# AC 2010-1888: A SOPHOMORE LEVEL DATA ANALYSIS COURSE BASED ON BEST PRACTICES FROM THE ENGINEERING EDUCATION LITERATURE

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# A Sophomore Level Data Analysis Course Based on Best Practices from the Engineering Education Literature

### Introduction

As educators are well aware, the customary educational setting in which students develop problem solving skills is one where the numerical values presented are specific and absolute. The deterministic nature of the end-of-chapter type problems is imbedded in their minds well before students even matriculate.<sup>1,2</sup> However, as practicing engineers, they will confront the variation associated with measured data in the real world. Ideally, it is beneficial to prompt students to attend to the concept of variation early in their undergraduate studies. This paper describes the instructional structure and design of a large sophomore level data analysis and statistics class based on best educational practices. It is delivered to chemical, biological and environmental engineers directly following the material and energy balance courses. The goal of the course is to have students recognize that variation is inevitable, and teach them skills to quantify the variation and make engineering decisions which account for it while still utilizing model based problem solving skills.

The instructional design is based on constructivist and social constructivist models of learning. A constructivist perspective views learning as individually constructed based on the learner's prior knowledge, interpretations, and experience with the world, and views cognitive conflict as a stimulus for learning.<sup>3</sup> In addition, a social constructivist perspective views the social interactions and cultural context in which learning occurs as critical.<sup>4</sup> Based on these perspectives, it is believed that learning is facilitated when students (1) are engaged in solving real-world problems, (2) use existing knowledge as a foundation for new knowledge, (3) are immersed in a community centered classroom culture, and (4) are prompted to use metacognative skills and strategies.<sup>5</sup> The course architecture is designed to match the teaching model of Kolb,<sup>6,7</sup> and encourage the development of intellectual growth as modeled by Perry, in which students' view of knowledge ascends from dualism, to multiplicity of views, and then to contextual relativism.<sup>8</sup> While this paper is presented in a course specific context, it is believed these principles are useful to instructional design, in general.

### Kolb Learning Cycle and Class Architecture

Kolb<sup>6,7</sup> developed a system of selecting classroom activities based upon his research related to adult learning. As schematically shown in Figure 1, there are four "quadrants" of ways that people learn: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Two of these stages, concrete experience and abstract conceptualization, operate in the realm of knowing (how they perceive) while the other two, reflective observation and active experimentation, involve transformation of knowledge. It is by perceiving and then transforming knowledge that people learn. Much has been written about Kolb's system and its success in engineering education.

Kolb's system has many applications to engineering education from identifying the particular learning style of students and faculty to counseling students towards certain professions or job types. Our Additional content of the Kolb interest is related to the use of the Kolb learning cycle as a method to organize classroom activities, an approach primarily developed by McCarthy<sup>10</sup> for the K-12 system and applied to engineering education by Svinicki and Dixon.<sup>11</sup> This approach's basic claim is that maximum inculcation of new concepts, ideas and ckills occur when learning activities give full attent



Figure 1. Kolb's Learning Cycle

skills occur when learning activities give full attention, in order, to each quadrant of this cycle.

As shown in Figure 1, students are taught in a defined learning cycle that involves the following fours steps:

- 1. **Inspiration.** This step transfers a concrete experience to internal consideration (personal reflection) through answering the "Why should I learn this?" question in a way that the student is intrinsically motivated. In engineering education, this step is accomplished through showing the students why the new material is important to real-world engineering practice and the necessity of inculcation of this new material to be a successful engineer. This step is intended to be the "hook" for student learning.
- 2. **Information Transfer**. This step transfers the reflection of Step 1 into the logical construction of concepts, paradigms, approaches and potential skills through answering the "What do I need to know?" question. This step represents most classical education involving textbooks and lectures and tends to be information rich. Step 2 can be complex and abstract as it may require new language, concepts, paradigms, and ideas. Retention is most effectively achieved by making connections to students' prior knowledge and requires use of both lower and high level cognitive levels.
- 3. **Practice under Constrained Conditions**. This step transfers the new information gained in Step 2 to practice under highly constrained conditions. This step requires active learning principles. The classical approach in engineering education is the short-answer homework problem, but discussions, laboratories and group problem solving are also successful. Obtaining laboratory data to verify predictions from the materials learned in Step 2 is another common approach for Step 3. Additionally, the emerging use of technology in the classroom can be applied in this step.
- 4. **Connection to the Real World**. In Step 4, the students are required to expand the analysis, synthesis, evaluation applications used in Step 3 under conditions of fewer constraints. The ideal situation is to move to a real-world engineering design that requires not only technical analysis and synthesis, but evaluation of technical, environmental and

social quality. We firmly believe that this connection to the real world needs to be continuously made in classrooms across the curriculum.

The class schedule is constructed to facilitate a weekly Kolb cycle. It is divided into ten topics, one for each week of the quarter. Class delivery includes a lecture, a laboratory and a recitation. All four laboratory sections are scheduled between the lecture and recitation. Each topic is then organized through a set of activities that correlate to each quadrant in Kolb's learning cycle. Inspiration (quadrant 1) and new information (quadrant 2) are presented in the lecture. The laboratory allows active practice under controlled conditions (quadrant 3) and the recitation prompts reflection and generalization to the real world (quadrant 4). Engagement is promoted in recitation using the Web-based Interactive Science and Engineering (WISE) Learning Tool.

### Inspiration – context in the real world

Following the Kolb cycle, topics are introduced in the context of engineering practice. This approach is reinforced from the start of day 1, where the activities in the syllabus are preceded by a contextual learning exercise of the real world application of the course content, as shown in Figure 2.

You have just been hired as a process engineer at Beaver BioProducts. After briefly showing you the process of their best selling product, your boss, the hiring manager, has taken the opportunity to follow her lifelong dream and go on a safari in Africa, while the only other process engineer who knows this process has recently left the company for a competitor.

Two days after her departure (at 2 AM!), you get a call from the process technician, that the yield in the process has dropped by 20% - the lowest yield since the process start-up 3 years ago.



Generically, what steps would you take to resolve this problem? Place these steps in the order they should be performed.

Figure 2. Introductory class activity used in day 1 before the syllabus is discussed.

Early in the term, students complete two open-ended assignments in which they must attempt to display and reconcile real data from several sources. These exercises are intended, in part, to challenge the students' view of the "right answer," and promote more sophisticated epistemologies. Problems include analyzing and correlating reported CO<sub>2</sub> concentration and temperature climate data,<sup>12,13</sup> and reconciling different sources of oil production data.<sup>14,15</sup> These exercises are then discussed in the recitation after the problems are turned in. A sample set of analysis for the oil production data is shown in Appendix A.

Weekly topics presented in the course are introduced in their engineering context. For example, the Normal distribution is demonstrated by first fitting a sample of viscosity data of an

unspecified solution from a batch chemical process.<sup>16</sup> Similarly statistical process control is motivated by data of film thickness obtained by the author from a microelectronics manufacturing facility.

### Lecture – Information Transfer

In lecture new material that covers the week's topic is presented. It is contextualized by the introduction, and, frequently, cues are given that relate the presentation to the week's laboratory activity. This portion of the course reflects common classroom practices and is not discussed in depth.

## Laboratory – Practice under Constrained Conditions

The core of the instructional design for this course occurs during the weekly laboratory sessions. This activity allows engagement of students in step 3 of the Kolb cycle, practice under constrained conditions. The two-hour laboratory contains a maximum section size of 24 students. A worksheet is provided to students for each laboratory. The worksheet is designed to both as a scaffold for students to direct them through the laboratory tasks and as a tool to provide opportunities for reflection on the meaning of the tasks in terms of the course content. Students have to complete worksheets individually, but are encouraged to collaborate and discuss amongst one another.

The course instructor typically introduces the laboratory and periodically checks in; however, it is primarily instructed by a Graduate Teaching Assistant. In 2008, an undergraduate student assistant was added to each section to alleviate the time demands. The undergraduate students have previously completed the course. The instructors have two major roles: (1) they circulate

around the room and check off items in the worksheets, and (2) they answer questions and clarify tasks and course material.

The laboratory focuses on different elements of data analysis each week. The laboratory topics, activities and data mode are shown by week in Table 1. Over the ten week quarter, students participate in a wide range of activities that span the elements of experimentation. Depending on the week, the activity can emphasize designing experiments, collecting meaningful data, analyzing data (usually in multiple ways), or reporting results. The activity mode column represents the source of activity, e.g., how the data are obtained. In 2008, the regression laboratory changed to use a modified Pressure cooker to verify the Clausius-Clapeyron Equation, as adopted



Figure 3. Laboratory 4 in 2008.

from the literature.<sup>17</sup> A picture of students performing the revised laboratory 4 (and which Laboratories 9 and 10 are based) is shown in Figure 3. Several other laboratory activities are based on educational materials reported in the literature, as referenced in Table 1.

Three virtual laboratories were developed at Oregon State University to rapidly generate datasets unique to each group so that the two hour laboratory period could focus on data analysis and interpretation, or on experimental design. In laboratory 3, students generate large parallel data sets that the class collected in laboratory 2. In this way, students can experientially learn about sampling distributions. Laboratory 6 is a kinetics experiment of a biological system. The third virtual laboratory allows students to collect data on a food processing example so that they can apply and analyze a set of experiments using Design of Experiments. In 2008, it was moved to a homework problem.

Beginning in 2008, the activity modes are distributed as follows: 4 times physical laboratory or hands on activity, 2 times virtual laboratory, 2 times working with data available in a spreadsheet (static data), and 2 times communication of data (peer review of writing and oral reports). Laboratories 4, 9 and 10 were changed from 2007 to 2008.

Table	<b>Table 1</b> . Laboratory activities to reminice Kolo step 5, practice under constrained conditions.							
Week	Торіс	Activity	Activity Mode					
1	Summary Statistics and Box	1970 Draft Lottery Data	Data presented in Excel					
	Plots	Analysis <sup>18,19</sup>						
2	Sampling and Probability	Distributions of Coin Flips and	Active: students flip coins and					
	Distributions	Response Time <sup>20</sup>	test response times (ref x)					
3	Sampling from Populations,	Coin Flip Simulation and Sampling	Virtual laboratory developed					
	Sampling Distributions:	Applet <sup>21</sup>	in house and applet on web					
4	Regression and Model Fitting	2007: Determination of Heat Input	Hands-on laboratory					
	from Experimental Data:	2008 – 2009: Verification of the						
		Clausius-Clapeyron Equation <sup>17</sup>						
5	Writing	Rubric Aided Peer Assessment	Peer Review of Laboratory 4					
			report					
6	Regression Analysis	Rate Constant Determination for the	Virtual laboratory developed					
		Hydrolysis of Sucrose	in house					
7	Statistical Process Control	Silicon Oxynitride Chemical Vapor	Data presented in Excel					
		Deposition						
8	Measurement System Analysis	SiO <sub>2</sub> thickness measurements using	Hands-on laboratory					
	and ANOVA: Gage R&R	an ellipsometer						
	study							
9	Design of Experiments	2007: Food Processing Case Study	Virtual laboratory developed					
			in house					
		2008 – 2009: Optimize laboratory 4	Hands-on laboratory					
10	Oral Report	2008 – 2009: Presentation of lab 9	Oral Presentation					

Table 1. Laboratory activities to reinforce Kolb step 3, practice under constrained conditions.

### **Recitation – Reflection and Active Learning with WISE**

Recitation is the last scheduled class activity of the week, and is taught to the entire class (82-90 students) by the course instructor. It is designed to allow students to reflect on the topics covered that week, including the laboratory activities and the homework they just turned in. Content is also generalized and connected back to the real world completing the Kolb cycle.

Often the topics covered in recitation extend from the work students have done in laboratory that week. A few general examples follow. In Week 1, the class discusses the different ways that the 1970 Draft Lottery Data Analysis is presented in the original *Science* paper,<sup>18</sup> which leads to a more general discussion about steps in the analysis of data. This activity has the ancillary benefit of orienting students to technical journal literature. In Week 2, the sample averages and standard deviations from each lab section are shown, so that they can relate the variability in sampling statistics to a known population (coin flip data). After students peer review one another's written reports in Week 5, students interactively identify common writing mistakes followed by group discussion. After practicing making Control Charts in laboratory in Week 7, an industrial case study of Statistic Process Control in which some practical issues had to be overcome is presented and discussed.<sup>22</sup> Practical issues and context of Design of Experiments is discussed in Week 8 through an industrial example in ink jet printer pen process development.

A central learning tool to actively engage the large class is the Web-based Interactive Science and Engineering Learning Tool (WISE).<sup>23</sup> WISE is designed to utilize the College of Engineering's Wireless Laptop Initiative so that every student in a class is simultaneously engaged, creating a learner centered environment based on active learning. It can be used to develop activities that probe for conceptual understanding and deeper level thinking. It allows real-time formative assessment by the instructor. WISE builds on the current educational methodology in physics, chemistry, and biology classrooms that has shown that active learning pedagogies are more effective for student learning than traditional lecture.<sup>24-26</sup> Two elements of WISE make it particularly useful. First, students are assured of anonymity in their responses. Second, the automatic recording of student responses allows instant summarization of students understanding and convenient collection of the results for analysis.

WISE allows an instructor to pose to the class different types of questions including: multiple choice answers, multiple choice with short answer follow-up, numerical answers, short answers, ranking, drawing, and Likert-scale survey. After the students have submitted a response to an activity, the instructor can review a summary of the results with the class. Bar graphs are automatically compiled for student responses to multiple choice questions. For short answers, the instructor can view the set of responses and select specific answers to share with the class. Depending on the class response, the instructor can choose an appropriate method (e.g. peer instruction, instructor explanation) to reinforce or correct the response.

An example of the student interface of a short answer question is shown in Figure 4, while part of a ranking exercise is shown in Figure 5. Students individually answer these questions on their laptops. In Figure 4, students must demonstrate the generalization of regression analysis using matrices by identifying a cubic regression equation from the matrix form. This form has not been

discussed before in class and requires students demonstrate understanding by extending the formulation developed in class to a new situation.

Figure 5, shows a "ranking" exercise. Ranking exercises are comparative tasks that require students to rank multiple situations on a specified criterion. A properly designed ranking exercise will assist students in understanding the relationship between the conditions described in the problem and the ranking criteria. For example, in the case described in Figure 5, students must understand that the correlation coefficient depends not only on the magnitude of variation, but on the slope of the regression line as well.

Learning Tool	Conceptualization Exercise						
UNIVERSITY	In class, we learned how to generalize the least square method of simple linear regression using a matrix method and the following equation Y = XB. For the X matrix given below answer the following questions:						
rtual <u>Hand Raise</u> tercises udy <u>Group</u> y Statistics omepage	1. W 2. W 3. W	/hat is /hat is /hat w	the the ould	san mo l the	size? quation that is being used? rector be?		
gged in as:		[ 1	1	1			
	_	8	4	2			
tact point		27	9	3			
o Koretsky	v	64	16	4			
	$\Lambda =$	125	25	5			
		216	36	б			
		343	49	7			
		512	64	8			
	Short Answ	er:					
	Please rate l	how c	onfic	lent	are with your answer.		
	substantiall unsure	y me	odera unsu	ately re	utral moderately substantially confident confident		
	~						

Figure 4. Example of short answer WISE exercise as seen from the student interface.

The following plots represent different sets of measured data. On all plots the x-axis is the same and the y-axis range is the same. Rank the plots in order of the correlation coefficient, from largest to smallest. If you cannot distinguish between two cases, mark it as a tie.



Figure 5. Example of part of a WISE ranking exercise.

#### Assessment

Assessment data are reported over the span of the three years this course has been delivered. They are primarily based on student perceptions of the laboratory and the WISE activities through a Likert scale survey and written comments. While the real world context implicit in the Kolb cycle can be inferred from some written comments, a more comprehensive assessment strategy would be useful. The enrollment in the class was 82 students in Year 1, 87 students in Year 2 and 90 students in Year 3. The research protocol was approved by the IRB and only responses from those students who signed an informed consent form are included. Response is over 90% of the students enrolled.

Table 2 presents Likert scale responses of student perceptions of the laboratory experience. Data for the first five laboratories were collected at the midpoint in the course, while the last five were collected at the end of the term. Representative written comments for each laboratory are presented in Appendix B. Data from 2007 and 2009 are shown. Students were asked to rate the laboratories effectiveness. Results are generally positive (useful to strongly useful). As discussed above, laboratories 4 and 9 were changed in 2008 and laboratory 10 was added. In general, the preference of laboratories varied from year to year. For example, the peer assessment of laboratory reports was the least popular laboratory in 2007 (3.80) but received a relatively high score in 2008 (4.28).

Lab	Торіс	Mode	2007	2009
1	Summary Statistics and Box Plots: 1970 Draft	Static	4.28	3.97
2	Sampling and Probability Distributions: Coin Flips and	Hands-on	4.11	3.93
	Response Time			
3	Sampling from Populations, Sampling Distributions: Coin	Virtual	4.24	3.69
	Flip Simulation and Sampling Applet			
4	Regression and Model Fitting from Experimental Data:	Hands-on	3.83	
	Determination of Heat Input			
	Regression from experimental data Verification of the	Hands-on		4.06
	Clausius Clapeyron Equation			
5	Laboratory Report Peer Evaluation	Communication	3.80	4.28
6	Analysis: Rate Constant Determination for the Hydrolysis of	Virtual	4.26	3.93
	Sucrose			
7	Statistical Process Control: Silicon Oxynitride Chemical	Static	4.46	4.13
	Vapor Deposition			
8	Measurement System Analysis: Ellipsometer Gage R&R	Hands-on	4.40	4.37
	study			
9	Design of Experiments Virtual	Virtual	4.33	
	Design of Experiments – optimize laboratory 4	Hands-on		4.22
10	Design of Experiments – Oral Report	Communication		4.15

Table	2. Assessment	data for labor	atories, using a	Likert-scale (	1=strongly	disagree to	5=strongly agree)
			, ,	(	0,	0	0,0,

A different assessment was used in 2008. Students were asked to state the most effective and the least effective laboratory. The most effective included the revamped laboratory 9 (29 responses), laboratory 8 (18 responses) and laboratories 4 and 7 (12 responses each). The top three in effectiveness were the hands-on laboratories. Conversely, the laboratories rated as least effective were: laboratory 1 (17 responses) laboratory 5 (15 responses), laboratory 3 (13 responses) and laboratory 2 (12 responses). These laboratories were early in the term which focused more on statistical methods and theory. The laboratories later were more directed towards engineering applications.

One student who cited laboratory 8 as the most effective explained:

that it was a "real world" experiment; utilizing actual results that we collected ourselves. similarly, i enjoyed the pressure cooker lab for this reason.

This response illustrates the value of hands-on laboratories in connecting to the concrete experience quadrants in the Kolb cycle. On the other hand, such hands-on laboratories tend to be time consuming and do not cover the full spectrum of the data analysis process. The following response is also indicative of hands-on laboratories to induce the positive effect of the Kolb learning cycle:

I thought that Lab 9 was the most helpful because it gave us the opportunity to apply many of the things we had learned to a real world problem. We were also given very little explicit instruction, which really made us think for ourselves. My second favorite lab was probably the Ellipsometer Gage R&R study because we were able to take hands-on measurements, then apply the statistical method of ANOVA to them. ANOVA was something that was kind of difficult to understand without doing it yourself, so I thought this lab was very helpful.

On the other hand, in discussing Laboratory 1, with static data, one student wrote (see Appendix B):

It reinforced the material presented with real data analysis. The real data made the topic more interesting. Also, the experience increased my knowledge retention since I had to figure out how to accomplish certain parts on my own.

While another student said of Laboratory 7:

This Lab applied skills that I can see myself using in my career. And allowed me to relate process control to statistical analysis of the process.

There were many responses that connected a real world context to conceptual understanding as those cited above. However, the following response indicates a student who has more difficulty with this approach:

It (Laboratory 9) was the first lab where we already had an opportunity to grasp the concepts we needed to use in the lab before we started. so that instead of struggling to develop an understanding of the concepts while we were working through the lab we were able to preemptively apply our knowledge and prepare so that during the lab we could execute the lab instead of try to figure out what in the world is going on like with all the other labs.

In their assessment students were asked to comment on the laboratory instruction approach of using a combination of a faculty member, a graduate student instructor, and an undergraduate student instructor. These responses are again consistent with the theoretical framework of the Kolb cycle. For example, one student wrote:

It was a fantastic system! What was taught in lecture was even more understood in lab, especially with a grad and undergrad teaching the labs.

Moreover, many responses to this question reinforce the social constructivist perspective. For example, on student wrote:

The combination of the different instructors made is effective for learning. It was easy and confortable to confront the undergrads for help since they are my peers. It was also good having the facultiy and grad students there for the in depth information that the undergrads lacked.

This comment indicated the nature of the social roles in learning. The following response reiterates this view:

I feel that help was very accessible in the lab. It was really nice having the different kinds of support, because an undergraduate will see things differently than a faculty member or a graduate student instructor. I think it was really helpful to have people who can help you see things in several different ways.

Finally, one student commented on being able to envision the path towards expertise:

I think it worked very well. The different levels through the course provided a gateway system, allowing to see the understanding increase all the way up made me feel better about myself as well. It made me see that I did in fact need to learn it as it may be hard, but it really would get better with time and experience with it. I enjoyed the method quite a bit, it was extremely useful for help in learning in lab.

Assessment data for Web-based Interactive Science and Engineering Learning Tool (WISE)

Student perceptions of the use of WISE in this class were also measured using a survey consisting of Likert-scale questions. The survey was administered at the end of the term. Results from 2008 and 2009 are summarized in Table 3.

 Table 3. Assessment data for Web Based Interactive Science and Engineering (WISE) Learning Tool, using a Likert-scale (1=strongly disagree to 5=strongly agree)

Question	2008	2009
The short answer follow-ups to multiple choice questions helped me to	4.05	4.02
think more about the question and the answer that I chose.		
I am more actively involved in class when WISE is used	3.94	3.78
Seeing the class responses to a concept question (bar graph) helps		3.88
increase my confidence.		
I have to think more in class sessions that use WISE than those that do	3.72	3.74
not.		
If WISE was used in other classes, my conceptual understanding in	3.63	3.45
those classes would be better.		
Using WISE helps me to understand the concepts behind the problems.	3.61	3.52
In this course, I am more aware of my misunderstandings than in	3.57	3.79
courses taught by traditional methods.		

Written comments about WISE also reinforce its role in formative assessment and reflection: Its always good to check yourself and see how you are doing. Even if you got all of the WISE questions wrong it still gives the ability to better understand how we're thinking about it and gives the chance to go back and rethink how we are going about solving problems. WISE is a good tool to have in the classroom.

I'm not sure what to say... it is kinda helpful, like to get feed back on if you're actually geting stuff and I like that the teacher gets to see if we are actually getting stuff and knows if he should slow down or if he can speed up. sometimes the questions seemed off the wall.

### Summary

This paper describes the instructional structure and design of a large sophomore level data analysis and statistics class based on best educational practices. It is delivered to chemical, biological and environmental engineers directly following the material and energy balance courses. The goal of the course is to have students recognize that variation is inevitable, and

teach them skills to quantify the variation and make engineering decisions which account for it while still utilizing model based problem solving skills. The instructional design is based on constructivist and social constructivist models of learning. The course architecture matches the teaching model of Kolb and encourage the development of intellectual growth as modeled by Perry. The class schedule is constructed to facilitate a weekly Kolb cycle. It is divided into ten topics, one for each week of the quarter. Class delivery includes a lecture, a laboratory and a recitation. All four laboratory sections are scheduled between the lecture and recitation. Each topic is then organized through a set of activities that correlate to each quadrant in Kolb's learning cycle. Context rich problems, laboratory practice and reflective recitations are used. Assessment of students indicates that they perceived the laboratories and recitation pedagogies to be effective. There were many responses that connected a real world context to conceptual understanding.

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Appendix A. Sample analysis from Oil Production exercise

- All three sources, while covering different time spans, generally reconcile and show the same trends.
- Source 3 is higher, but that is to be expected, since it contains natural gas and other liquids, in addition to crude oil. The production of crude oil is the dominant factor.
- The transformed data shows periods of general linear trends of production with year. The production rate shows a natural break in the period pre-1973 and post 1982
- The data between 1973 and 1982 are sporadic and sparse
- Portions of the data from Figure 1b representing each distinct period is fit to a line. Values of the linear regression coefficients and the correlation coefficient are shown in Table 1.



Figure A.1. A. Data from 3 sources B. Linear fit of two regions of ln transformed data shown in Figure 1b. Data from refs 14 and 15.

<u> </u>	1		
	slope	intercept	$R^2$
Pre - 1975	0.074	-142	0.996
Post - 1985	0.013	-221	0.953

Table A.1. Regression model parameters and correlation coefficients.

• From the fit above for every Mbbl produced in a given year, we can calculate we can predict how much oil we would expect to be produced the next year. Pre 1975, we see a 7.7% increase in production, post-1985 a 1.3% increase

### Appendix B. Sample written comments for each laboratory in 2009

Table B.1 presents some sample student comments. While the majority of responses were positive, as indicated by the values in Table 2, a sample negative comment is included from each laboratory for comparison.

Lab	Positive Comment	Comment Suggesting	Negative Comment
240		Improvement	
1	It reinforced the material presented with real data analysis. The real data made the topic more interesting. Also, the experience increased my knowledge retention since I had to figure out how to accomplish certain parts on my own. The only down side was the time it took to complete the lab (However, I believe I learned more in the end.)	It was a little long, and entirely theoretical. It may have been more interesting if we had reconstructed the draft lottery problem (i.e. pulled badly mixed balls out of a bucket)	I already know the basic uses of excel and I felt like this lab was not very helpful and more time consuming and tedious. I thought it was a waste of my time. It may have helped jog my memory of how to use excel but I can do that reading the book.
2	The coin flipping lab was useful in showing how sample statistics relate to known population parameters. I thought it effectively drove this point home.	Again in this lab I was still lost by the newness of things. I didn't understand until a day or so later that there was a difference between a binomial distribution and a normal distribution. The concepts come pretty fast and I don't usually understand everything until after I have done the homework at the end of the week.	This lab was way too long. I don't like having to spend time out of class on lab. I thought it was useful in that it made me practice what I learned, but I could have practiced it in about an hour and would have been fine. The labs in general are too long and by the end I'm tired of doing the same computations in excel or statgraphics.
3	I thought this was a great lab in demonstrating the improved accuracy of larger sized samples. After doing the coin flips manually the lab before, it was easy to understand what was taking place with the simulation.	I liked how this lab took what we learned from the last lab and added onto it. This lab would have been less frustrating if we had been given the correct information during our lab section instead of at the end.	too similar to the previous lab didn't really learn that much just about sample size
4	I liked that in this lab, we were responsible for collecting the data. The group I was in got data which verified the clausius clapeyron equation to an R^2 value of 0.99. It was cool to be able to verify this theoretical equation in a lab.	We, so far in this lab all we have done is collect data so it was not much help for this class yet but I think it will be helpful once we start dealing with the data.	Taking the data ourselves didn't really enhance my knowledge on statistics.
5	I think the most useful thing about this process was reading other peoples report, and seeing and thinking critically about how the same question was approached by them. I think it might have been nice if we could take home the lab report and give it to them the next day in class, however as I feel I was a little pushed for time when grading the lab report.	This could have been extremely useful, the group I was paired with did not know enough about the lab to correct mine. So they had minimal corrections for me which made it hard when I went back to further edit my lab. Choosing my partners would have been better!	My peers didn't really give me much constructive feedback on my personal lab so it was not extremely helpful. With that being said, I think it has the potential to be a very useful tool, so it shouldn't be eliminated based on just one experience. I did feel that I got something out of reading other reports and seeing the various methods they chose to organize and present their information.

Table B.1. Sample of written comments for each laboratory in 2009

Lab	Positive Comment	Comment Suggesting Improvement	Negative Comment
6	The regression analysis on the simulated data was really helpful because you used data collected in lab (what you would normally do) and then were able to perform the regression analysis that you would usually do on Excel by hand. It was a good context for applying what we had just been learning about.	I liked the chance to apply regression skills to an actual process. Using a process that was more based in chemical engineering and less chemistry would have been more interesting for me though. I feel thats the case for most of these labs and problems, the engineering problems are the most interesting.	This lab was very confusing. The linear regression was hard to follow and at times seemed overwhelming.
7	I liked this lab, it definitely helped me understand the control limits and specification limits as well as the cp and cpk values better and how to obtain them from a bunch of raw data. It was useful to practice what we learned in class before we had to do it for homework. Once again, lab could have been shorter, maybe take out some of the repetitive parts of the labs, where we do the same thing over and over again. Same with the homework, its very repetitive.	This lab was interesting due to its practical applicability. It was effective enough at getting students to demonstrate knowledge of statistical process control, though little explanation of the underlying theory occured until much later. So, a little more theory at the beginning of lab would likely help in student comprehension.	I would have liked to not be given the data but rather understand how the data was collected and not jump in the middle of the process with minimal understanding.
8	All of the equations from class for the ANOVA tables finally came to make sense after doing the lab. With so many complicated equations, just writing them down and hearing how to do them isn't enough to fully understand them. Actually calculating, as we did in the lab made everything become much more clear.	I liked that we took measurements and actually dealt with them. However, my group was last to use the ellipsometer. We set up our Excel file so that all the tables and calculations were done already, then we just entered the numbers. However, this made it hard to see what we did with the numbers. I would have liked to have more tools to take measurements so that we wouldn't have to wait until the end of class for our turn.	This lab was probably the most stressful for myself. ANOVA can be a hard concept to learn, and given that we werent given a formal instruction in how to fill an ANOVA table out, it was pretty stressful trying to figure out. I thought working with the thin films was a good idea though.
9	I enjoyed this lab the most, it was nice to be able to approach a completely open-ended problem, because I like being able to come up with my own answers. It would have been helpful if groups could have been arranged at the end of the previous lab, so that we could have time to brainstorm beforehand	Good but really hard. I would have liked another week to work on it before it was due. I felt REALLY rushed when doing the calculations and making the power point. It was really hard for use to find time together during this time because all the classes are so demanding during this time of the term.	very unclear directions on what was being tested. And I know that was part of the process. Having a limited amount of time to both come up with an experiment and then perform the test was very very very difficult. If this lab was two labs combined it would have been a much better experience.
10	The lab period discussion was very 'dynamic' as described in class and allowed for a high level of learning to occur for those interested students. This period may have been improved were it not during dead week, though this is understood to be unavoidable. In all, this was a very effective lab for learning which presentation methods were and were not effective.	A harsh learning experience. Like ripping tape off an open wound. But I will always remember what a professor expects for processing data from now on.	what you want is an open ended presentation and so, we don't know what you want

 Table B.1 (continued). Sample of written comments for each laboratory in 2009