Student Perspectives on Introductory Biology Labs Designed to Develop Relevant Skills and Core Competencies

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Setting

The Pennsylvania State System of Higher Education (PASSHE) has 14 schools across the state, amongst which Indiana University of Pennsylvania (IUP) is the largest. IUP is a teaching/research/doctoral university that offers more than 140 undergraduate majors and over 70 graduate programs. Faculty research, publish, and consult in their fields while focusing their energy in the classroom.

Students come from a wide range of high school programs, reflecting their rural, suburban, or urban character. There is a wide range of preparation, motivation, and interest among the 15,000 students studying at IUP.

Overview

Several decades ago as president of the University of Minnesota, Meredith Wilson urged educators to conceive of the students as the greatest energy source available on campus (Wilson 1967). He noted that there are at least 10 times as many students as teachers, and if we conceive of students as supplicants gathering to be taught, we are left with only a small population of teachers as the active agents. If, instead, we regard students as learners, they become the essential engines of their education, and we unleash 10 times as much intellectual power.

Even more so today, we recognize that students are the active agents for successful learning. The National Science Education Standards (NSES) emphasize empowering students to share responsibility for learning. To make this happen, the standards envision teachers guiding students in active and extended scientific inquiries that focus on the *use* of scientific knowledge, ideas, and content (NRC 1996).

This approach is also highlighted in a landmark document, *Vision and Change in Undergraduate Biology Education: A Call to Action*, supported by the American Association for the Advancement of Science (AAAS) and the National Science Foundation (NSF). Brewer and Smith (2009) state that

> the practice of biology requires more than just understanding core concepts. To understand, generate, and communicate knowledge about the living world, students need to develop and apply relevant skills. Therefore, in addition to understanding concepts, undergraduates must have opportunities to develop core competencies to better prepare them to practice biology, as well as to address the complex biology-related issues that our society faces. (p. 11)

With these challenges in mind the biology laboratory curriculum at IUP has been created. The intention is to develop core competencies and relevant skills in our first-year introductory biology students that will grow with them as they go through upper-level courses and into their careers.

Major Features of the Introductory Biology Lab Program

The biology department at IUP has been teaching introductory labs for many years. The labs have been developed over time as new ideas are contributed by the many faculty teaching sections of the course. This year a group of several faculty gathered the most successful ideas, reflecting what is done well, and identified the recurring challenges. The labs were modified by faculty consensus to address these common issues:

- Reinforce difficult core concepts with hands-on learning.
- Teach relevant skills that students can further develop and apply.
- Focus on the most important core competencies students need, with less concern for broad coverage of content.
- Teach techniques for independent learning and research.
- Prepare students to succeed in later courses for which this course is a prerequisite.
- Be interesting and useful to all students, having a wide range of interests, motivation, and preparation.
- Be accessible to students underprepared from high school.
- Stay within a limited budget.
- Value limited faculty time.

Evidence for Success

Type of Information Collected

Whatever the appropriate criteria for judging teaching, the foremost question is how were the student learners affected? A biology lab survey was given to the students at the end of the semester asking them to evaluate the labs (Figure 6.1). The students ranked all the labs as 1st (most), 2nd, 3rd, down to 10th (least) on these survey questions.

Figure 6.1. Lab Survey Given to Introductory Biology Students at the End of the Semester

Name ______________________________

First complete the rankings for questions 1–5 in the tables below.
After fully completing the tables, answer the 2 questions that follow the second table.
Thank you.

1. Rank all 10 labs. Which labs helped you to learn the most biology facts and concepts?
2. Rank all 10 labs. Which labs helped you to learn the most lab skills?
3. Rank all 10 labs. Which labs were most interesting to you?

	Rank 1 for most and 10 for least		
Labs (in the order done during the semester)	**Your Ranking for Question 1**	**Your Ranking for Question 2**	**Your Ranking for Question 3**
Intro to the Scientific Method. Generating and testing hypotheses from data sets.			
Microscopy. Using a microscope, observing cells with a microscope.			
Water Relations. Osmosis in potatoes exposed to various sucrose concentrations.			
Spectrophotometry. Beet tissue homogenate absorbance spectrum and standard curve.			
Spectrophotometry. Using a standard curve to assay beet tissue exposed to acetone and methanol.			
Enzymes. Acid phosphatase assays of various plant tissues.			
Mitosis and meiosis. Microscope observations of cells dividing, and paper diagrams.			
Mendelian Genetics. Corn monohybrid and dihybrid crosses, Chi square tests, problems.			
DNA fingerprinting and forensics. Restriction enzyme cuts of DNA, and gel electrophoresis of DNA fragments.			
Plasmid DNA transformation of bacteria, agar plating, Glo gene expression.			

4. Rank all 10 labs. Which labs had the most difficult concepts to understand?

5. Rank all 10 labs. Which labs required the most time to complete, when including time spent outside of lab, either to understand it or to write it up?

	Rank 1 for most and 10 for least	
Labs (in the order done during the semester)	**Your Ranking for Question 4**	**Your Ranking for Question 5**
Intro to the Scientific Method. Generating and testing hypotheses from data sets.		
Microscopy. Using a microscope, observing cells with a microscope.		
Water Relations. Osmosis in potatoes exposed to various sucrose concentrations.		
Spectrophotometry. Beet tissue homogenate absorbance spectrum and standard curve.		
Spectrophotometry. Using a standard curve to assay beet tissue exposed to acetone and methanol.		
Enzymes. Acid phosphatase assays of various plant tissues.		
Mitosis and meiosis. Microscope observations of cells dividing, and paper diagrams.		
Mendelian Genetics. Corn monohybrid and dihybrid crosses, Chi square tests, problems.		
DNA fingerprinting and forensics. Restriction enzyme cuts of DNA, and gel electrophoresis of DNA fragments.		
Plasmid DNA transformation of bacteria, agar plating, Glo gene expression.		

6. If we were to keep the overall best 3 labs, which 3 labs would you recommend we keep, and why? Provide a brief explanation.

7. If we were to eliminate 3 of these labs, which 3 labs would you recommend we eliminate and why? Provide a brief explanation.

   - Which labs helped you to learn the most biology facts and concepts?
   - Which labs helped you to learn the most lab skills?
   - Which labs were most interesting to you?
   - Which labs had the most difficult concepts to understand?

- Which labs required the most time to complete, when including time spent outside of lab, either to understand it or to write it up?

The student's rankings of the labs by these questions formed the outcomes assessment. It revealed the student's ideas of their development in skills, content, and inquiry. The results were compiled with a frequency table (Table 6.1), counting which labs students felt helped them learn the most, were most interesting, were most difficult, or were most time-consuming.

Table 6.1. Average Rankings of Labs on the Biology Lab Survey

(Rank of 1 is most and 10 is least. *N* = 91 students)

	Average rankings from 1–10 (1 is most, 10 is least)				
Labs	**Q1. Learn facts concepts**	**Q2. Learn lab skills**	**Q3. Interesting**	**Q4. Difficult**	**Q5. Most time**
Intro to scientific method	7.4	6.9	8.1	8.3	8.3
Microscopy	6.1	4.6	6.5	8.2	7.7
Water relations, osmosis	5.3	5.9	5.7	5.9	5.4
Spectrometry, standard curve	5.1	4.5	5.4	5.3	4.7
Spectrometry, assay tissue	5.8	5.2	5.8	5.2	4.8
Enzyme assays	5.3	5.9	5.3	4.4	4.7
Mitosis and meiosis	4.1	6.4	5.7	5.8	5.9
Mendelian genetics	4.7	6.4	5.0	5.9	5.3
DNA fingerprinting	3.8	3.5	2.8	5.3	4.1
DNA transformation, bacteria	5.0	4.5	3.9	5.1	5.9

A second survey was also given to the students at the same time, the biology attitude scale (Russell and Hollander 1975). This survey measures how comfortable students are with biology (Figure 6.2, p. 80). This survey consists of a set of statements, each expressing a feeling toward biology, such as, *I am always under a terrible strain in a biology class* or, *Biology is fascinating and fun*. Students were asked to strongly agree, agree, be undecided, disagree, or strongly disagree. The results were quantified by assigning numbers to each response (strongly agree = 1, agree = 2, undecided = 3, and so on) and compiled with a frequency table (Table 6.2, p. 81).

Figure 6.2. The Biology Attitude Scale Given to Students at the Same Time as the Lab Survey

Name ________________________________

Each of the statements below expresses a feeling toward biology. Please rate each statement on the extent to which you agree. There are no right or wrong answers. Your response will have no impact on your grade. Thank you for responding thoughtfully.

Place an "X" in the cell of your response to each statement. For each, you may:

	Strongly agree	Agree	Be undecided	Disagree	Strongly disagree
1. Biology is very interesting to me.					
2. I don't like biology, and it scares me to have to take it.					
3. I am always under a terrible strain in a biology class.					
4. Biology is fascinating and fun.					
5. Biology makes me feel secure, and at the same time is stimulating.					
6. Biology makes me feel uncomfortable, restless, irritable, and impatient.					
7. In general, I have a good feeling toward biology.					
8. When I hear the word "biology," I have a feeling of dislike.					
9. I approach biology with a feeling of hesitation.					
10. I really like biology.					
11. I have always enjoyed studying biology in school.					
12. It makes me nervous to even think about doing a biology experiment.					
13. I feel at ease in biology and like it very much.					
14. I feel a definite positive reaction to biology; it's enjoyable.					

Table 6.2. Frequency Distribution Table of Raw Results on the Biology Attitude Scale

(For example, 29 students strongly agreed with Q1 that biology is interesting. $N = 91$ students)

	Strongly agree	Agree	Be undecided	Disagree	Strongly Disagree	Average score
	#1s	#2s	#3s	#4s	#5s	
Q1. Biology interesting	29	45	9	6	2	2.0
Q2. Don't like; scares me	1	7	7	48	28	4.0
Q3. Terrible strain	6	17	15	37	16	3.4
Q4. Fascinating and fun	13	50	18	10	0	2.3
Q5. Secure; stimulating	4	27	38	21	1	2.9
Q6. Restless; irritable	0	10	20	38	23	3.8
Q7. Good feeling	16	50	13	11	1	2.2
Q8. Hear word; dislike	1	10	6	51	23	3.9
Q9. Approach hesitation	3	14	10	49	15	3.6
Q10. Really like bio	17	44	17	11	2	2.3
Q11. Enjoyed studying	25	36	7	20	3	2.3
Q12. Nervous do expt	0	6	6	53	26	4.1
Q13. At ease in bio	10	40	23	17	1	2.5
Q14. Definite positive	16	38	20	17	0	2.4

The negatively framed questions were converted so a lower value is a more positive response. Specifically, the new value for these questions equals 6 minus the original value so 1 becomes a 5, 2 becomes a 4, and so on. The questions converted in this way were questions 2, 3, 6, 8, 9, 12. After converting these questions, a sum of all 14 questions and an average was computed, thus creating a single summary score that quantified how positive each student was about biology. A total of 91 students filled out complete surveys so these individual scores were grouped into percentiles (Table 6.3, p. 82). For example, the most positive 10% of the class (the 90th percentile) scored a sum of 1.36, equivalent to answering most positive (strongly agree) to two-thirds of the attitudinal questions and positive (agree) to the remaining one-third of the questions.

Table 6.3. Percentile Groups of Students Based on the Single Summary Score That Describes How Positive They Were to Statements About Biology From the Biology Attitude Survey

(Negatively framed questions were converted so a lower value is a more positive response. The score is a composite of 14 statements ranked on a scale of 1–5 based on whether students agreed or disagreed with 1 being strongly agree, 3 neutral, and 5 strongly disagree. N = 91 students)

Percentile of class based on attitude about biology	Overall score
90th	1.36
80th	1.71
70th	1.93
60th	2.07
50th	2.21
40th	2.36
30th	2.57
20th	2.79
10th	3.14

Results From Attitude Scale

The results show that students' overall attitude about biology was very positive (Table 6.3). A total of 80% of the class scored 1.0 to 2.79 indicating that they are on the positive side of undecided. Even more, the top 35% of the class scored values from 1.0 to 2.0 demonstrating that they had strongly positive to positive attitudes about biology in the survey. Only the bottom 10% of the class was slightly negative in their attitudes given a 10th percentile value of 3.14. As a consequence student responses were sorted into two groups based on their attitudes. Those most positive about biology, the 35% of the class with average scores from 1.0 to 2.0, were compared with those less positive about biology with average scores below 2.0 in t-tests of ranks of particular labs from the biology lab survey. Table 6.4 (p. 87) contains the average rankings of the labs for these two groups of students.

Results From the Biology Lab Survey

DNA Labs

Ranking student responses to questions 1–3 about learning the most facts, concepts, lab skills, and being the most interesting, demonstrated a clear strong preference (Table 6.1, p. 79). The DNA fingerprinting lab was the highest ranked lab with a score of 3.8, 3.5, and 2.8 for questions 1–3, respectively. This score was statistically higher than the score of the next highest lab ($p<0.001$). A total of 41 out of 91 students surveyed ranked it as the most interesting lab all semester and 22 students ranked it number 1 in learning the most biology facts and concepts. The second most preferred lab was the plasmid DNA transformation of bacteria lab, with ranks of 5.0, 4.5, and 3.9 for questions 1–3, respectively. This score was higher than the score of the next ranked lab, and the difference was significant ($p=0.05$). Together these two labs had more first- and second-place rankings than any other labs all semester. These rankings were not affected by student's attitudes about biology.

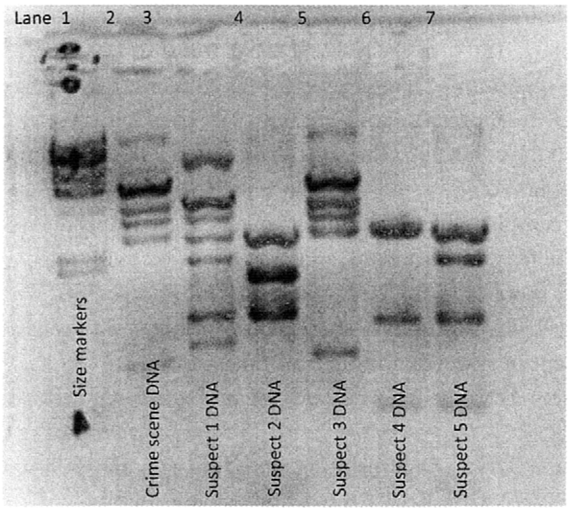
These labs were complex and required understanding advanced concepts and integrating genetics, molecular biology, biochemistry, and new hands-on skills to carry them out. Students spent five weeks on these labs, and they were the most expensive and time-consuming to supply. A goal of these labs was to have students doing DNA manipulations using procedures and equipment current in research and forensic laboratories. As faculty, we consider the skills students learn in these DNA labs to be relevant and reinforce difficult core concepts with hands-on learning.

The content of the DNA fingerprinting and forensics lab followed standard research protocols for cutting DNA with EcoR1 restriction enzyme and separating the fragments based on size on an agarose gel with electrophoresis. The DNA was sourced from a simulated crime scene or paternity analysis. A student gel is shown in Figure 6.3 (p. 84), from which it is apparent that suspect 3 has a DNA match with the crime scene DNA. Students gave oral courtroom-style presentations of their results and were challenged to provide explanations at a level understandable by a jury. The forensic component was interesting and motivating to students with a wide range of interests.

The plasmid DNA transformation of bacteria lab introduced a standard research protocol used to move genes from one organism to another. The plasmid contains genes of interest that can be moved into bacteria, which then incorporate the new genes and code for new traits. The plasmid contains a gene for resistance to the antibiotic ampicillin. Ampicillin can be selectively incorporated into the growth medium for the bacteria (or not), allowing bacteria to grow or not, depending on whether they have been able to acquire new traits from the plasmid during transformation.

Figure 6.3. Gel of Student Results From DNA Fingerprinting Lab

(Samples of DNA cut with restriction enzyme run on an agarose gel to sort by size. The smallest DNA fragments run from the top well to the bottom of the gel. It is apparent that the banding pattern of the crime scene DNA closely matches that of suspect 3. Lane 1 is standard size markers. Lane 2 is crime scene DNA. Lane 3 is DNA from suspect 1. Lane 4 is DNA from suspect 2. Lane 5 is DNA from suspect 3. Lane 6 is DNA from suspect 4. Lane 7 is DNA from suspect 5.)

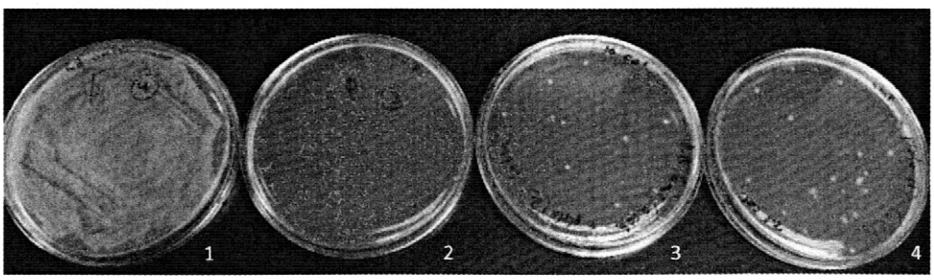


The plasmid also contains a gene originally obtained from jellyfish that codes for green fluorescent protein (GFP), but the protein is only expressed if the sugar arabinose is added to the nutrient medium. The protein causes the bacteria to glow a brilliant green color under ultraviolet light, confirming that the GFP gene is active, and identifying which colonies contain the transformed bacteria. Figure 6.4 illustrates how easily visible these new traits are when the bacteria are grown on different mediums and exposed to ultraviolet light.

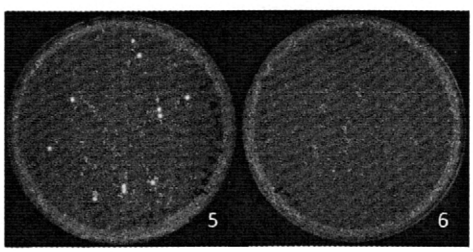
Figure 6.4. Example of Results From Plasmid DNA Transformation of Bacteria Lab

(Bacteria were either transformed with plasmid DNA containing an ampicillin antibiotic resistance gene and the GFP gene, or not (the control). The GFP gene codes for Green Fluorescent Protein, which is expressed (synthesized) when transformed cells are grown in nutrient medium (LB agar) with added arabinose, a sugar. The GFP causes cells containing it (here bacteria) to glow a brilliant green color when exposed to ultraviolet light. The green glowing bacterial colonies with UV light in Plate 5 are the descendents of the bacteria that were transformed with the plasmid DNA containing the GFP gene. In this manner genes of interest can be moved into bacteria and detected if the transformation was successful. Plate 1, a control, shows a continuous lawn of bacterial colonies since none have been transformed, and the nutrient medium supports all growth. Plate 2, a control, shows no bacterial colonies since none have been transformed, and with the nutrient medium containing the added antibiotic ampicillin, none can grow. Plates 3 and 4 show only about 10 bacterial colonies that can grow with the added ampicillin antibiotic, and these are the bacteria successfully transformed with the plasmid DNA. Plate 5 shows the green glowing bacterial colonies with UV light successfully expressing the GFP gene when the nutrient medium contains the sugar arabinose. These are the transformed bacteria of interest. Plate 6 shows the transformed bacterial colonies not glowing in UV light since the medium does not contain arabinose.)

Plate 1	Plate 2	Plate 3	Plate 4
Nutrient medium. No GFP DNA. No amp resis DNA.	Nutrient medium with ampicillin. No GFP DNA. No amp resis DNA.	Nutrient medium with ampicillin and arabinose. With GFP DNA. With amp resis DNA.	Nutrient medium with ampicillin. With GFP DNA. With amp resis DNA.



See lawn of colonies — See no colonies — See ~10 colonies — See ~10 colonies



See colonies are green with uv light — See colonies are NOT green with uv light

The contrast between the expression of the ampicillin resistance gene and the GFP gene provides venues for students to understand complex genetic mechanisms. The important value of these techniques is that they provide an accessible and very real illustration of gene expression, mechanisms of genetic selection, and ways that organisms acquire new traits. Students see that they can further develop and apply these techniques for independent learning and research.

Student comments reveal that it was interesting because it was real. Much of the equipment had been borrowed from a research lab, such as pipetters, gel boxes, camera, an ultraviolet light, and petri plates. One student said she loved all the fancy equipment, it felt "sciency." Another student wrote, "They are the most interesting to me and they are really fun to do." It was motivating because it worked well, and students could see it working. When the gel was running there were bubbles rising from the electrodes, and the blue dye front was advancing. Complex ideas that were talked about in lecture were explained again and reinforced by the procedures. Bain (2004, p. 31) states, "People learn best when they ask an important question that they care about answering, or adopt a goal that they want to reach."

Students did not prefer these labs because they were easy or quick; on the contrary, they ranked these labs among the most difficult to understand and time consuming (Table 6.1). The DNA fingerprinting lab was ranked 5.3 and 4.1 for questions 4 and 5, and for the same questions, the plasmid DNA transformation lab was ranked 5.1 and 5.9. A challenging aspect for teachers is that this set of techniques, Restriction Fragment Length Polymorphism (RFLP) analysis due to Single Nucleotide Polymorphisms (SNPs), has been dropped from the current version of the textbook, *Campbell's Biology 9th edition*, although it was in the 8th edition (p. 417).

Spectrophotometry and Enzyme Labs

Other labs that students ranked highly for learning facts, concepts, lab skills, and being interesting were a set of three labs designed to teach spectrophotometry skills and enzyme assays (Table 6.1, p. 79). These rankings of high learning were even higher for the 35% of students who had a higher biology attitude summative score (Table 6.4). *T*-tests for differences in sample means of ranks were significant for 2 of the 3 labs, 4.7 to 5.2 $p=0.13$ for spec1, 5.1 to 5.8 $p=0.05$ for spec2, and 5.1 to 5.8 $p=0.05$ for the enzyme lab. This survey statistic means that students who strongly agree with positive statements about biology indicated they learned even more, and found it even more interesting, than students who simply agreed. It is also notable that students were not put off by the difficulty of the labs: across the 10 labs for the semester these 3 labs were ranked as 3 of the 4 most difficult ($p<0.001$). Reassuringly, these results show that students have robustness for learning even if the content is difficult.

These labs were complex and required extensive wet chemistry, instrumentation, calculation, timing, and computer graphing to complete. During this three-week sequence the skills and content of each lab reinforced and continued from the previous week. They were inexpensive and relatively simple to supply.

Table 6.4. Average Rankings of Labs on the Biology Lab Survey

(Combining questions 1, 2, and 3, for an average, and combining questions 4 and 5 for an average. Results are presented for the 35% of students most positive about biology (overall score in Table 3 less than 2.0), and for the 65% less positive, from the Biology Attitude Survey. *N* = 91 students)

	Average rankings from 1–10 (1 is most, 10 is least)			
	From students with *more* positive biology attitude		**From students with *less* positive biology attitude**	
Labs	**Q1, Q2, Q3. Learn facts, concepts, skills; interesting**	**Q4, Q5. Difficult; Time-consuming**	**Q1, Q2, Q3. Learn facts, concepts, skills; interesting**	**Q4, Q5. Difficult; Time-consuming**
Intro to scientific method	7.5	8.2	7.5	8.4
Microscopy	5.7	8.1	5.7	7.9
Water relations, osmosis	5.6	5.9	5.7	5.4
Spectrometry, standard curve	4.7	5.1	5.2	4.8
Spectrometry, assay tissue	5.1	5.0	5.8	4.9
Enzyme assays	5.1	4.9	5.8	4.2
Mitosis and meiosis	5.7	6.7	5.2	5.3
Mendelian genetics	5.3	5.7	5.3	5.5
DNA fingerprinting	3.1	4.8	3.5	4.7
DNA transformation, bacteria	4.0	5.4	4.8	5.7

The labs began with living respiring plant tissue, a fresh beet. A measured quantity of tissue was homogenized and first used to determine an absorbance spectrum and the peak absorption wavelength. Measured quantities of water were used to produce a standard curve in units of grams beet tissue per milliliter water. The second week, beet tissue cores were exposed to treatments that would disrupt the cell membranes. These treatments were organic solvents, such as acetone, methanol, and ethanol, and in another experiment, temperature extremes. The standard curve constructed the first week was used the second week to quantify the grams of tissue disrupted. The third week continued concepts and skills from the previous weeks to assay the amount of acid phosphatase, an enzyme that hydrolyzes a phosphate group from many substrates in many types of cells. The activity of this enzyme was used as an indicator of the effects on the biochemistry of the cell of various treatments. The specific treatments were decided by students as they generated and tested hypotheses about the effect of various environmental exposures on living cells. Students chose a wide variety of cell types, mostly various vegetables, and interpreted and communicated their results in written and oral discussion.

Students wrote on the survey that these labs were successful because "they are the most realistic labs for future biology labs" and the labs "all are challenging biology topics that I will use in my career." Students were motivated to generate data themselves. They had to keep track of quantities, use calculations, draw graphs, and then use the graph to convert information (standard curve). They conceived of their own hypothesis, did their own experiments, negotiated the equipment, and analyzed the results. All these activities were helpful to students, as one wrote, "good explanation of concentration." Another stated, "illustrates a great concept in a clear lab." One student said, "by that time, it wasn't so stressful trying to figure out how to work the spectrophotometer." Another, "all of these labs really got the mind engaged and weren't that hard to do at this level." Students quickly learn their answers are neither right nor wrong, but must derive from their data.

Generating and Testing Hypotheses Lab

The calculation of average rank of student responses to the lab survey revealed that one lab scored significantly below all the other labs (Table 6.1, p. 79). Students indicated that they learned the least facts, concepts, skills, and were least interested in the lab that introduced the scientific method ($p<0.001$ when compared to the next low lab). Students also ranked this lab as the easiest and quickest, questions 4 and 5 on the survey, but it was not significantly easier and quicker than the next low lab ($p=0.17$). Student attitudes about biology did not affect the relative ranking of this lab (Table 6.4, p. 87; $p=0.48$, t-test for difference in sample means). This is consistent with earlier results that students do not necessarily find easy, quick labs interesting, or learn much from them.

This introductory lab consisted of a narrative that explained the scientific method, hypothesis testing, experimental design, and valid interpretations of data. It also included several data tables that students were asked to consider, generate an appropriate hypothesis, and graph the data in a way that highlights the distinctions of the hypothesis.

Student comments reflected the opinion that labs should closely follow lecture content, "I recommend that [other labs instead] be kept because they all contain a large amount of useful information and they provide good resources for lecture exam preparation for when the textbook material can seem overwhelming." This outlook was shared by another student, "not very helpful, confusing." One found it worthwhile "because of the experience of lab methods."

Perhaps this lab is weak because starting inquiry is rough. Inquiry viewed as developing scientific thinking, scientific understanding, and science as a hypothesis-driven process is difficult to initiate. Students need time to adjust to thinking in lab and trusting that the "correct answer" is not a single answer but a conclusion consistent with what the data reveal.

Next Steps

Student responses to surveys on their labs are clear: the most interesting labs for students to learn concepts and skills can be difficult and time-consuming, but they must be real, and have relevant challenges. Students had very positive attitudes about biology in general. With this information, our next steps are also clear: continue to develop engaging labs to build core competencies. Then we will motivate students to be the active agents of their own education and unleash the greatest energy source available on campus.

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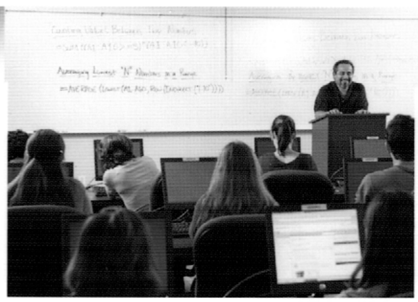

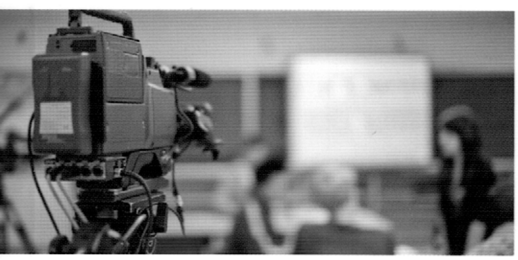

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