Integrating the Financial Aspects of Laboratory Procedures into Electron Microscopy Courses at a Community College and Materials Science Courses at a University

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Abstract

Basic financial issues related to the cost of performing standard laboratory procedures and materials analyses have been incorporated into two courses in an attempt to teach students how to plan an experiment from the financial and time viewpoints. These two course involved two very different audiences (technical program students at a community college, engineering students at a research university), but in both cases the student's responses were similar. They did not realize how much of the total cost was personnel, they consistently underestimated how much time various procedures take. Also, when planning an experiment where the cost perspective was considered, it helped them see the resource side of experimental work, not just the academic side, and it helped them manage their time better. It also helped them understand how one makes money in engineering.

Introduction

Laboratory courses generally deal with laboratory procedures, data analysis and interpretation, and presenting the findings, but rarely the financial costs involved in doing this type of work. Technical and engineering managers are keenly aware of these costs, and the administration is certainly (somewhat) aware of how much laboratory courses cost, but our students generally have no idea how much the experiment they are doing costs, and how much similar work done in industry would cost. To teach this very practical and real-world aspect of their profession the authors have begun asking their students to develop budgets for their laboratory experiments, project the costs of analyses they are learning, and even manage an inventory of supplies.

Spreadsheets can be used effectively to teach engineering and scientific principles and for teaching a structured approach to problem solving. Recent efforts at integrating spreadsheets into materials science courses at U.C. Davis have been successful [1]. The one aspect that until now has been ignored in these efforts, the reason spreadsheets were invented, to perform financial calculations in a table-like format. This is now being incorporated into a laboratory course at U.C. Davis and have been incorporated into an electron microscopy course at San Joaquin Delta College. The approaches and applications in each case are slightly different, but their common goals are to teach the students to think in terms of costs, and financial opportunity, as well as technical and scientific terms.

Electron Microscopy

Over the last couple of years, a number of postings to the microscopy list server asked questions on how to calculate a recharge rate for a piece of equipment, a service, or a specimen preparation procedure. With so many people asking how to calculate a rate, it was decided to add a homework problem set to a course in "Advanced Biological Transmission Electron Microscopy" or more commonly referred to as EM37.

EM37 is a course designed to expose the students to a variety of different specimen preparation techniques for transmission electron microscopy. These specimen preparation procedures can be quite simple involving just a couple of steps taking a few minutes to procedures with many steps requiring over a week to complete.

In prior courses the students have learned how to operate a transmission electron microscope and how to use an ultramicrotome. They had all passed a safety test on instruments they would use as well as chemical and radiation safety. But none knew what it cost to run a microscope, how much it cost to dispose of waste chemicals, or how much it cost to prepare a sample.

A lecture was given in a computer lab where each student had access to a computer and the Internet. Each student went to the web site of a supplier of microscopy products and a new workbook was opened in Microsoft's Excel. The first worksheet was titled chemicals and a list of all chemicals used in a typical specimen procedure was listed. The next column was the amount (g, ml), and the following column was the cost. (See the first spreadsheet printout.) A new worksheet was titled bulk chemicals. This is where the cost of buffers, fixatives and stains were calculated: Chemical Grams used/Chemical Amount * Chemical Cost plus Time to Prepare * Labor Cost. As part of the homework, the students were asked to break this worksheet down to individual worksheets listing the step-by-step procedure for making a buffer, fixative or stain. Final part of the homework was to create a worksheet called 'STD TEM Prep' which was a procedure for taking tissue and preparing it for TEM and a cost breakdown with a total per sample cost. (See the second spreadsheet printout.) The lecture ended with the 'what if' questions that Excel is so good at answering. What if labor had a 10% salary increase? What if the price of Gluteraldehyde goes down $1.00? What if it takes 30 minutes to make a solution instead of 15 minutes?

Many of the students found in the beginning the problems to be difficult due mostly to their inexperience with Excel. After the lecture in the computer lab and an hour of use most had learned the simple basics of Excel, how to copy and past and enter the simple formulas and linking it to more than on cell on different pages. Several students experiment with color to highlight important areas. All students enjoyed getting a 10% raise and seeing how it affected the change in pricing. Interestingly, the students' estimates of the cost of preparing one TEM sample ranged from $102 to a high of $698 to prepare one sample for TEM, which generated a bit of discussion about salaries. As a follow up, the students were asked to search the web to find sample postings of other institutions to see the rates others charge and compare them with their own. Many students were surprised at the pay cut they were going to have to take.

Materials Science

In a third year materials characterization course the students get a chance to use a number of analytical instruments, including a scanning electron microscope, and x-ray diffractometer, an x-ray radiography system, optical microscopes, and even some ultrasonic inspection equipment, including an acoustic microscope. The experiments also require a modest amount of consumables, and a lot of the students' time. Beginning in the winter 2005 quarter the course objectives include the financial costs of doing the experiments. The goal is to get the students to understand what the costs associated with their experiments are and to deal with them as if they were going to provide an estimate of the cost and finally send a bill to someone for the laboratory work.

At the beginning of the quarter the students are given an itemized list of the unit costs of instrument time, consumables, and technician time. They are then be asked to look at their syllabus to figure out as best as they can how much of each they will need, and then to develop a budget for doing each experiment. In this budget they must also decide how much salary they are paid, add benefits to this and estimate their hourly rate. A typical hourly cost calculation for personnel would be similar to the following:

1. Estimate the Personnel Cost

Base Annual Salary:	$40,000
Benefits Rate:	26%
Benefits:	$10,400
Total Annual Personnel Cost:	$50,400

2. Estimate the Hours Available for the Projects

Hours worked in a year:	52 weeks * 40 hours = 2,080 hours/year
Holidays:	16 days/year = 128 hours/year
Vacation:	2 weeks/year = 80 hours/year
Sick Leave:	1 week/year = 40 hours/year

Meetings, training, etc.: 2 hours/week + 1 week/year = 184 hours/year
Other (email, etc.): 1 hour/day = 260 hours
Available Hours: 2,080 - 128 - 80 - 40 - 184 - 260 = 1,388 hours/year

3. Calculate the Hourly Personnel Cost
Total Annual Personnel Cost: $50,400
Available Hours for Projects: 1,388
Hourly Personnel Cost: $50,400/1,388 = $36.31/hour

See the third spreadsheet printout for another example of this calculation plus a list of other costs.

Once the students have established the unit costs of each piece of equipment, supplies, and their time, they can start to build a budget for each experiment. They start by estimating how much time they expect to spend preparing for the experiments, doing the experiments, and finally analyzing the data and writing the reports. They can also add indirect cost overhead, just like the faculty do when developing their grant proposals. This cost estimate is turned in at the start of the laboratory session. The fourth spreadsheet printout is an example of a budget for one of these experiments.

During the quarter the students keep track of how much time they spend on each assignment, how much instrument and technician time they use, and any incidental costs. This expense report is turned in with their laboratory report.

At the end of the quarter the students are asked to compile the expense reports into one final summary of costs, and to compare this to their original budget. The summary includes a break down of costs which may include pie charts illustrating the relative cost of instrumentation, materials, and personnel. Their final report summarizes not only the costs of the work done but also the accomplishments, basically, the outcomes from each experiment. The text of these reports are limited to 2 pages plus figures and the summary page printout from their spreadsheet.

During the first laboratory meeting of the quarter the students are shown how to use spreadsheets to prepare a budget. They are walked through the process of developing a multi-sheet spreadsheet that covers the basic costs of instrumentation, personnel and consumables on one sheet, and the basic budgets and cost reports on the following sheets. This spreadsheet is used through out the quarter, and in building it the students learn how to organize their financial data and to create a spreadsheet that can be easily expanded and yet can be easily understood, and used, by others. Once the students have prepared their first budget it generally takes them only about 10 minutes to prepare the expense reports and budgets for the other experiments. It simply requires duplicating the previous budget and adjusting the values.

Discussion

The experiences in the electron microscopy course told us that by adding some fairly simple spreadsheet exercises the students could explore, and better understand, an important aspect of their profession. It taught them how much things cost, how much people cost, and it also got them to start thinking about how they could approach their job with an eye towards the financial success of their company, perhaps even their own company. The experience added a dimension to this course that is usually never discussed, and if so, only in very general terms, and makes them much better prepared to enter the workplace.

In the materials characterization course the students get to see how much it costs to provide engineering services to a client as well as the cost of conducting academic research. They get an opportunity to project their costs, and later to compare this to the actual costs. In projecting these costs, the students must consider which tools they will be using, supplies needed, and how much time they expect to spend on the project. In other words, prepare for the experiment before class starts, always a difficult part of teaching laboratory courses.

Formal assessment tools have not been used in these efforts. In the electron microscopy course the class size was quite small so the instructor got to work closely with each student. The students struggled with the assignments at first, so the instructor set up additional sessions where he could walk them trough the initial exercises. Once they had a working spreadsheet the students were able to build on to it when preparing budgets for the experiments that followed. In discussions with the students the diversity of experience in budget matters became clear, as was the fact that we were teaching budgeting skills to people who don't balance their own check books. Several students had had careers in industry and described a completely different approach where the budgets were based on very loose and generalized estimates of the overall cost.

At the time of this writing the materials characterization course is still being taught. While class size is larger, 25 students, the class meets in the lab in smaller groups. During the first week the students had to be walked through the process of establishing their basics costs and developing their initial budgets. Once they had their initial budgets it was easy to add the cost of the other experiments. Assessment will take the form of a survey and a discussion session during the last week of the quarter which the author reserves for of a review and discussion of the course's outcomes and an invitation to use the facility and the skills they have learned as they work on projects in other courses. Questions will address the following:

- Did these budget exercises help you prepare for these experiments?
- Did these exercises help you understand the cost issues associated with engineering work and research?
- Did these exercises help you understand the cost of doing business as an engineer?
- Did making these budgets help you manage your time better?

- Do you think these exercises will help you in designing and preparing a proposal for your senior design projects?

The results of the surveys will be presented at the conference.

Summary

These exercises can be easily incorporated into practically any course where itemized costs or equipment, supplies, and personnel can be established. The microscopy and materials characterization courses here were ideal since the instruments had established recharge rates and many of the specimen preparation procedures were standardized and in industry tend to be done very often.

In the two courses described here teaching the costs of technical and engineering procedures addressed an issue that is relevant to the students real reason they attend college, to get a good job and/or launch a career. Of course, there are those intellectually stimulating aspects of higher education we all enjoy, but the student's real motivations are almost always something more practical, immediate, and relevant to the individual, and we all want to motivate our students.

By incorporating these financial matters into their studies the relevance to their careers, and to their personal goals, we can motivate them to start thinking about ways to apply their knowledge to real engineering problems and will have a better understanding of what it takes to be successful in a technical/engineering profession that is actually operating within the business world.

Bibliography

1. M. Meier, Integrating Spreadsheets into an Introductory Materials Science Course, ASEE Proceedings of the Annual Conference and Exposition, Salt Lake City, Manuscript # 2004-1604, (2004).

Biographical Information

Michael L. Meier received his B.S. in Materials Engineering from North Carolina State University in 1979 and his M.S. (1986) and Ph.D. (1991) in Materials Science and Engineering from the University of California, Davis. In 1993 he returned to UC Davis where he is now the director of Materials Science Central Facilities, a materials characterization facility, and is very active in outreach efforts and developing the laboratory teaching program.

Michael Dunlap graduated from the Electron Microscopy program at San Joaquin Delta College in 1981 and got his B.S. in Biology at U.C. Davis in 1985. He is an electron microscopist in Materials Science Central facilities, in the department of Chemical Engineering and Materials Science at U.C. Davis.

	Amount	Cost	Purchased From
BEEM® Capsules, Size 00	100 /pkg	$ 7.35	Ted Pella
Cacodylate, Sodium	450.00 g	$55.00	Ted Pella
DER 736	250.00 g	$15.50	Ted Pella
DMAE	25.00 g	$6.00	Ted Pella
EtOH, 100%	200.0 ml	$8.00	Ted Pella
Glutaraldehyde 25%	100.0 ml	$18.00	Ted Pella
Glutaraldehyde 50%	100.0 ml	$38.50	Ted Pella
Hydrochloric Acid	250.0 ml	$116.35	Fisher Scientific
Labor	1.00 hr.	$30.00	
Lead Citrate, Trihydrate	10.00 g	$17.00	Ted Pella
NSA	450.00 g	$25.60	Ted Pella
OsO4, Crystal	0.50 g	$21.00	Ted Pella
Phosphate, dibasic	450.00 g	$38.00	Ted Pella
Phosphate, monobasic	450.00 g	$18.75	Ted Pella
Phosphotungstic Acid	25.00 g	$25.40	Ted Pella
Spurr's Embedding Kit	1.00 g	$53.50	Ted Pella
Ruthenium Red	1.00 g	$39.75	Ted Pella
Uranyl Acetate	25.00 g	$160.00	Ted Pella
VCD (ERL4206)	225.00 g	$64.00	Ted Pella

TEM SAMPLE PREPARATION

#	Step	Duration	ETOH	Total amounts	Time to Prepare	Cost of Chemicals	Total cost to Prepare
1	Immerse tissue in 2.5 % Glutaraldehyde in Sorensens Phosphate Buffer, pH 6.8adjusted, over night.			10.0 ml	0.25 hr.	$ 1.43	$ 8.93
2	Wash tissue in 3 changes of Buffer. 5 min ea.			50.0 ml	0.50 hr.		$ 15.00
3	Wash tissue in H20. 5 min ea.				0.50 hr.		$ 15.00
4	Post fix by Immersing tissue in 2% OsO_4 for 2 hrs.			4.0 ml	0.25 hr.	$ 2.28	$ 9.78
5	Wash tissue in 3 changes of H20. 5 min ea.				0.50 hr.		$ 15.00
6	Dehydrate using a series of ethanol washes:						
	a. 50% ETOH and 50% H20	15 min ea.		10.0 ml	0.50 hr.	$ 2.40	$ 17.40
	b. 75% ETOH and 25% H20	15 min ea.		10.0 ml			
	c. 95% ETOH and 5% H20	15 min ea.		10.0 ml			
	d. 100% ETOH -3 times	15 min ea.		30.0 ml			
7	Embed tissue in Spurr's resin:		ETOH	Resin			
	a. 2/3 ETOH and 1/3 resin	4 hr.	10.0 ml	5.0 ml	0.50 hr.	$ 53.50	$ 68.50
	b. 1/3 ETOH and 2/3 resin	4 hr.	5.0 ml	10.0 ml			
	c. 100% resin 3 changes	4 hr.		45.0 ml			
8	Place sample and fresh resin in BEEM capsule and heat in a 70° C oven for 24 hr. to harden plastic.				0.10 hr.	$ 0.07	$ 3.07
					3.10 hr.	$ 59.69	$ 152.69

Cost per Sample:	$ 152.69
Number of Samples:	15
Cost:	$ 2,290.30

File: EMS-162L Budgets.qpw
Owner: Mike Meier
Created: 04-Jan-2005
Revised: 04-Jan-2005

Description: Budgeting and Costs of the EMS-162L Experiments

2. Basic Instrument, Supplies, and Personnel Costs

Instrument	Abbr.	Basic Hourly Rate	Technical Support Rate
FEI High-resolution Scanning Electron Microcope	SEM	$30.00	$40.00
Philips CM-12 Transmission Electron Microscpe	TEM	$27.00	$40.00
JEOL Scanning Transmission Electron Microscope	STEM	$40.00	$40.00
Scintag X-ray Diffractometer	XRD	$15.00	$40.00
Bruker/AXS Nanostar Small-Angle X-ray Sacttering	SAXS	$20.00	$40.00
Optical Microscopy	OM	$0.00	$40.00
Acoustic Microscopy	AM	$0.00	$40.00
X-ray Radiography	XRR	$0.00	$40.00
Perkin-Elmer Thermal Analysis	PETA	$25.00	$0.00
VCR XLA Ion Mill	XLA	$10.00	$40.00

Personnel

Annual Hours:	2088	hours
Holidays:	128	hours
Vacation:	112	hours
Sick Leave:	112	hours
Net Hours:	1736	hours
Meetings, etc.:	104	hours
Training:	16	hours
Other:	252	hours
Net Productive Hours:	1364	hours

Title:	Engineer
Salary:	$40,000
Benefits Rate:	26.00%
Benefits:	$10,400
Employee Cost:	$50,400
Hourly Employee Rate:	$36.95

Other Costs

Overhead Rate: 48.50%

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Description: Budgeting and Costs of the EMS-162L Experiments

3. Experiment 1, Optical Microscopy

1. Laboratory Instrumentation and Analyses

	Instrumentation Costs			Technician Support			
Instrument	**Rate**	**Hours**	**Cost**	**Rate**	**Hours**	**Cost**	**Total**
SEM	$30.00	3	$90.00	$40.00	3	$120.00	$210.00
TEM	$27.00	0	$0.00	$40.00	0	$0.00	$0.00
STEM	$40.00	0	$0.00	$40.00	0	$0.00	$0.00
XRD	$15.00	1	$15.00	$40.00	1	$40.00	$55.00
SAXS	$20.00	0	$0.00	$40.00	0	$0.00	$0.00
OM	$0.00	5	$0.00	$40.00	0	$0.00	$0.00
AM	$0.00	0	$0.00	$40.00	0	$0.00	$0.00
XRR	$0.00	0	$0.00	$40.00	0	$0.00	$0.00
PETA	$25.00	0	$0.00	$0.00	0	$0.00	$0.00
XLA	$10.00	0	$0.00	$40.00	0	$0.00	$0.00
	Total:	9	$105.00	Total:	4	$160.00	$265.00

2. Supplies and Services

	Cost	Percentage
Metallography Supplies:	$0.00	0.00%
EM Sample Preparation:	$0.00	0.00%
Chemicals:	$0.00	0.00%
Film and Darkroom:	$0.00	0.00%
Office and Computer Supplies:	$25.00	100.00%
Other:	$0.00	0.00%
Total:	$25.00	100.00%

3. Personnel

Engineer Rate: $36.95 per hour

	Hours	Cost	Percentage
Research, Preparation:	3	$110.85	15.79%
Laboratory Work:	9	$332.55	47.37%
Data Analysis:	3	$110.85	15.79%
Report Preparation:	3	$110.85	15.79%
Report Presentation:	1	$36.95	5.26%
Other:	0	$0.00	0.00%
Total:	19	$702.05	100.00%

4. Summary

	Cost	Percentage
Instrumentation and Analyses:	$265.00	26.71%
Supplies and Services:	$25.00	2.52%
Personnel:	$702.05	70.77%
Total:	$992.05	100.00%