Whitworth Digital Commons
Whitworth University

Chemistry Faculty Scholarship | Chemistry

11-22-2015

Assessment of Learning Gains in a Flipped Biochemistry Classroom

Deanna Dahlke Ojennus
Whitworth University, dojennus@whitworth.edu

Follow this and additional works at: http://digitalcommons.whitworth.edu/chemistryfaculty

 Part of the Biochemistry Commons, Educational Methods Commons, and the Science and Mathematics Education Commons

Recommended Citation

Ojennus D.D. Assessment of learning gains in a flipped biochemistry classroom. *Biochemistry and Molecular Biology Education*. 2015 Nov 23. (doi:10.1002/bmb.20926).

This Article is brought to you for free and open access by the Chemistry at Whitworth University. It has been accepted for inclusion in Chemistry Faculty Scholarship by an authorized administrator of Whitworth University.

This is the pre-peer-reviewed version of the following article: Ojennus D.D. Assessment of learning gains in a flipped biochemistry classroom. *Biochem Mol Biol Educ.* **2015** Nov 23. (doi:10.1002/bmb.20926), which has been published in final form at http://onlinelibrary.wiley.com/doi/10.1002/bmb.20926/full.

Assessment of Learning Gains in a Flipped Biochemistry Classroom

Deanna Dahlke Ojennus

Department of Chemistry, Whitworth University, 300 W. Hawthorne Rd., Spokane WA, 99251

Abstract

The flipped classroom has become an increasingly popular pedagogical approach to teaching and learning. In this study, learning gains were assessed in a flipped biochemistry course and compared to gains in a traditional lecture. Although measured learning gains were not significantly different between the two courses, student perception of learning gains did differ and indicates a higher level of satisfaction with the flipped lecture format.

Keywords: flipped classroom, inverted classroom, hybrid course, learning gains, biochemistry

The flipped classroom has become increasingly popular in STEM higher education in recent years, largely due to the volume of supporting anecdotal evidence and positive student response. It is not surprising that students quickly accepted the shift in pedagogical approach considering that YouTube has become a ubiquitous source for fast, bite-sized pieces of information as well as entertainment. Although the benefits reported by instructors and students are numerous, very little has been published attempting to quantify increases in learning gains achieved through adoption of a flipped classroom model for teaching. Thus, this study explicitly examines differences in learning gains between a flipped and a traditional lecture classroom and compares actual learning gains to learning gains perceived by students.

Background

In the flipped (or inverted) classroom, the traditional teacher-centered lecture is placed outside the regularly scheduled class time while activities that normally are assigned as homework are brought into the classroom. This is frequently done by recording lectures and making them available for students to watch on their own time outside of class. This leaves classroom time free for "homework" activities which may include other evidence-based teaching and learning strategies, such as problem-based learning [1-2], inquiry-based learning [3-4], project-based learning [5-6], and cooperative learning [7] without the need to sacrifice course content.

In the seminal book *Flip Your Classroom: Reach Every Student in Every Class Every Day*, Bergmann and Sams [8] provide anecdotal evidence on the benefits of flipping a classroom as observed in their own chemistry classrooms at Woodland Park High School in Colorado. Observed benefits included 1) helping busy students (such as student athletes) catch up on material missed due to frequent absences, 2) helping struggling students by allowing them to set the pace with content on demand, and 3) allowing teachers to get to know their students better due to increased teacher-student interaction in the classroom.

The flipped classroom strategy using streaming video lectures was first implemented and reported in higher education in economics [9] and has since become increasingly popular among STEM disciplines including statistics [10] and engineering [11]. Chemistry higher education has been slower to adopt the inverted classroom approach, however several recent reports have been published assessing this pedagogical approach primarily in General Chemistry [12], Organic Chemistry [13-14], Analytical Chemistry [15], and GOB courses [16-17].

In this study, learning gains were assessed between two sections of upper-division undergraduate biochemistry courses, one of which was taught in a traditional teacher-centered lecture format and the other was taught as a flipped classroom. The idea of spending classroom time on activities other than lecture is not new to biochemistry courses. For example, a lecture-free format has been implemented effectively at Seattle University in process-oriented, guided-inquiry learning biochemistry classrooms

(POGIL) [18]. It has also been suggested that the Khan Academy videos can serve as a convenient route to flipping any biochemistry course as the multimedia for lecture delivery is readily available to anyone [19]. There are also reports of where flipped classroom models have been introduced in biochemistry classrooms at Columbia University [20] and at the Stanford University School of Medicine [21]. However, as far as the author knows, nothing yet has been published attempting to quantify differences in learning gains between traditional and flipped classrooms within an upper-division biochemistry course. This study aims to determine if anecdotal evidence supporting flipped classroom instruction can be validated as an observed change in measured learning gains as well as to compare student perceptions of learning gains between the two types of classrooms.

Course Design

The upper-division biochemistry course at Whitworth University is a year-long sequence taught over two semesters. In the fall of 2014, high student enrollment allowed for two sections of Biochemistry I to be offered, one section was taught as a traditional lecture while the other was taught as a flipped classroom. Classes were taught in back-to-back time periods by the same instructor.

Course assessment measures were identical in both classes, the only difference was how lectures were presented and how time was spent in class. In the traditional classroom, students received a 55 minute lecture that used a combination of powerpoint images and board work with note outlines. On occasion the class read assigned research articles and then worked in small groups to answer questions about the work as it related to the course material.

In the flipped classroom, the same lecture content was pre-recorded as narrated Powerpoint presentations using Panapto [22] and posted on the student course management system, Blackboard Learn [23], ahead of class. Videos ranged between 9 and 38 minutes in length and averaged 21 minutes. Students in the flipped classroom were asked to view the lecture videos before class and come to class prepared to work on chapter homework problems in small assigned groups. Both classes were assigned identical homework problems, but only the flipped classroom worked on these homework problems in class. Both classes were also assigned textbook readings prior to class and were required to complete a pre-class reading comprehension activity online using the Sapling Learning system [24].

Course Demographics

The traditional lecture had 33 enrolled students and the flipped had 28 enrolled students. Each class had some students enrolled as writing-intensive (W) which required literature based writing assignments in place of a cumulative final (6 in traditional, 2 in flipped). A total of 29 traditional lecture students and 25 flipped lecture students participated in the study (Table 1). All study participants completed a pre-test, a post-test, and a survey.

Assessment of Learning Gains

Pre- and Post-Tests

A pre- and post-test was administered to each section consisting of thirty questions, three from each textbook chapter (Chapters 4-12 from Voet, Voet, & Pratt [25]), ranging in difficulty from low to high cognitive skill as defined by Bloom's taxonomy [26] (Figure 1).

Independent sample t-tests comparing means in the flipped and traditional classrooms for pre-test, post-test, and normalized learning gains [27] was performed (Table 2). Analyses for the post-test scores and normalized learning gains resulted in $p > 0.05$ (two-tailed), indicating that the null hypothesis must be accepted and no statistical difference was observed within 95% confidence. Differences in pre-test scores were statistically significant ($p = 0.041$) and likely are due to skewed demographics (juniors vs. seniors) between the two sections.

The flipped classroom appears to have higher learning gains in low level cognitive questions than the traditional classroom. This is not necessarily unexpected since the flipped classroom consisted of mostly juniors while the traditional classroom was mostly seniors. Thus, students in the flipped classroom likely started with a smaller knowledge base than the traditional classroom students. However, upon comparing learning gain means at low, medium, and high cognitive level questions using independent sample t-tests, all resulted in $p > 0.05$ (two-tailed), thus no statistical difference between means was found and we must accept the null hypothesis that lecture format did not affect learning gains.

Exams and Final Grades

Three exams and a cumulative final were administered to each class. Each exam covered three chapters of material and consisted of short answer essay questions and calculations. Both the traditional and flipped classrooms performed nearly identically on these exams. Exam class averages were within standard error of each other on every exam when compared between flipped and traditional classrooms (Table 3). When final grades were assigned, a higher correlation between overall course performance and measured learning gains was observed in the traditional lecture than the flipped classroom (Figure 2). This may indicate that the flipped classroom is more supportive of weaker students than the traditional lecture. Unlike the traditional lecture, the students that exhibited the highest normalized learning gains were not the students receiving the highest grade in the flipped class.

Student Assessment of Learning Gains (SALG)

A LIKERT scale SALG survey adapted from Seymour *et al.* [28] was administered at the end of term. Students were asked to assess their own perception of learning gains and acquired skills in several areas (Tables 4 and 5). Only one learning gain area exhibited a significant difference in means between flipped and traditional classrooms ($p = 0.028$), thus students in the flipped classroom perceived on average that they were more comfortable with complex ideas after taking the course than the traditional lecture

students. Of all the skills surveyed for improvement only one exhibited a significant difference in means between the flipped and traditional classrooms, working effectively with others ($p = 0.0018$). Since group work on problem-solving activities was limited to only thirty minutes once every couple of weeks in the traditional classroom, the flipped classroom spent considerably more time working in small groups and therefore perceive that their skill in cooperative learning had improved.

Student Assessment of the Course

When students were asked to rate each course element in terms of usefulness to their learning, a difference was observed in two areas (Table 6). The lecture was ranked as highly useful by both, but was significantly higher in the flipped lecture than the traditional ($p = 0.00096$). The usefulness of classroom group work and activities was also ranked very differently between the two and found to be far more useful in the flipped lecture ($p = 2.1 \times 10^{-9}$). Strayer [10] also observed in quantifiable student perception surveys that students in inverted classrooms placed a higher value on group learning than students in traditional classes. Similarly, students in an inverted analytical chemistry class [15] reported a stronger dependence on cooperative learning at the end of the semester as indicated in a decrease in their impression to work best individually.

Student comments were solicited at the end of the survey asking them to comment on the usefulness of any course aspect towards achieving learning gains. In the traditional course, only a couple comments were provided about the lecture. One student commented that "*the lecture format was very student-friendly – you just showed up and copied what was written […] it was very clear [but] it didn't require a lot of engagement*." Another student said that the lecture moved "*at a break-neck speed through some sections*". Far more students commented on the usefulness of the video lectures in the flipped classroom and included the following comments:

- *The flipped classroom was great. Lectures were organized and concise and I loved being able to pause or replay content.*
- *The video lectures helped a ton not only because it allowed me to take notes at a slower pace, but it also allowed us to work on problems in class with [the instructor's] help.*
- *I really enjoyed the flipped schedule. I thought I was able to better learn the material because I could watch the video as many times as I had wanted.*
- *It was very helpful to be able to rewatch lectures, pause when I needed to, and bring questions to class.*
- *The flipped lecture style made me wish that every one of my classes was also flipped. Online lectures allowed me to go at my own pace, which was extremely helpful.*
- *I did not think I was going to like the flipped lecture style, but it was actually very helpful to rewatch videos when needed.*
- *Learning the material on our own time and then working with peers and [the instructor] in class proved very beneficial to my learning. It is easy to go into "zombie mode" after sitting through three-four hours of lecture a day. Bouncing ideas off each other, teaching my group and being taught by my group seemed like a much better use of class time than taking notes on a lecture.*

Conclusions

This study showed no appreciable difference in overall measured learning gains observed between flipped and traditional biochemistry classrooms. Similar observations were made in organic [13-14] and analytical chemistry [15] classes when comparing overall course performance on exams or final grades between flipped and traditional classrooms. In contrast, improvements in course performance have been observed in inverted general chemistry classroom performance [29]. This suggests that the flipped model is more successful in improving student performance within introductory level chemistry courses than in higher level courses. Also, flipped chemistry classrooms have reported better retention rates of students who successfully complete the course [13][29], making it a more effective strategy for those courses that suffer from a high number of withdrawals or failures.

Although overall learning gains were unaffected, students in the flipped biochemistry lecture perceived that they were on average more comfortable dealing with complex ideas and working effectively with others at the end of the course than traditional lecture students. Written comments from students solicited in the survey also indicated high satisfaction and support of the flipped lecture format which is in agreement with SALG survey results in which students in the flipped class ranked the lecture higher in usefulness to their learning than the traditional class. Student comments about being able to re-watch the video lectures and go at their own pace were frequent and corroborates Bergmann and Sams' observations about the benefits of flipping.

These are only preliminary results for a flipped biochemistry class and additional study will be needed. In particular, it should be determined if the disparities in the junior/senior or male/female ratios between the flipped and traditional classes had any impact on the measured learning gain outcomes. Also, it should be noted that the students in both sections of the course are predominantly high achieving, even among Whitworth University students, are either pre-med or earning a B.S. in chemistry, and have benefited from small class sizes (>80% of classes have 30 or less students) throughout their program of study. It would be interesting to determine if larger biochemistry class sizes or other upper-division classes with a higher incidence of withdrawals or failures would exhibit a similar trend.

From a teaching perspective, the flipped classroom was better in terms of both pacing and student-instructor interaction. Classroom time could be spent helping students within small groups work on problems and allowed the instructor to intervene early to correct student misconceptions. It was easier to get to know each individual student's strengths and weaknesses as well. On the negative side, preparing the lecture videos took significant prep time, but it is anticipated that updating the videos will require less work when taught for the second time. Although flipping did not appear to improve measured learning gains, the student buy-in and increased instructor-student interaction are still convincing arguments to try this pedagogical approach.

Acknowledgements

Thanks to Whitworth University for providing a Teaching with Technology grant in support of this study. Many thanks also to Dr. Trisha Russell who proctored pre- and post-tests.

Statement on Ethical Research

This was a voluntary study which was approved by Whitworth University's Institutional Review Board for the fall semester of 2014. Students were offered an extra credit incentive for completing the pre-test, post-test, and survey. Extra credit was provided whether or not they chose to be a study participant.

References

[1] H.S. Barrows (1996) Problem-based learning in medicine and beyond: A brief overview, New Directions for Teaching and Learning, 68, 3-12.
[2] D. Boud, F.I. Feletti, Eds. (1997) The Challenge of Problem-Based Learning, 2nd ed., Kogan Page, London.
[3] J. Schwab (1960) Inquiry, the Science Teacher, and the Educator, The School Review, The University of Chicago Press 68, 176-195.
[4] V.S. Lee, ed. (2004) Teaching and Learning Through Inquiry: A Guidebook for Institutions and Instructors, Stylus Publishing, Sterling, VA.
[5] M.J. Prince, R.M. Felder (2006) Inductive teaching and learning methods: Definitions, comparisons, and research bases, J. Eng. Educ. 95, 123-138.
[6] M.J. Prince, R.M. Felder (2007) The many faces of inductive teaching and learning, J. College Sci. Teach. 36, 533-568.
[7] D.W. Johnson, R.T. Johnson, K.A. Smith (1991) Active Learning: Cooperation in the College Classroom, Interaction Book Company, Edina, MN.
[8] J. Bergmann, A. Sams (2012) Flip Your Classroom: Reach Every Student in Every Class Every Day, 1st ed., International Society for Technology in Education.
[9] M.J. Lage, G.J. Platt, M. Treglia (2000) Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment. J. Econ. Educ. 31, 30-43.
[10] J.F. Strayer (2012) How learning in an inverted classroom influences cooperation, innovation and task orientation, Learn. Environ. Res. 15, 171-193.
[11] B.M. Clemens, C. Nivargi, A. Jan, Y. Lu, E. Schneider, J. Manning (2013) Adventures with a flipped classroom and a materials science and engineering MOOC: "Fools Go Where Angels Fear to Tread", MRS Online Proceedings Library, 1583, opl.2013.774/1-opl.2013.774/6.
[12] J.D. Smith (2013) Student attitudes toward flipping the general chemistry classroom, Chem. Educ. Res. Pract. 14, 607-614.
[13] J.M. Fautch (2015) The flipped classroom for teaching organic chemistry in small classes: is it effective?, Chem. Educ. Res. Pract. 16, 179-186.
[14] M.A. Christiansen (2014) Inverted Teaching: Applying a New Pedagogy to a University Organic Chemistry Class, J. Chem. Ed. 91, 1845-1850.

[15] N. Fitzgerald, L. Li (2015) Using presentation Software To Flip an Undergraduate Analytical Chemistry Course, J. Chem Ed. (10.1021/ed500667c).
[16] D.R. Quirk Dorr (2014) Correlating online learning resources to student achievement in the flipped classroom. Abstracts of Papers, 247th ACS National Meeting & Exposition, Dallas, TX.
[17] D.R. Quirk Dorr (2013) Flipping to adapt to multiple learning styles at Minnesota State University, Campus Technology, online at http://campustechnology.com/Articles/2013/03/27/Flipping-To-Adapt-to-Multiple-Learning-Styles-at-Minnesota-State-University.aspx?Page=1.
[18] V. Minderhout, J. Loertscher (2007) Lecture-free Biochemistry, Biochem. Mol. Biol. Educ. 35,172-180.
[19] G.R. Parslow (2012) The Khan Academy and the Day-night Flipped Classroom, Biochem. Mol. Biol. Educ. 40, 337-338.
[20] B.R. Stockwell, M. Cennamo (2014) Reimagining the undergraduate science course, ASBMB Today, online at http://www.asbmb.org/asbmbtoday/201405/Education/.
[21] C.G. Prober, C. Heath (2012) Lecture Halls without Lectures – A Proposal for Medical Education, New Engl. J. Med. 366, 1657-1659.
[22] Panopto Video Platform for Businesses and Universities: http://panopto.com.
[23] BlackBoard Learn|Learning Management System: http://www.blackboard.com/learning-management-system/blackboard-learn.aspx.
[24] Sapling Learning | Engaging Students, Empowering Educators: http://www2.saplinglearning.com/.
[25] D. Voet, J.G. Voet, C.W. Pratt (2013) Fundamentals of Biochemistry, 4th ed., John Wiley & Sons Inc.
[26] B.S. Bloom, M.B. Englehart, E.J. Furst, W.H. Hill, D.R. Krathwohl (1956) Taxonomy of Educational Objectives, the classification of educational goals – Handbook I: Cognitive Domain, David McKay Company, New York.
[27] R. Hake (1998) Interactive-Engagement versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses, Am. J. Phys. 66, 64-74.
[28] E. Seymour, D. Wiese, A. Hunter, S. Daffinrud (2000) Creating a Better Mousetrap: On-line Student Assessment of their Learning Gains, National Meetings of the American Chemical Society Symposium, San Francisco, online at http://www.flaguide.org/resource/articles.php.
[29] K.W. Ruddick (2012) Improving chemical education from high school to college using a more hands-on approach, unpublished doctoral dissertation, University of Memphis, Memphis, TN.

Table 1. Classroom demographics for study participants. Class standing was determined by anticipated completion dates. Any fifth-year seniors or post-baccalaureate students were grouped with the seniors.

	Participants (N)	Juniors	Seniors	Female	Male
Traditional	29	7	22	19	10
Flipped	25	22	3	9	16

Table 2. Measured learning gains compared between traditional and flipped classrooms. Pre- and Post-test scores are calculated as a percentage of correct questions out of thirty multiple-choice questions. Normalized learning gains [27] were calculated as the difference between pre- and post-test percentages divided by 100% -% pre-test score. A t-Test was performed to compare differences in means between traditional and flipped learning gains. Only pre-test scores demonstrated a statistically significant difference in means ($p < 0.05$), likely because there were fewer seniors in the flipped course. The mean learning gain on low cognitive skill questions was considerably higher for the flipped classroom, although the t-Test gave a two-tailed $p > 0.05$ ($p = 0.057$), therefore the null hypothesis cannot be discarded and the means cannot be treated as statistically different. (SEM = Standard Mean Error, SD = Standard Deviation)

	Mean Pre-Test (SEM, SD)	Mean Post-Test (SEM, SD)	Mean Normalized Learning Gain <g> (SEM, SD)	Mean <g> High Cognitive Skill (SEM, SD)	Mean <g> Medium Cognitive Skill (SEM, SD)	Mean <g> Low Cognitive Skill (SEM, SD)
Traditional (N = 29)	39.3% (1.6, 8.6)	64.8% (2.6, 14.0)	0.42 (0.04, 0.20)	0.33 (0.04, 0.19)	0.48 (0.07, 0.39)	0.38 (0.10, 0.54)
Flipped (N = 25)	34.3% (1.8, 9.0)	65.1% (2.8, 14.0)	0.47 (0.04, 0.20)	0.33 (0.05, 0.25)	0.44 (0.06, 0.29)	0.61 (0.06, 0.30)
t-Test, p (two-tailed)	0.041	0.95	0.44	0.93	0.66	0.057

Table 3. Exam grades compared between traditional and flipped classrooms. Three exams were given over the course of term and one cumulative final. Fewer study participants took the cumulative final (N = 23 and 24) as it was optional for students enrolled as writing-intensive. (SEM = Standard Mean Error, SD = Standard Deviation)

	Exam 1 (SEM, SD)	Exam 2 (SEM, SD)	Exam 3 (SEM, SD)	Final Exam (SEM, SD)
Traditional (N = 29, 23)	80.0 (2.9, 15.7)	82.8 (2.1, 11.5)	81.5 (2.5, 13.7)	77.1 (3.1, 14.7)
Flipped (N = 25, 24)	80.2 (2.5, 12.5)	83.6 (2.6, 12.9)	79.8 (2.5, 12.4)	78.4 (2.3, 11.5)

Table 4. SALG survey results evaluating improvement in different skill areas. The SALG survey was administered to both classes at the end of the term. Responses were anonymous and some students chose to complete the survey even though they opted out of the rest of the study. There were 31 surveys completed in the traditional (T) class and 27 completed in the flipped (F) class. Means were analyzed by two-tailed t-Tests. (5 = "I gained a great deal", 4 = "I gained a lot", 3 = "I gained somewhat", 2 = "I gained a little", and 1 = "I gained nothing/not at all")

How much has this class added to your skills in each of the following?	**Class**	**5**	**4**	**3**	**2**	**1**	**Not Resp.**	**Mean**	**p**
Solving problems	T	3	14	12	2	0	0	3.6	0.075
	F	10	9	6	2	0	0	4.0	
Designing/proposing experiments	T	2	12	11	4	2	0	3.3	0.57
	F	4	8	11	3	1	0	3.4	
Finding trends in data	T	5	17	5	4	0	0	3.7	0.12
	F	10	12	3	2	0	0	4.1	
Drawing conclusions	T	12	12	4	3	0	0	4.1	0.42
	F	13	9	4	1	0	0	4.3	
Critically reviewing articles	T	4	4	12	11	0	0	3.0	0.60
	F	4	7	7	8	1	0	3.2	
Working effectively with others	T	2	12	11	6	0	0	3.3	0.0018
	F	13	6	5	2	0	1	4.2	
Scientific communication	T	2	11	10	8	0	0	3.2	0.43
	F	7	4	11	4	1	0	3.4	
Critically evaluating others' interpretation of data	T	1	8	9	9	4	0	3.3	0.10
	F	3	10	7	5	2	0	3.2	

Table 5. SALG survey results evaluating learning gain areas. (5 = "I gained a great deal", 4 = "I gained a lot", 3 = "I gained somewhat", 2 = "I gained a little", and 1 = "I gained nothing/not at all")

To what extent did you make gains in any of the following as a result of what you did in this class?	Class	5	4	3	2	1	Not Resp.	Mean	p
Understanding main concepts	T	15	13	3	0	0	0	4.4	0.35
	F	17	9	0	1	0	0	4.6	
Understanding relations between concepts	T	9	15	5	1	0	1	4.1	0.24
	F	11	13	3	0	0	0	4.3	
Understanding relation to other science and math	T	13	8	9	0	1	0	4.0	0.89
	F	7	13	7	0	0	0	4.0	
Understanding relevance to real-world issues	T	9	11	10	1	0	0	3.9	0.29
	F	8	8	5	4	2	0	3.6	
Understanding the nature of biochemistry	T	15	14	2	0	0	0	4.4	0.48
	F	19	5	2	1	0	0	4.6	
Appreciating the methods of biochemistry	T	12	14	4	1	0	0	4.2	0.30
	F	15	8	4	0	0	0	4.4	
Ability to think through a problem or argument	T	6	16	7	2	0	0	3.8	0.19
	F	11	11	4	0	1	0	4.1	
Confidence in your ability to do biochemistry	T	7	11	11	2	0	0	3.7	0.11
	F	7	15	5	0	0	0	4.1	
Feeling comfortable with complex ideas	T	6	10	10	5	0	0	3.5	0.028
	F	9	11	7	0	0	0	4.1	
Enthusiasm for biochemistry	T	12	9	7	3	0	0	4.0	0.66
	F	9	12	5	1	0	0	4.1	

Table 6. SALG survey results evaluating the usefulness of each required course element. (5 = "Was of very much help", 4 = "Was of much help", 3 = "Was of moderate help", 2 = "Was a little helpful", and 1 =" Was of no help")

How much did each of the following aspects of the class help your learning?	Class	5	4	3	2	1	Not Resp.	Mean	p
Sapling on-line questions	T	2	12	13	4	0	0	3.4	0.23
	F	6	8	11	2	0	0	3.7	
Weekly chapter problem sets	T	17	11	1	1	1	0	4.4	0.49
	F	19	4	3	1	0	0	4.5	
Lectures (either on-line or in-class)	T	17	9	4	1	0	0	4.4	0.00096
	F	25	2	0	0	0	0	4.9	
In-class group work on activities or problem sets	T	2	6	11	10	2	0	2.9	2.1×10^{-9}
	F	15	10	2	0	0	0	4.5	
Assigned readings from the textbook	T	4	6	11	9	1	0	3.1	0.40
	F	2	6	10	5	4	0	2.9	

Figure 1. Examples of pre- and post-test questions ranked at low, medium, and high cognitive skill levels. Low level questions tested basic understanding, vocabulary and definitions. Medium level questions asked students to apply learned concepts, and high level questions required students to analyze data and draw conclusions using more than one learned concept.

Low

Binding of oxygen to hemoglobin is said to be cooperative because

a. Oxygen binds more tightly to hemoglobin than myoglobin
b. Oxygen can bind to four different sites on hemoglobin
c. Oxygen binds more tightly to hemoglobin than carbon monoxide
d. Oxygen affinity increases as more oxygen binds to hemoglobin

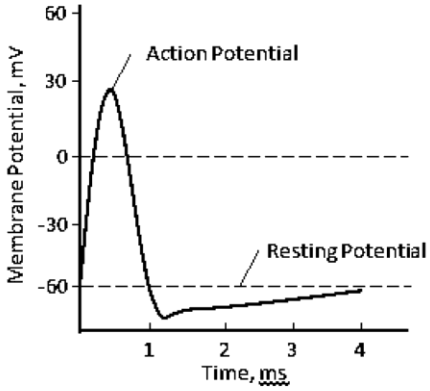
Medium

Which of the following fatty acids would have the highest melting point?

a. Palmitic acid (C16:0)
b. Arachidic acid (C20:0)
c. Oleic acid (C18:1n-9)
d. Arachadonic acid (C20:4n-6)

High

The following represents the membrane potential of a nerve cell undergoing an action potential. At which point (or points) in this graph would the free energy of transport for potassium and sodium ions depend only upon the respective concentrations of these species and not on the fact that they are charged?



a. At 0.5 ms
b. At 1.2 ms
c. At 0, 1, and 4 ms
d. At 0.3 and 0.8 ms
e. None of the above

Figure 2. Correlation between learning gains and overall course performance. The traditional classroom (solid diamonds, solid line) exhibited a stronger correlation between overall course performance and normalized learning gains (R^2 = 0.52 vs. R^2 = 0.21) than the flipped classroom (open squares, dashed line). It is of interest to note that many of the students with the highest learning gains in the flipped classroom were not the "A" students.