochemical literature, and deep (rather than surface) learning, which can be practiced through in-class activities (*6–8*). Other goals for active learning may include communication skill development, enhanced ability to work in groups, improved attitudes, increased motivation, higher retention rates and a decrease in the achievement gap (*5*, *11*, *15–18*). For example, a meta-analysis examining problem-based learning at a Dutch medical school found improved interpersonal skills (*19*). Students using PBL completed the program sooner and with a higher retention rate, with a smaller, positive effect for acquiring medical knowledge (*19*).

Recently there has been increased interest in course-based undergraduate research experiences (CUREs), which involve all students in the course in addressing an authentic research question (*20*, *21*). Elements of a CURE include using scientific techniques, making discoveries that fit into broader scientific endeavors, collaboration, iteration, and authentic product production (*20*, *21*). CUREs have been proposed to have a myriad of benefits for students, including increasing persistence in science majors, and offering the experience to all students in a course rather than a self-selected group of students who volunteer for other research experiences (*20*).

Here I share my journey of introducing in-class activities in biochemistry lecture courses over the past five years. While detailed descriptions of implementing POGIL in full-class periods have been given elsewhere (*17*, *22*, *23*), here I share my experience with a hybrid approach in Biochemistry I, a move from full-class lecture to half lecture and half in-class activities, and include impacts on broad measures of student success and satisfaction. This foundation influenced the way I developed Biochemistry II during a course redesign. I initially mimicked what I did in Biochemistry I but evolved to link individual in-class activities and develop a CURE. After sharing my specific experiences, I discuss common concerns about making a switch to active learning and provide specific recommendations for making a smooth transition.

Active Learning Modifications to Biochemistry I

In Fall 2014 I introduced in-class activities in Biochemistry I, the first semester of a two semester sequence, by adding guided-inquiry worksheets. There are well-regarded published POGIL activities for Biochemistry which I used throughout the Fall 2014 semester (*24*). I ultimately decided to write my own activities, typically using at least one image from the textbook, so I could specifically target my learning objectives with in-class activities reinforcing and expanding upon content initially introduced in lecture.

At Metropolitan State University of Denver (MSU Denver), Biochemistry I is offered twice per week in 110 min blocks. Class formats before and after the introduction of active-learning segments are shown in Table 1. Groups of three to four students were formed on the basis of proximity in the classroom. This strategy worked in a classroom with movable, individual desks as well as in a classroom where students shared long tables, in which some students would turn around to work with students behind them. Other class formats were unchanged, including the learning objectives, weekly online homework assignments, weekly short (approximately 10 minutes long) quizzes, and clicker questions in lecture portion. I continued to give four midterm exams and the 2012 ACS Biochemistry exam (40 core questions) as the final exam. One slight change is that I shifted from giving 1 point/day for attendance (4% of total grade) before in-class activities to 2 points/day with in-class activities (7% of total grade). In both cases the lowest two attendance scores were dropped from the students' grades.

Table 1. Class Format before and after Addition of In-Class Activities

Before in-class activities (F13, S14)	*After in-class activities (F14, S15, F15, S16)*
10 min quiz (one day a week)	10 min quiz (one day a week)
45-55 min lecture	45-55 min lecture
5 min break	5 min break
50 min lecture	35 min in-class activity
	15 min reporting out

Fractional attendance (classes attended/total classes), final grades and ACS exam scores were compared for students who completed the whole semester, as measured by taking the ACS exam, from before and after the shift to POGIL instruction using unpaired, two-tailed t-tests (F13, S14, n = 59; F14, S15, F15, S16, n = 122). Pearson correlation coefficients were computed for class attendance (number of classes attended during the semester) and ACS Biochemistry exam score as well as for class attendance and final grade in course. All statistical analyses were performed using GraphPad Prism.

Impact on Attendance

In my Biochemistry I course there was a significant correlation between attendance and ACS final exam score, as well as attendance and final grade in the course, by Pearson correlation (Table 2). This correlation was observed before the introduction of in-class activities semesters (F13, S14) and after the introduction of in-class activities (F14-S16). These results are consistent with prior research, which shows class attendance in college is positively correlated with student grades (*25–27*). In addition, the meta-analysis shows that class attendance is a better predictor of college grades than SAT scores, high school GPA, study habits and study skills (*25*).

Table 2. Correlation between Attendance and Student Performance

	F13-S14 Attendance vs. ACS exam score	*F13-S14 Attendance vs. Grade %*	*F14-S16 Attendance vs. ACS exam score*	*F14-S16 Attendance vs. Grade %*
Pearson r	0.2799	0.6896	0.3023	0.4622
95% confidence interval	0.02566 to 0.5001	0.5265 to 0.8038	0.1316 to 0.4556	0.3099 to 0.5914
R squared	0.07834	0.4756	0.09138	0.2136
P value	0.0318	<0.0001	0.0007	<0.0001
Significant? (alpha= 0.05)	Yes	Yes	Yes	Yes
n	59	59	122	122

The combination of adding in-class activities and a modest increase in the number of points possible for class participation led to a statistically significant increase in attendance among students who persisted to the final. As shown in Figure 1A, attendance increased from an average of 77.2% (n = 59, SD = 11.76) of class periods attended to 88.5% of class periods attended (n = 122, SD = 19.62). Implementation of POGIL in an organic chemistry discussion section led to a significant increase in attendance of about 12%, similar to the amount seen in this study (*22*). In an introductory biology course that already had high overall attendance, active-learning activities led to a statistically significant increase in attendance of approximately 4% (*11*).

Overall, final course grade percentages were increased, but not significantly, after the addition of in-class activities (F13,14 mean = 82.92, SD = 12.5, n = 59; F14-S16 mean = 84.19, SD = 10.97, n = 122). However, when looking only at the lowest quartile of student grades (Figure 1B), the final grade percentages significantly increased, from a F13,14 lowest quartile mean of 66.59% (SD = 7.217, n = 15) to a F14-S16 lowest quartile mean of 70.46% (SD = 4.764, n=31). Thus, in-class activities with a small number of points associated with attendance benefited the grades of lower achieving students. In addition, the number of students who persisted to the final and ended up receiving less than 60% (an F) in the course decreased from 8.5% before in-class activities to 0.8% after the introduction of in-class activities. This effect was predicted by Credé et al., as even a modest increase in grades can dramatically affect the failure rate (*25*).

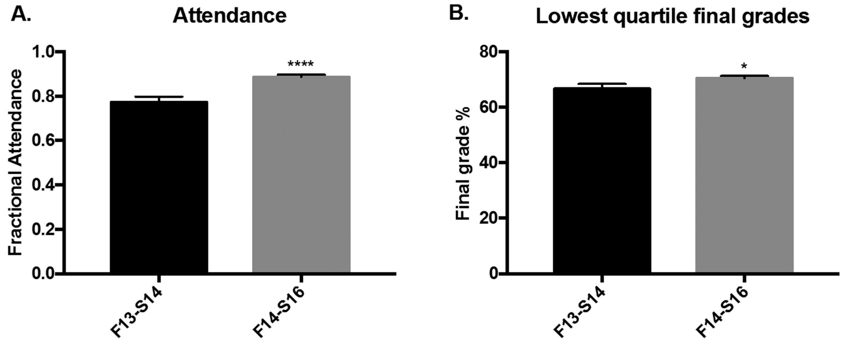

*Figure 1. Impacts of In-Class Activities on Attendance and Student Performance. The two semesters before (F13-S14) and the four semesters after (F14-S16) introduction of in-class activities were compared with respect to fractional attendance (A) and final grades of students in the lowest quartile of the class (B). All graphs show mean with SEM. A significant difference was seen for attendance ($p < 0.0001$, ****) and in the lowest quartile of final grades ($p = 0.0351$, *).*

Biochemistry I ACS Final Exam Scores

The 2012 ACS Biochemistry exam (40 question core version) was given to all the compared Biochemistry sections. The scores for the two semesters prior to adopting in-class activities (F13, S14) were compared with scores from the four following semesters in which I used in-class activities (F14, S15, F15, S16). As shown in Figure 2A, the ACS exam scores were statistically unchanged by the introduction of in-class activities (F13, S14 mean = 21.93, SD 5.681, n = 59; F14-S16 mean = 22.48, SD = 5.511, n=122). These results are consistent with published data showing that POGIL does not result in any losses on standardized tests (*4*). When specifically looking at the lowest quartile of students, the observed increase had a but still did not meet the threshold for significance, see Figure 2B (F13, S14 mean = 14.67, SD = 2.637, n=15; F14-S16 mean = 15.90, SD = 2.039, n = 31)

When specific ACS exam questions were compared from before (F13, S14) and after (F15, S16) the introduction of a consistent set of in-class activities, scores on three of the 40 questions were statistically significantly different using the cutoff of $p = 0.00125$ required to control for the family-wise error rate. Interestingly, one of the three questions was answered more poorly after the intervention; it was on a topic that was intentionally dropped from the course, and moved to Biochemistry II, after the introduction of the in-class activities. Student scores were higher on two questions after exposure to the in-class activities and, perhaps not surprisingly, both were on topics covered by the in-class activities. These results capture some of the gains and losses that come with covering a smaller amount of content in the semester but with greater depth.

Ideally, after students complete an activity on a concept, they will have increased their understanding of the concept and made gains in other areas targeted by the activity. These other gains may include confidence in interpreting data, working effectively in a group, or reflecting on the learning process. However, it can be challenging to measure gains in learning, even in the conceptual area. A foundational concepts in biochemistry inventory, with a pretest and posttest format, showed students in a large lecture course made clear gains in some concepts, like bond energy and pH/pK_a, but did not with respect to concepts of alpha helix structure and protein function, despite using an in-class activity targeting alpha helix structure (*28*). This negative result is an important reminder that students do not always make the learning gains that we expect and the value of including assessment measures to verify predicted gains.

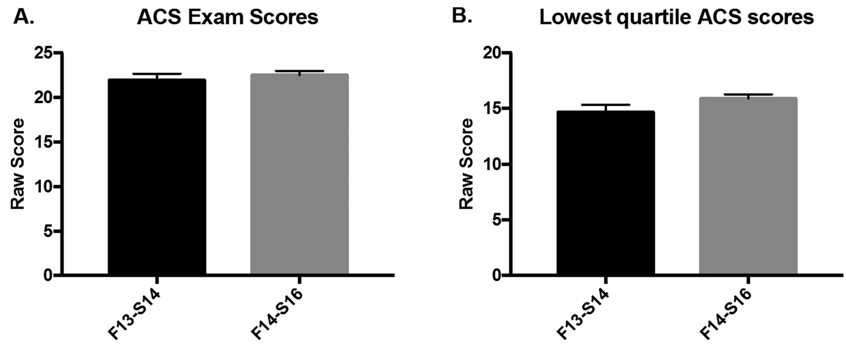

Figure 2. Impacts of In-Class Activities on ACS Biochemistry Exam scores. The two semesters before (F13-S14) and the four semesters after (F14-S16) introduction of in-class activities were compared with respect to ACS Biochemistry final exam scores (A) and Biochemistry ACS final exam scores of the lowest quartile of students (B). All graphs show mean with SEM. No significant change was seen for total biochemistry ACS final exam scores ($p = 0.5394$) or lowest quartile ACS scores ($p = 0.0871$).

Impact on Ratings of Instruction

One concern I had upon making the switch to half-active learning in the classroom is that student ratings of instruction (SRI) scores might decrease, especially during initial attempts at implementation (*11*). Students have been shown to value lectures and individual active learning but to be suspicious of the value of cooperative learning (*29*). MSU Denver student ratings of instruction (SRI) have only two questions: evaluation of the course as a whole, and evaluation of the instructor's contribution to the course. For each question the options are excellent (6), very good (5), good (4), fair (3), poor (2) or very poor (1). SRI scores from semesters prior to using in-class activities (F13, S14, n = 47) were compared with scores after introducing in-class activities (F14, S15, F15, S16, n = 99) using unpaired t-tests.

I was pleased to observe that the SRI scores for both the course as a whole (Q1) and the instructor's contribution (Q2) were statistically unchanged after the switch (see Figure 3). The 50/50 mix of half-lecture and half in-class activities may be perceived more favorably by students than a complete switch to in-class activities (*11*). In this present study, the same instructor taught the lecture-only as well as the active learning classes, which differs from the study by Walker and colleagues in which significantly lower scores were found in the active section but instructors differed between sections (*11*). I communicated reasons for my change in teaching style with the students in an attempt to gain buy-in, sharing that the activities would break up the monotony of a long lecture (110 minute) and that we would bring some of the frustration that students would otherwise encounter in homework into the classroom, where classmates and the instructor are available as resources. Finally, I used the in-class activities as a foundation for some exam questions, providing evidence to the students that their effort on in-class activities will also help their performance on the exams, which students value (*29*).

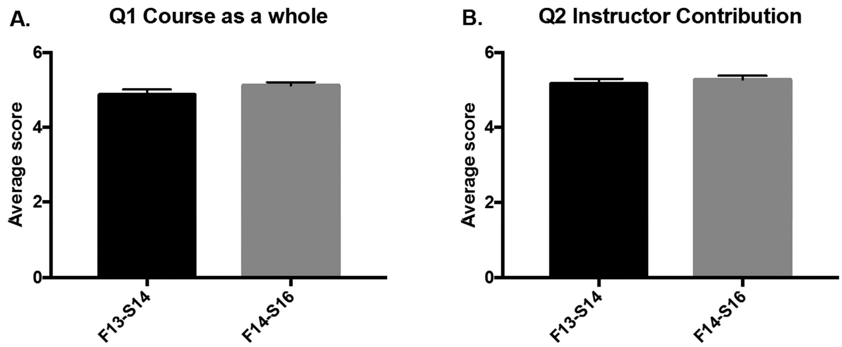

Figure 3. Student ratings of instructor (SRI) scores for course as a whole (A) and instructor contribution (B). All graphs show mean with SEM. No significant change was seen for SRIs before and after introduction of in-class activities (Q1 p = 0.1237, Q2 p = 0.4842).

Guided Inquiry Activities for Biochemistry II

New Course Preparation as an Opportunity to Introduce In-Class Activities

In Spring 2016, the MSU Denver Department of Chemistry began offering a new version of Biochemistry II, which had been previously taught as a special topics course and is now a second semester continuation of Biochemistry I. I used this new course format as an opportunity to prepare approximately hour long lectures to be followed by approximately 50 minute in-class activities. These activities provided students opportunities to read biochemical literature and interpret figures. My experience was that it did not take any longer to develop in-class activities than to prepare lectures for the first time, particularly through the use of chapter references in the textbook as a starting place in my search for appropriate and relevant articles. These activities were based in part on experiences I had in seminar style courses in graduate school but with the goal of offering more support and scaffolding for students.

Opportunity to Introduce a CURE

After teaching Biochemistry II in this format for two semesters, I developed a linked series of activities involving online Biochemistry resources for DNA and protein sequences. The following semester I modified that linked set of activities to involve proteins related to iron uptake in insects, a topic of interest for a research project I am performing in collaboration with Dr. Maureen Gorman at Kansas State University. By linking the activities to my research I developed a Course-based Undergraduate Research Experience (CURE) called "A Bioinformatic Look at Iron Uptake in Insects" (*30*). While CUREs typically have been found in laboratory settings, the ability to perform bioinformatics work anywhere there are computers helped facilitate my incorporation of a CURE into biochemistry lecture. A resource for finding CUREs is CUREnet (*31*).

A major goal of my CURE is for students to gain experience with commonly used sequence databases and sequence analysis tools, such as organism independent databases UniProt (*32*) and NCBI (*33*), data publicly available an online resource for the *Drosophila melanogaster* community called FlyBase (*34*), multiple sequence alignment tool Clustal Omega (*35*), and protein family database Pfam (*36*). Student findings can help inform our research and make a contribution to increasing human knowledge, which is another benefit. Students were assigned to groups and to a specific protein (and its gene) related to iron uptake in insects. The groups spent the second half of the class period working on guided activities that I wrote to guide use of resources. The topics for the in-class work are summarized in Table 3, alongside the lecture topic for the day. Each group member individually would make an entry with answers to questions and a record of their investigation in a free online notebook program called Benchling (37), which I graded five times during the project. The final product was a group memo to my collaborator, who provided written feedback to the students. I graded the draft and final memos and gave additional feedback at each stage.

Table 3. Overview of CURE Piloted in Fall 2018

Day	*Lecture Topic*	*Group Activity Topic*
1	Review of nucleic acids	Discuss past group work experiences and strategies for success
2	Introduction to iron uptake in Drosophila project	Explore an assigned protein sequence in UniProt
3	DNA replication	Use FlyBase to explore the gene related to the assigned protein sequence (gene of interest, GOI); Benching entry #1 due
4	Genomes and ENCODE project	Explore mRNA transcripts for GOI in FlyBase and link to Eukaryotic Promoter Database
5	Transcription	Analyze RNAseq data for GOI available in FlyBase; Benchling entry #2 due
6	Splicing	Introduction to amino acid alignments with protein isoforms from GOI
7	Translation	Introduction to protein BLAST searching; find homologs of assigned protein in other insect species; Benchling entry #3 due
8	Histones and regulation of gene expression	Protein domain families and PROSITE; PBLAST with a protein domain of interest
9	Signal transduction through nuclear receptors	Make multiple sequence alignments of BLAST search results; Benchling entry #4 due
10	DNA repair	Time in class to work on memos to collaborator summarizing results
11	Finish DNA repair; review for midterm 1	Draft memo due at end of day; Benchling entry #5 due
12	Midterm #1	Draft memos returned
13	Metabolism Review	Last chance to work on memos in class
14	Lipid metabolism	Final memo due

I emphasized to the students that the skills they learned could be transferred to other research questions. This was reinforced in the second half of the course, when the students built on the skills developed during the first half of the semester to analyze a protein of their choosing. The individual research paper required students to generate a multiple sequence alignment comparing their protein of interest to a related protein that has a solved 3D structure and to explore elements of structure as they relate to the protein function. These open-ended projects require students to think deeply and synthesize multiple concepts. Advantages of such projects include students working at a higher level (for example, within Bloom's taxonomy) and with more motivation (*1*).

An end of semester anonymous survey question about the CURE included three open ended questions. In response to "What were the greatest benefits you gained from participating in this project?" two thirds of the students mentioned using the online databases and tools. For example, *"The greatest benefit from this project came from learning how to use different research tools available online in a practical and relevant way."* A remaining almost thirty percent commented on iteratively "doing" science and conducting research. *"Compared to my other science classes, I felt like there was room for error but there was an ability to quickly learn from it and also to put in our input as well. It really made us feel like we were actually "doing" science instead of just lecture."* Another student commented about *"feeling it preps for a real world transition into a work place."*

Students were also asked, "How would you like to see this project changed in the future?" Twenty percent of the students wished there had been less group work. *"I would prefer to not do a group paper for the first project. I enjoyed the second research project and didn't find anything I'd like to change."* Thirteen percent wished for more clarity about group expectations and how to use resources. For example, one student wrote to suggest *"assigned roles or an example of expectations of the final contribution or participants."* Defined roles are a standard element of POGIL and could be incorporated into a longer project like this CURE. One third of the students did not make any suggestions for improvement.

I also requested testimonials from previous students to enhance student buy-in at the beginning of the semester. For example, one former Biochemistry II student wrote, *"Honestly, when I first took Biochem 2, I really didn't think bioinformatics had anything to do with the science or research I was interested in. When I got to grad school I found that it is really heavily used in many different areas of research (even biophysics and engineering!). Immediately, in two of my grad level courses, we were expected to use BLAST, UniProt, ExPASy, and more without any guidance from the professor. So, it was really helpful having a leg up because I had experience working with them from this [Biochemistry II] project."*

Addressing Instructor Concerns about Active Learning Pedagogies

Challenges with Implementing Active Learning Pedagogies

POGIL activities fit within single class periods and there are also published POGIL materials available, yet implementing active learning pedagogies can be challenging (*17*, *24*). Selection (and often development) of the in-class activities and gaining facilitation skills for guiding students working in small groups requires time and effort. In fact, the majority of faculty trained at workshops for new methods fail to implement them (*38*, *39*). In addition, reduction or elimination of lecture often leads to concerns about covering all the content in the course. In some cases students have been found to focus positive comments on their professor in lecture-only courses and, in a more active learning setting, switch the positive feedback to the course itself (*11*), although fortunately that has not been my experience.

In-Class Activity Development

My approach to writing activities has been to start with my learning objectives, which is sometimes called backward course design (*1*). A planning tool for using backward design to support lesson development for active learning was used for a non-majors biology course and can be applied to the biochemistry classroom as well (*40*). I found figures or other content that students would benefit from having time to look at in more detail. I considered images from lecture slides that provoked confusion and were difficult to explain quickly in lecture as good candidates for in-class activity questions. A study on active and problem-based learning in introductory biology suggests group exercises are ideally challenging enough that it is hard for students to solve them on their own but over 50% of the groups can complete them as a team (*16*). I have found that it is helpful to follow the POGIL activity format, starting with more directed questions that are eliciting observations, then moving on to convergent questions that require students to identify patterns or draw conclusions, and ideally including divergent questions that require application of concepts, synthesis of information, or creative thinking (*23*). It is also important to pay attention to how the activities actually work in class. I have found that it works best if I modify my activities right after class so that they are ready for the following semester and, as has been observed previously, it is valuable to incorporate student feedback in future iterations of the activity (*16*).

Concerns about Quantity of Content Covered

Concerns about covering the same amount of content that would be covered in a lecture-only classroom can be addressed in multiple ways. Content can be shifted from lecture to in-class activity so that it is covered, but in a slightly different way than before. For example, I now cover coordinated regulation of glycolysis and gluconeogenesis through an in-class activity rather than lecture. Additionally, content can be moved outside the classroom using strategies from “flipped classrooms” or online learning, such as assigned readings, video lectures, and homework questions (*41*, *42*). There might be a dual advantage to coupling flipped classrooms with adding in-class POGIL activities as there have been learning gains documented for flipped classrooms, including increased scores from lower performing students in a general chemistry II classroom (*43*). We can also streamline our PowerPoint or other lecture materials to set the stage for in class activity rather than intensive content delivery (*40*). Finally, there may be some topics that can be omitted while maintaining the same course learning objectives.

Advantages for Instructors

Unfolding of the Learning Process

An advantage of in-class activities is that the instructor can see the learning process unfolding, which includes instructor exposure to difficult concepts for students prior to seeing their incorrect answer on an exam question (*44*). This provides an opportunity to address chronic misunderstandings, such as thinking energy is released when a bond breaks (*28*, *45*, *46*). When observing students discussing a question related to this concept, I realized how content from my lecture, a statement about potential energy being stored in bonds, was contributing to that misunderstanding. While others have previously made the observation that describing energy as being stored in bonds is problematic, had I not been listening to my students reason out-loud in class, I would still be unaware how I was contributing to their confusion (*47*). Other instructors value active learning opportunities for insights into learning processes and as a chance to reflect on our instruction (*14*, *46*).

Ongoing Innovation

My switch to half lecture and half in-class activities had the additional advantage of facilitating additional innovation in the biochemistry classroom. I can adjust the activities and ratio of lecture, active learning in the classroom, and assignments outside of the class depending on the content covered. By having blocks of time in the classroom that are more flexible, I was able to implement a seven-week course-based undergraduate research experience based on my work on iron uptake in insects during Biochemistry II.

Shifting away from a lecture-only format provides opportunities for additional skill development in the classroom. One of my goals is student preparation for life after graduation, whether they attend graduate school or obtain a professional position. As our students transition to graduate or professional schools and careers, they need to be proficient in processing and learning information in a more independent manner. This is in part why the GRE subject tests and the MCAT have passages and figures to be read and analyzed. The skills important for the acquisition of new knowledge include visual literacy, reading and understanding biochemical literature, and deep (rather than surface) learning, all of which can be practiced through in-class activities (*6–8*). Other goals researchers have aimed to address through active learning include communication skills, ability to work in groups, improved attitudes and retention rates, increased motivation, and decreasing the achievement gap (*5*, *11*, *15–18*).

Opportunities with the Growth of Open Educational Resources

Using in-class activities requires a switch from lecture content delivery and brings the freedom to address learning objectives in a variety of ways (*40*). A creative focus on meeting learning objectives dovetails with the growing movement to use open educational resources (OER), which allow free reuse, remixing and redistribution with the appropriate attribution (*48*). Facilitated by Creative Commons licensing, there is now an unprecedented opportunity to share instructional materials through repositories including OER Commons (*49*), LibreTexts (*50*), MERLOT (*51*), and CUREnet (*31*). In the future we could have a robust community of practitioners sharing activities through such resources.

Strategies for Making a Switch

Goals

My recommendations for instructors looking to make a change in their classroom are to reflect on what is already working well, then identify elements they would like to change and why. My goal for Biochemistry I was to have students actively engaging with content in the classroom and encountering points of challenge and confusion while their classmates and I were available. I appreciated being able to share some content in lecture, so I kept about half of my lecture time and made my lectures more efficient. I then introduced activities that required application of content, reading, and figure analysis. In the context of Biochemistry II, my goal has evolved into students transferring classroom knowledge to using bioinformatics based tools and data sets to generate new knowledge. This has required a more elaborate, connected set of activities.

Finding or Creating Activities

For in-class activities, instructors can explore existing content, including the Foundations of Biochemistry book and case studies through the National Center for Case Study Teaching in Science (*24*, *52*). Directed case studies have been used in a variety of capacities in the biochemistry classroom, both for in-class and homework purposes (*44*). Another easy entry point is having students focus on careful figure analysis using figures from their textbook (*8*). I have had a positive experience creating in-class activities that specifically target my learning objectives, and this approach is addressed more in another chapter in this book (*14*). Resources for writing in-class activities include the POGIL Project (*53*), as well as a planning tool that integrates backward design with active learning (*40*).

Student Buy-In and Groups

Facilitating group work requires decisions about how to compose groups, whether to impose group roles and a willingness to engage with students and support effective group functioning (*54*). More complicated projects, like a CURE, require the students to work together because of their complexity, which can elicit positive group interdependence (*55*).

Gaining student buy-in is important. A challenging activity may generate some frustration but also larger learning gains than a more straightforward activity (*56*). Sharing this information with students, along with other relevant student benefits, is important for generating student participation and engagement. I got excellent advice for how to sell my Biochemistry II CURE from a former student who returned to serve as a learning assistant for the class. I now have a conversation with the class exploring why scientific research is important and why an opportunity to participate in research is beneficial.

Establishing the relevance of the assignment will also help support group function, as does design of an appropriately challenging assignment (*55*). As a first day group activity in Biochemistry II we had students in groups reflect upon past group work experiences to highlight what had worked well, potential pitfalls, and strategies for overcoming obstacles. Students recognized the importance of communication and shared responsibility. We also shared strategies from highly-functioning groups in previous semesters, including simple ones like sharing contact information and coordination of task management, to support group efficacy.

Feedback and Assessment

Be sure to build in many opportunities to get feedback from your students. One strategy is to have students write down comments about how the group functioned or challenging content areas at the end of class. This results in a short note for the instructor from each group that gives quick insight. Mid-semester surveys, end of project feedback forms, and end of semester reflections can provide a broader student perspective and are particularly valuable for iterating course design between semesters. Students also appreciate that we value their feedback and that we are actively working to continually improve our courses.

Assessment of learning and other outcomes can come through evaluation of student work, including quizzes, exams, presentations and, my favorite for Biochemistry II, a memo to my collaborator. It helps with student buy-in and course alignment to include skills developed during the in-class activities on the quizzes or exams. The perennial student question, "Will this be on the exam?" can be annoying. I find it very satisfying to say, "Yes, this is fair game for the exam," for everything that we cover in the class, including the content in the in-class activities. When looking at assessment data, keep in mind that maintaining the same level of achievement is a success because the intervention did not cause any harm. Identifying other gains, such as in attitude or ability to work in groups, will require targeted assessment in those domains. I have found a continual cycle of assessing, reflecting and iterating helps me stay engaged with my teaching and the larger fields of science education and how learning works. I encourage readers to explore how active learning can help increase the excitement and energy in the classroom, as well as depth of engagement with biochemical content, both for the instructor and the students.

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