Final Report

Project Title: Assessment of Textbook-Free Courses in the Biochemical Engineering Field As Vehicles for Lifelong Learning

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Summary

Textbooks are common sights in undergraduate engineering classes. There are classes in which the textbook is followed closely, some in which it is not followed at all, and anything in between. However a textbook is always **required.** Studies show that students feel more comfortable in "textbook based" classes than in classes without one, in spite of the high cost of textbooks. Unfortunately, in today's technological word it is impossible to cover **current** knowledge in a single monograph and thus it is becoming more important to explore alternatives to a textbook in engineering classes. Research about the use of textbooks in engineering classes is very limited. We started a study to determine the effect of textbook free classes on the development of **lifelong learners**. It was necessary first to evaluate the epistemological beliefs of the students and their ability to understand primary sources. A three-years-long study was started and an online survey for alumni was developed. Modifications to the Bioseparations course were introduced to facilitate the use of primary sources.

Purpose of project

The objective of this project was to investigate the effect of using alternative ways to deliver content in place of textbooks on the ability of the students to become lifelong learners.

The results of this study will be used to design, in a follow up project, a route map for those who desire replacing the textbook by alternative materials.

Our hypothesis is that a textbook-free course will have an impact on the ability of the students to become lifelong learners. We hypothesize that a textbook-free class will impact the following aspects that characterize a lifelong learner (Courter et al., 2012): (1) be better prepared to plan their own learning, (2) be able to assess and monitor their own learning, and (3) be able to independently find and use technical information.

The main task for this year was to obtain feedback from former and current students about the effect of a textbook-free class on their lifelong learning abilities.

Introduction

Biochemical Engineering is a relatively new discipline often housed in Chemical Engineering departments. The Biochemical Engineering Program at Missouri S&T started approximately 25 years ago and has affected hundreds of students. The curriculum consists of a heavy dose of biology and chemistry and of most of the core Chemical Engineering courses. In addition, the students in the emphasis program take a bioseparations class, a biological reactors class and two laboratories where they learn the practical aspects of cell culture and separations of biological molecules.

I have been teaching a Bioseparations course without a textbook for 10+ years and a Bioreactors Class for a couple of years. The material has been given to the students through Blackboard. The material consists of (1) A number of scientific papers and vendors' material for each of the main core topics, (2) A series of power point slides that I use to support my lectures (the slides are not used as the main teaching method in this class), (3) Reading guidelines. Textbooks in Biochemical engineering are of little use because of the dynamics of the field. For example, the hybridoma technique to produce monoclonal antibodies was developed 40 years ago and today the production of monoclonal antibodies is the most rapidly growing pharmaceutical sector. Moreover, monoclonal antibodies or antibodies fragment are produced today using disposable technology, non-existent 20 years ago.

Most American college professors are reluctant not to use a textbook. Gary Reiness (editor, CBE Life Science Education; in Klymkowsky (2007)) reflected: “few of us would consider teaching a course without using a textbook. Over the years, they have become more colorful, more encyclopedic, and accompanied by more ancillary materials such as CD-ROMs, study guides, and websites. The question most instructors ask themselves is most likely which textbook to use, not whether to use a textbook. But does the use of textbooks really help students learn better?”

Podolefsky and Finkelstein (2006) surveyed 800 students in four physics classes about the use of textbooks in college classes. Some of their conclusions do not support the use of textbooks in college classes. Only 37% of students regularly read, less than 13% read often and before the lecture. They found no correlation between reading habits and course grades. Students identify textbook with homework and lecture with exams.

Another study from Carpenter et al. (2006) (British Publishers study) reached the opposite conclusion. Textbooks are important but the students do not know why. Do the instructors? Some leave students to pick a book from a reading list, while a roughly equal number suggests students pick one of several alternative main course texts. It is worth comparing this British experience in which only 15% of lecturers ‘adopt’ a required text with the American practice in which the almost universal practice is for the Professor to choose one book for his or her course, which is then bought new or used by the vast majority of students. A greater anxiety is that some lecturers may not be aware of how critical they are in the decision to purchase and may not appreciate that a less than strong endorsement for a book means is it less likely to be bought.

A reflection by Paulsen and Feldman (1999) about epistemological beliefs reads “Faculty, in their roles as college teachers and designers of learning environments, should assume a greater responsibility for promoting motivationally and educationally productive epistemological beliefs among their students”. Is there a correlation between naïve epistemological beliefs and the use of textbook in classes? Are students exposed to primary sources more epistemologically sophisticated?

There are no indications, in the students’ comments of the last fifteen years, that the lack of a textbook is a major hurdle in this Bioseparations class. There are, however, some indications that some students feel “fragile” without a textbook.

Methodology

Surveys were developed to evaluate the epistemological beliefs of the students, their ability to read and understand primary sources, their perception of lifelong learning, and the association (or lack off) between primary sources based education and the ability to become lifelong learners. The following guidelines were used to develop the surveys:

1. Background of the respondent (current student, year of graduation, highest degree, current occupation, etc.)
2. The survey (limited to 30 questions or less) should:
   (a) Explore epistemological beliefs of respondent.
   (b) Explore lifelong learning concepts of respondent.
   (c) Explore value of textbook free classes on lifelong learning of the respondent

Early in the project we realized that the ability of the students to efficiently use primary sources depends on their epistemological beliefs. A survey borrowed from C.R.E.A.T.E. (Hoskins et al., 2001) was used in a second semester sophomore class, Thermodynamics I,

(Appendix A, Survey I). The same survey will be administered in a first semester junior class, Thermodynamics II in Fall 2015. This surveying will continue for 3 consecutive years. The survey covers the factors and aspects of the epistemological beliefs and their comfort level on reading primary sources shown in Table 1.

Table 1. Definitions of Factors related to primary sources and Aspects of epistemological beliefs.

Factor/Aspect	Definition
F1	Decoding primary literature
F2	Interpreting data
F3	Active reading
F4	Visualization
F5	Thinking like a scientist
F6	Research in context
A1	Knowledge is certain
A2	Ability is innate
A3	Attitude toward science

This survey was modified to include questions about the use of textbooks and lifelong learning perceptions and administered to second semester junior students (Bioseparations) at the end of the semester and second semester senior students (Bioreactors) at the end of the semester (Appendix B, Survey II). In addition Survey 1 was also administrated to the Bioseparations students the first week of classes.

A separate on-line survey addressing primary sources reading, use of textbooks and epistemological believes was prepared for alumni of the Biochemical Engineering Emphasis Program (Appendix D, Survey III).

The longitudinal study will be completed in two more years. The collection schedule is shown in Table 2.

Table 2. Surveying schedule

Class	Fall 14	Spring 15	Fall 15	Spring 16	Fall 16	Spring 17
Thermodynamics I	**S1**		S1		S1	
Thermodynamics II		**S1**		S1		S1
Bioseparations		**S1 and S2**		S1 and S2		S1 and S2
Bioreactors		**S2**		S2		S2

Red entries correspond to surveys already administered and analyzed.

Our initial surveys show that the students have difficulties in understanding the material presented in primary sources. Therefore we started implementing aspects of C.R.E.A.T.E. in the Bioseparations class.

Results

A preliminary survey (Appendix C) was administered in the Spring Semester of 2014 to the Bioreactors and Bioseparations classes. The purpose of this survey was to sense what was the opinion of the students about the lack of textbook in the class and how familiar they were about lifelong learning. The results are summarized in Figure 1.

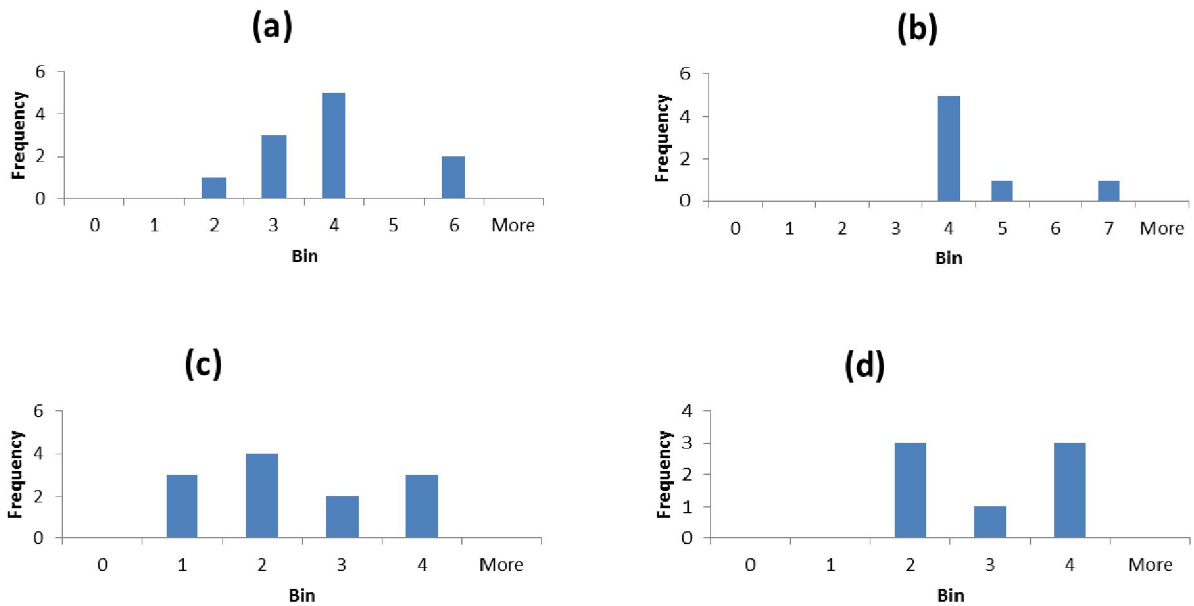

Figure 1. Responses to: (a) Bioreactors Question (3); (b) Bioseparations Question (3); (c) Bioreactors Question 1 and (d) Bioseparations Question 1. Frequency corresponds to number of responses in each category.

The scores for Question 2 were: Bioreactors: 2.75 (0.45 SD) and Bioseparations: 2.85 (0.38). It is important to notice that no students selected the use of a single textbook as the best delivery system. After this introductory survey we decided that we need to know more about the learning characteristics of our students to pursue the goals of this project. In particular, we wanted to know what is the ability of our students to read primary sources, which are their epistemological believes and what is their understanding of lifelong learning.

The surveys that needed to be developed should answer the questions summarized in Table 3.

Table 3. Categories of questions included in the survey and the populations affected.

Question	Population
Do they know how to read a primary source	Current students
What are the epistemological beliefs of our students	Current and former students.
How do their epistemological beliefs correlate with their ability to become lifelong learners	Current and former students
Are textbooks a hurdle for the students' development into sophisticated thinkers?	Current and former students

We started implementing pieces of the **C.R.E.A.T.E**. approach to teach our students to read primary sources. The acronym stands for: **C**onsider. Concept map paper introduction, note topics for review, define new issue(s) to be addressed, begin defining relevant variables and determining their relationships. **R**ead. Define unfamiliar words, annotate figures, create visual depictions (sketch "cartoons") of the individual sub studies that underlie each figure or table. Transform data presented in tables into a different format (graph or chart). **E**lucidate hypotheses. For each figure, define the hypothesis being tested or question being addressed by the work that generated the data illustrated. Rewrite the title of each figure in your own words. **A**nalyze and interpret the data. Using the hypotheses, questions, cartoons, diagrams, and charts and/or graphs, determine what the data mean. Fill in a data analysis template for each figure to track the logic of each experiment and prepare for class discussion. After all figures and tables have been analyzed, create a concept map for the paper, using each illustration as a map node to reveal the logic of the study design. **T**hink of the next **E**xperiment. "If I had carried out the studies described in this paper, how would I follow up?" Design two distinct studies, and cartoon one on a transparency for in-class discussion. Aspects of this process were introduced in the Bioseparations class which was surveyed at the beginning and at the end of the semester.

The results of the surveys are presented as parity plots in figures 2 to 5. The statistics of the surveys are presented in Tables 4 to 7. Scores are normalized to 100%. Positive responses have scores higher than 80%, neutral responses have scores in between 60 and 80 %, and negative responses have scores lower than 60%. We compare the responses of second semester sophomore students (Thermodynamics 1) and second semester junior students (Bioseparations) in Figure 2. The accompanying statistical data is summarized in Table 4. None of these two groups of students have been exposed to primary sources so far. A couple of observations are worthy. The ability of both groups to decode primary sources is very limited (F1) but the sophomores are statistically better than the juniors. ($P(T<=t)=0.06$). The sophomores are also more epistemologically sophisticated than the juniors (A2) but their differences are marginally significant ($P(T<=t)=0.09$). All the scores are in between 60 and 80%, suggesting naïve epistemological beliefs and problems interpreting primary sources.

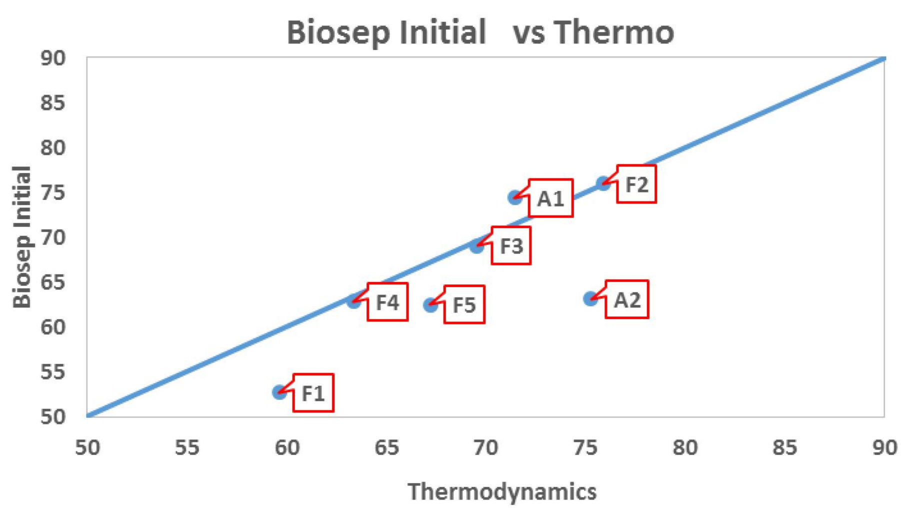

Figure 2. Comparison of the responses to Survey 1 from sophomore (Thermodynamics, Fall 2014) and junior (Bioseparations, beginning Spring 2015) students. F1 thorough F5, A1 and A2 are defined in Table 1.

A comparison between the sophomores (Thermodynamics 1) and the juniors after one semester of using primary sources (Bioseparations) shows a very different picture (Figure 3 and Table 5). Factor 3 (active reading) and Aspect 1 (Knowledge is certain) now have scores higher than 80% for the junior class. The different between the two classes are statistically significant in this Factor and Aspect. Although the responses from the juniors are above the 45 degree line, the differences between the two samples are not statistically significant at 95% confidence. The

Bioseparations students (Junior) have improved their ability to decode primary sources (from 53% to 64%) and the differences are statistically significant.

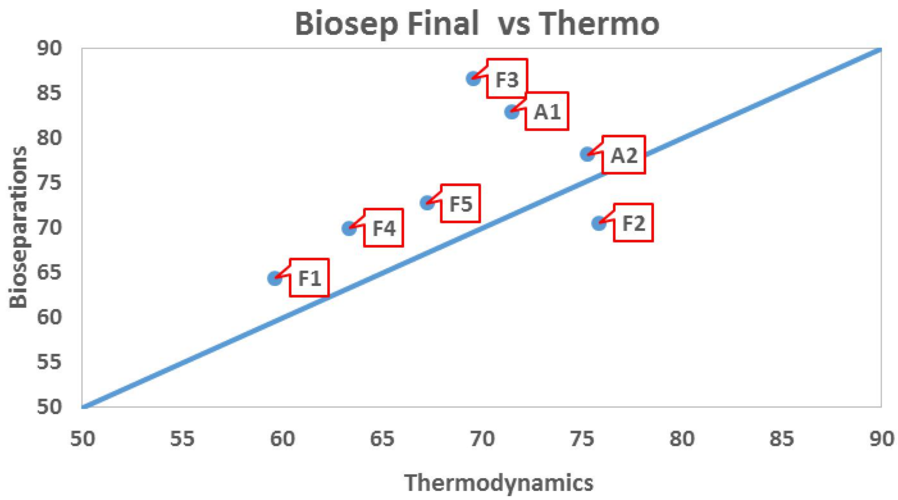

Figure 3. Comparison of the responses to Survey 1 from sophomore (Thermodynamics, Fall 2014) and Survey 2 from junior (Bioseparations, end of Spring 2015) students. F1 thorough F5, A1 and A2 are defined in Table 1.

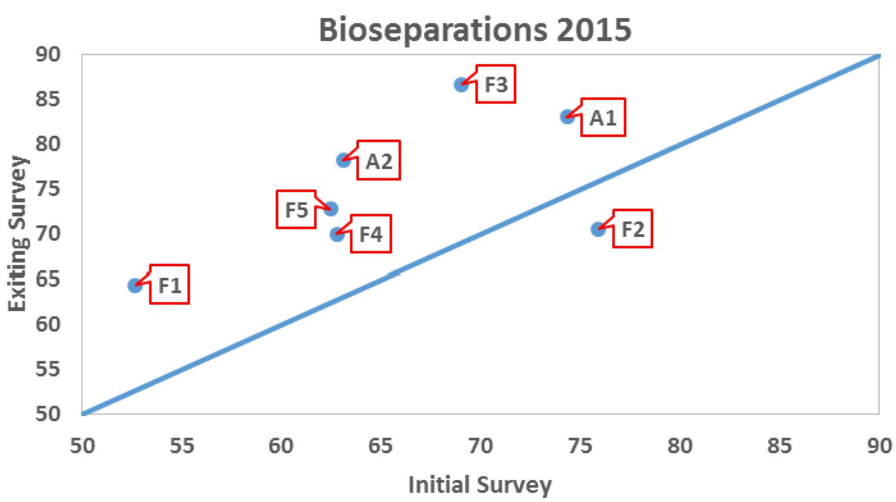

Figure 4. Comparison of the responses to Survey 1 (Bioseparations, beginning of Spring 2015) and Survey 2 (Bioseparations, end of Spring 2015). F1 thorough F5, A1 and A2 are defined in Table 1.

The difference between the same group of students at the beginning and at the end of the semester (Figure 4 and Table 6) are striking and several factors and aspects (F1, F3, F5, A1 and A2) show differences that are statistically significant. As mentioned before, their ability to decode primary sources is still quite limited. This group of students will be tested again in Fall 2016. There is drastic (and positive) change in their epistemological beliefs after one semester of being exposed to a class that uses primary sources as the main teaching material. Their scientific curiosity has improved (F5) from 62% to 73% ($P(T<=t)= 0.04$).

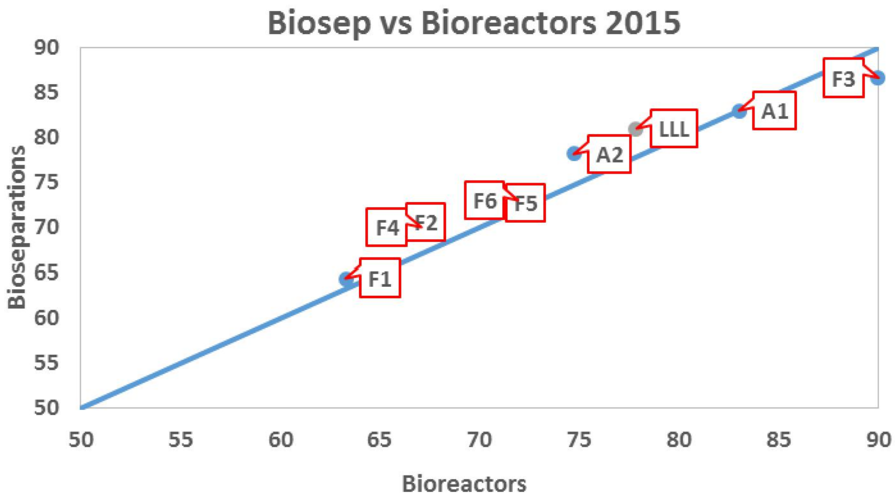

Figure 5. Comparison of the responses to Survey 2 from juniors (Bioseparations, end of Spring 2015) and graduating seniors (Bioreactors, end of Spring 2015). F1 thorough F5, A1 and A2 are defined in Table 1.

Table 4. Comparison between the initial Bioseparations survey and Thermodynamics 1

	Bioseparations First week		Thermodynamics		P (T<=t) – two tailed
	average	SD	average	SD	
F1	53	12	60	10	0.06
F2	76	9	76	12	1
F3	69	11	69	11	0.9
F4	62	16	63	10	0.9
F5	62	11	67	11	0.2
F6	87	13	84	12	0.4
A1	74	7	71	10	0.2
A2	63	26	75	14	0.09
A3	75	8	77	7	0.6

The data shown on Figure 5 (and Table 7) suggests that there is almost a perfect correlation between the scores of second semester juniors (Bioseparations) and graduating seniors (students taking the Bioreactors class). This is a matter of concern because it looks like the students have reach a plateau one year before graduation. Of course more data will be collected in the next two years to confirm or reject this trend. It is worrisome to conclude that the students are active readers but at the same time they cannot decode primary sources.

Table 5. Comparison between Bioseparations final survey and Thermodynamics 1

	Bioseparations Final Survey		Thermodynamics		P (T<=t) – two tailed
	average	SD	average	SD	
F1	64	18	60	10	0.3
F2	71	16	76	12	0.2
F3	87	15	70	11	0.0003
F4	70	15	63	10	0.1
F5	73	16	67	11	0.2
A1	83	9	71	10	0.0001
A2	78	13	75	14	0.4

Table 6. Comparison between initial and final surveys in the Bioseparations class

	Initial Survey		Final Survey		p(T<=t) – Two tailed
	Average	SD	Average	SD	
F1	53	12	64	18	0.03
F2	76	9	71	16	0.24
F3	69	11	87	15	0.0005
F4	63	16	70	16	0.19
F5	62	11	73	16	0.04
A1	74	7	83	9	0.003
A2	63	26	78	13	0.005

Table 7. Comparison between the final Bioseparations survey and Bioreactors survey

	Bioseparations Final Survey		Bioreactors		P (T<=t) –two tailed
	average	SD	average	SD	
F1	64	18	63	12	0.8
F2	71	16	66	14	0.3
F3	87	15	90	10	0.5
F4	70	16	67	11	0.5
F5	73	16	71	12	0.7
F6	73	16	72	14	0.9
A1	83	9	83	6	0.99
A2	78	13	75	9	0.4
LLL	81	11	78	9	0.3

In an attempt to improve the students' ability to use primary sources the following strategy was followed in the Bioseparations class. The students were divided in groups of two of three students each. They were assigned a particular research topic based on a single manuscript or news that in the eyes of the instructor represents substantial novelty into the field. The students prepared and presented a short presentation (no more than ten minutes).

Another modification to the current courses aimed at information gathering and processing has been the replacement of in-class tests by a combination of take home and in-class tests. This is being practiced in the Bioreactor class and will be extended to the Bioseparations course. The approach is quite simple. A new scientific paper is posted a couple of days before the exam. The students read the manuscript and then work on the topic during the take home portion of the exam. The topic is followed up in a portion of the in class test. The test papers are moved into the standard material for the following year. The students need to find additional information based upon their ability to understand the material in the scientific paper. "

Conclusion/Future Implications/Plans for Further Dissemination

Because of the short length of the study the conclusions are still preliminary. Still, we presented some preliminary results at the AIChE National Meeting on November, 2014. We did notice a drastic change in the epistemological believes and in the ability of reading primary sources in one group of students as they were introduced to a text free course for first time in their lives. We expect to continue this surveying for the next 4 semester to gather enough data to obtain meaningful information. The surveys given to our current studies were done in class (and on paper); they will be administered electronically starting this semester. We expect to present a paper in the 2016 ASEE National Conference (New Orleans June 26-29 and the next SHPE (Society of Hispanic Professional Engineers) in November 2016. At the end of our study I will submit a manuscript to the Journal of Engineering Education.

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Appendix A. Survey I (adapted from C.R.E.A.T.E.)
Class: Semester

Q1.The scientific literature is difficult to understand
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q2. When I see scientific journal articles, it looks like a foreign language to me
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q3.I am not intimidated by the scientific language in journal articles.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q4. I am confident in my ability to critically review scientific literature.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q5. I am comfortable defending my ideas about homework problems.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q6. It is easy for me to transform data, like converting numbers from one unit system to another one.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q7. If I see data in a table, it is easy for me to understand what it means.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q8. If I am shown data (graphs, tables, charts), I am confident that I can figure out what it means.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q9. It is easy for me to relate the results of a single experiment to the big picture.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q10. I could make a simple diagram that provides an overview of an entire experiment.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q11. If I am assigned to read a scientific paper, I typically look at the methods section to understand how the data were collected.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q12. I do not know how to design a good experiment
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q13. The way that you display your data can affect whether or not people believe it.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q14. When I read scientific information, I usually look carefully at the associated figures and tables.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q15. When I read scientific material it is easy for me to visualize the experiments that were done.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q16. If I look at data presented in a paper, I can visualize the method that produced the data.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q17. When I read a paper, I have a clear sense of what physically went on in a lab to produce the results and information I am reading.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q18. After I read a scientific paper, I don't think I could explain it to somebody else
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q19. I am confident I could read a scientific paper and explain it to another person.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q20. I enjoy thinking of additional experiments when I read scientific papers.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q21. I accept the information about science presented in newspaper articles without challenging it
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q22. Experiments in "model organisms" like the fruit fly have led to important advances in understanding human biology.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q23. Progress in curing diseases has been made as a result of experiments on lower organisms like worms and flies.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q24. I understand why experiments have controls.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q25. If two different groups of scientists study the same question, they will come to similar conclusions.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q.26The data from a scientific experiment can only be interpreted in one way.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q27 Because scientific papers have been critically reviewed before being published, it is unlikely that there will be flaws in scientific papers.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q28. Because all scientific papers are reviewed by other scientists before they are published, the information in the papers must be true.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q29. Sometimes published papers must be reinterpreted when new data emerge years later.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q30. Results that do not fit into the established theory are probably wrong.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree ○ Strongly Disagree

Q31. I think professionals carrying out scientific research were probably straight-A students as undergrads.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q32. You must have a special talent in order to do scientific research.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q33. Science is a creative endeavor.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q.34. I have a good sense of what research scientists are like as people.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q35. I do not have a good sense of what motivates people to go into research.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q36. Scientists usually know what the outcome of their experiments will be.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q37. Collaboration is an important aspect of scientific experimentation.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q38. On a scale of 1–5, rate your confidence in your ability to read and analyze science journal articles(1).

Q39. On a scale of 1–5, rate your understanding of “the way scientific research is done” or “the scientific research process.”

Q40. When was the last time that you read an article from the primary scientific literature (e.g., a journal article)?

Q41. How many articles from the primary scientific literature (e.g., journal articles) have you read?

Q42, Journal articles are (choose the single best answer) a) hard to read and not worth the effort, b) hard to read but worth the effort, c) easy to read but not worth reading, or d) easy to read and worth reading.

(1) For this item, 1 = zero confidence, 2 = slightly confident, 3 = confident, 4 = quite confident, and 5 = extremely confident.

b For this item, 1 = I don't understand it at all, 2 = I have a slight understanding, 3 = I have some understanding, 4 = I understand it well, and 5 = I understand it very well.

Q1-Q5	Factor 1: Decoding Primary Literature	Skills and Understanding of Scientific Primary Literature
Q6-Q9	Factor 2: Interpreting Data	
Q10-Q13	Factor 3: Active Reading	
Q14-Q17	Factor 4: Visualization	
Q18-Q21	Factor 5: Thinking Like a Scientist	
Q22-Q24	Factor 6: Research in Context	
Q25-Q30	Aspect 1: Knowledge is Certain	Epistemological Beliefs
Q31-Q32	Aspect 2: Ability is Innate	
Q33-Q37	Aspect 3: Attitude Toward Science	
Q40-Q41	Additional Unscored Data	

Appendix B. Survey II

Exiting Survey. Class:

1. If two people are arguing about something, at least one of them must be wrong.
   ○Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
2. Most things worth knowing are easy to understand.
   ○Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
3. Really smart students don't have to work as hard to do well in school.
   ○Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
4. How well you do in school depends on how smart you are.
   ○Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
5. No matter who you are, you can significantly change your intelligence level.
   ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
6. You can change even your basic intelligence level considerably.
   ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
7. To do academic research, you must be a straight A's student.
   ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
8. There would be more than one right answer to any given problem.
   ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
9. Results that do not reflect established theories are most likely incorrect.
   ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
   ○ Strongly Disagree
10. Data from a given experiment can only lead to one conclusion.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
11. Because all scientific papers are reviewed by other scientists before they are published, the information
    in the papers must be accurate.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
12. Theories and facts can change with time and new information.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
13. Scientific literature is difficult to interpret.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
14. I am confident in my ability to critically review scientific literature.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree

15. I am confident that I can defend my ideas about experiments.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
16. If I am presented data (graphs, tables, charts), I am confident that I can reach conclusions about its meaning.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
17. It is easy for me to relate the results of a single experiment to the big picture.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
18. The way that you display your data can affect whether or not people believe it.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
19. When I read a scientific paper, I carefully read the methods section in order to understand how the data was collected.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
20. If I look at data presented in a paper, I can visualize how that data was produced.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
21. After I read a paper, I feel that I could explain it to someone else.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
22. I accept information produced in peer-evaluated journal articles without challenging it.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
23. When reading scientific literature I am primarily concerned with the data and conclusions presented, and less concerned about the experimental methods used to obtain the data.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
24. A textbook contains all the necessary information to master a subject area.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
25. Textbooks are checked and edited multiple times, so it is unlikely that they contain incorrect knowledge.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
26. I usually only read scientific articles if a class assignment requires it.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree
27. Scientific articles are only useful to researchers and academics.
    ○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
    ○ Strongly Disagree

28. I believe that everything worth knowing can be learned in college and from on the job experience.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree
29. I am likely to read new scientific literature in my field when it is published.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree
30. I believe that learning after college is essential to professional success.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree
31. If a piece of information is important, my professors and employers will provide it for me.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree
32. I can stay current with scientific progress by simply watching the news and surfing the internet.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree
33. I plan to read scientific journals after I graduate.
○ Strongly Agree ○ Agree ○ Neither Agree or Disagree ○ Disagree
○ Strongly Disagree

Q14-Q16	**Factor 1: Decoding Primary Literature**	**Skills and Understanding of Scientific Primary Literature**
Q16-Q17	**Factor 2: Interpreting Data**	
Q18	**Factor 3: Active Reading**	
Q19-Q20, Q23	**Factor 4: Visualization**	
Q21-Q22	**Factor 5: Thinking Like a Scientist**	
Q24-Q26	**Factor 6: Textbooks vs. Journal Articles**	
Q1-Q2, Q8-Q12	**Aspect 1: Knowledge is Certain**	**Epistemological Beliefs**
Q3-Q7	**Aspect 2: Ability is Innate**	
Q27-Q33	**Life Long Learning**	

Appendix C. Preliminary Survey

Q1. you think this class has helped you to:

a. know how knowledge is organized,
b. how to find information
c. how to use information in such a way that others can learn from it
d. None of the above
e. All of the above

Q2. Lifelong learners are those who are: (1) better prepared to plan their own learning, (2) able to assess and monitor their own learning, and (3) able to independently find and use technical information

Do you think that a textbook free class like this one has helped you to become a lifelong learner?

a. Strongly agree b. Agree c. Disagree d Strongly disagree.

a:4, b:3, c:2 and d: 1

Q3.

The best material for a class is:

a. A single textbook
b. Multiple Textbooks
c. Scientific papers
d. Vendors Literature
e. 1+3+4
f. 2+3+4
g. 3+4