AC 2009-294: TEACHING MANY SECTIONS OF MATERIALS SCIENCE LABORATORY

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Teaching many sections of Materials Science Laboratory

Abstract

This paper describes the design and development of instructional materials for a sophomore-level materials science lab course. The design goal was to achieve both depth and consistency in laboratory instruction in all the sections within a quarter, and from one quarter to another. Each laboratory experiment now has a set of PowerPoint slides for classroom presentation, multiple choice questions to assess students' understanding of key concepts, and a survey to assess students' perception of the quality of materials and instruction.

Student performance data on selected multiple choice questions is presented along with the cumulative data from the student surveys. Preliminary assessment of this data and in-class quizzes indicates that we have achieved instructional consistency across all the lab sections. Student performance can be further improved if the course instructor explicitly relates the theoretical principles to experiments students do in the lab.
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Introduction

At our institution, every mechanical or industrial engineering major must take the introductory materials science course that includes a weekly lab component. The lab experiments cover standard mechanical testing and materials characterization techniques. In all experiments except x-ray diffraction, students get hands-on experience in using the lab equipment and instruments.

In the last seven years, our department has experienced such a significant growth in student enrollment that many of the lab sections in recent years were taught by student instructors. End of the academic quarter course evaluations indicated that the quality and depth of lab instruction varied significantly across the lab sections.

Our university is on quarter calendar system where each quarter is identified by a 5-digit code: first four digits indicate the beginning of the academic year and the last digit refers to the quarter (Fall = 1; Winter = 2; Spring = 3; Summer = 4). Table 1 lists the number of sections and instructors involved during the last two academic years. Each lab section is limited to a maximum of 12 students although on a few occasions this policy has been violated to accommodate students with schedule conflicts.

Table 1: 0304-344L Materials Science Lab

Quarter →	2007-1	2007-2	2007-3	2008-1	2008-2	2008-3
# of Sections	6	3	6	6	5	6
# of instructors	4	2	3	4	3	5
Total # of students	38	32	72	55	45	75

Excellence in lab instruction requires high-quality instructional materials that help both the instructor as well as students. Instructional depth can only be achieved if students are provided sufficient but not overwhelming details about the experimental principles and procedures. Instructional consistency can be realized if all instructors have access to the same high-quality materials, and demand similar level of rigor in lab reports by providing students with grading rubrics and a sample report as a template.

When the quality and depth of lab instruction is consistent across all sections, and from one year to another, we will ensure that our students are well-prepared for subsequent courses. We hope that student preparedness and satisfaction will contribute to higher retention and graduation rates.

With support of a Provost's Learning Innovation grant, we developed the standards and formats for instructional materials wherein each experiment includes (a) equipment details, (b) PowerPoint presentation slides on experimental principles and theory, (c) step-by-step instructions to use the equipment, (d) sample data and analysis, (e) a set of multiple-choice questions, and (f) a student survey. At the beginning of each term, these instructional materials are integrated into MyCourses, the online course management system developed by *Desire 2 Learn* (www.desire2learn.com) for our institution. Thus, all lab instructors and students now have access to and use the same instructional materials.

Assessment Rubrics and Design of Instructional Materials

For BSME curriculum to meet or exceed the accreditation criteria of the Accreditation Board of Engineering and Technology (ABET), our department has developed a set of nine mechanical engineering program outcomes (MEPO). Each core course in the curriculum has been assigned one or more of these nine MEPOs as primary or secondary outcomes, and will be assessed using five rubrics (AR1 through AR5) listed below on a scale of 1 to 5:

AR1: Course Learning Outcomes contribute to this MEPO
AR2: Course Learning Outcomes are supported by Syllabus Content and Topical Coverage
AR3: Course Content is consistent across all sections and academic quarters
AR4: Individual Graded Items demonstrate consistent measurement of Course Objectives
AR5: Individual Graded Items demonstrate consistent student achievement of Course Objectives

The instructional materials for the materials science lab course were designed in accordance with these five assessment rubrics. The course has nine objectives (C1 through C9) that are listed below:

C1. to obtain hands-on experience with materials testing and characterization equipment
C2. to reinforce theoretical principles with lab measurements and analysis
C3. to determine the mechanical properties of metallic materials
C4. to index an x-ray diffraction pattern, determine the crystal structure and identify the material phase using the PDF database
C5. to prepare metallographic specimens, examine the microstructures, and understand the effects of heat treatments
C6. to measure electrode potential difference in the three limiting type of corrosion cells
C7. to write concise laboratory reports using spreadsheet and word processing software

C8. to interpret and evaluate experimental results
C9. to become familiar with the ASTM standards for materials testing and characterization.

These course objectives were mapped to each primary and secondary MEPO assigned to the group of core courses identified as *Experiential Learning*. The parsing of each MEPO and its mapping to the course objectives is shown in Table 2.

Table 2: Mapping Course Objectives to assigned Mechanical Engineering Program Outcomes

Course Objectives →	C#1	C#2	C#3	C#4	C#5	C#6	C#7	C#8	C#9
Primary MEPO #6 ↓									
6a: Design Experiments									
6b: Conduct Experiments	√	√			√	√			
6c: Analyze Data		√	√	√	√	√		√	
6d: Interpret Data		√	√	√	√	√	√	√	
Secondary MEPO #1 ↓									
1a: Engage in M. E. Profession	√	√	√	√	√	√	√	√	√
Secondary MEPO #2 ↓									
2a: Design system or component									
2b: Meet customer specifications									
2c: Meet customer constraints									
2d: Define design requirements									
2e: Write design requirements									
Secondary MEPO #4 ↓									
4a: Use engineering techniques	√	√	√	√	√	√		√	√
4b: Use engineering skills	√	√	√	√	√	√	√	√	
4c: Use modern engineering tools	√	√		√	√	√	√		
4d: Apply math, science & engineering principles		√	√	√	√	√	√	√	
Secondary MEPO #7 ↓									
7a: Participate in multi-disciplinary teams									
7b: Participate in disciplinary teams	√		√	√	√	√			
Secondary MEPO #8 ↓									
8a: Communicate effectively by written means							√	√	
8b: Communicate effectively by verbal means									
8c: Communicate effectively by graphical means							√	√	

The department has not devised a scheme to assign a numerical rating (1 → 5) for any of the five assessment rubrics (AR1 → AR5). However, the data in Table 2 indicates clearly that the course is making significant contributions to both primary and secondary MEPOs except for MEPO #2 that focuses on engineering design.

Materials Science Experiments

The course consists of nine lab experiments, one per week. Depending on the course coordinator, the ninth experiment may change from one quarter to another. Before each experiment, the instructor presents the experimental principles and theory. This is followed by students in groups of three or four conducting the experiment with different materials or different experimental variables. At the end of the experiment, the entire lab section qualitatively (or semi-quantitatively) evaluates the experimental data and interprets the results. In the subsequent week, each student submits an individual lab report with more rigorous analysis of data and interpretation of results. Students submit a formal report for only the first eight of nine experiments, of which the best seven scores are counted in the lab grade. The eight experiments and their associated lab objectives are listed below.

Lab #1: Tensile Testing of Metallic Materials
L1a. Learn elastic and plastic behavior of metallic materials in monotonic tension
L1b. Learn the use of Instron/MTS 2500 kg UTS and clip-on extensometer
L1c. Conduct tensile testing experiment on 1018 T4 and T3 steel specimens
L1d. Conduct tensile testing experiment on 6061 T0 and T6 Al-Mg-Si-Cu specimens
L1e. Determine quantitatively elastic and tensile mechanical properties
L1f. Determine qualitatively the material's failure mode
L1g. Compare tensile behavior of the four tensile specimens
L1h. Become familiar with the ASTM E-8 standard
L1i. Submit a concise lab report with abstract, data, graphs, and discussion
L1j. Answer multiple-choice questions and student survey

Lab #2: Hardness Testing of Metallic Materials
L2a. Learn the relationship between indentation hardness and plastic deformation behavior
L2b. Learn the use of Brinell and Rockwell Hardness Testers
L2c. Conduct Rockwell Superficial Hardness tests on tensile specimens from Lab #1
L2d. Qualitatively relate hardness profiles to tensile behavior of the four specimens
L2e. Become familiar with ASTM E-10 (Brinell) and E-18 (Rockwell) standards
L2f. Submit a concise lab report with abstract, data, graphs, and discussion
L2g. Answer multiple-choice questions and student survey

Lab #3: X-ray Diffraction of Cubic Materials
L3a. Learn the principle of x-ray generation and diffraction
L3b. Review cubic crystal structures and crystallography nomenclature
L3c. Index a cubic x-ray diffraction pattern and determine the crystal structure
L3d. Determine the precise lattice parameter
L3e. Identify the cubic phase using the ICDD PDF-database
L3f. Submit a concise lab report with abstract, data, graphs, and discussion
L3g. Answer multiple-choice questions and student survey

Lab #4: Impact Testing
L4a. Learn about material toughness and its relation to other mechanical properties
L4b. Learn about ductile to brittle transition temperature
L4c. Conduct Charpy Impact tests on 4140 steel specimens of different tempers
L4d. Qualitatively relate Impact Toughness to Rockwell Hardness
L4e. Become familiar with ASTM E-23 standard
L4f. Submit a concise lab report with abstract, data, graphs, and discussion
L4g. Answer multiple-choice questions and student survey

Lab #5: Precipitation Hardening
L5a. Learn the principles of the four limiting types of strengthening mechanisms
L5b. Learn the principles and mechanism of precipitation hardening
L5c. Conduct the precipitation hardening experiment on 2024 Al-Cu-Mg alloy
L5d. Submit a concise lab report with abstract, data, graphs, and discussion
L5e. Answer multiple-choice questions and student survey

Lab #6: Metallography of Fully Annealed Steels
L6a. Learn about the Iron – Iron Carbide Phase Diagram
L6b. Learn about the microstructures in fully annealed plain carbon steels
L6c. Prepare metallographic specimens (cutting, mounting, grinding, polishing, etching)
L6d. Become familiar with ASTM E-2 standard
L6e. Examine using a microscope microstructures of 1018, 1045 and 1095 steels
L6f. Qualitatively relate microstructures to the resulting hardness
L6g. Submit a concise lab report with abstract, data, graphs, and discussion
L6h. Answer multiple-choice questions and student survey

Lab #7: Hardenability of Steels
L7a. Learn about hardenability of plain and low alloy steels
L7b. Conduct Jominy End-quench test on 1040 and 4340 steel specimens
L7c. Become familiar with ASTM A255-67 standard
L7d. Compare the hardenabilities of the two steel specimens
L7e. Submit a concise lab report with abstract, data, graphs, and discussion
L7f. Answer multiple-choice questions and student survey

Lab #8: Corrosion of Metals
L8a. Learn the principles of corrosion and the three limiting types of corrosion cells
L8b. Measure electrode differences in a variety of corrosion cells
L8c. Establish the galvanic series of given metals in brine solution
L8d. Submit a concise lab report with abstract, data, graphs, and discussion
L8e. Answer multiple-choice questions and student survey

For assessment rubric AR2, a table similar to Table 2 has been made that relates each lab objective to the corresponding course objectives. Even though the table is not included in this paper, the lab objectives L1a → L8e correlate to the course objectives C1 → C9.

Instruction Consistency across Multiple Sections

The third rubric (AR3) assesses consistency of a course across all section offerings in a quarter and from one quarter to the next. There are five components to assess this consistency: (a) Course Content/Topics and Syllabus/Pace, (b) Instructional Materials, (c) Grading Items and Grading Scheme, (d) Grading and Assigning Final Grade, and (e) Instructional Delivery.

Principles & Theory: Materials Science Lab is part of the 4-credit course *0304-344 Introductory Materials Science*. The textbook[1] in this course has adequate coverage of experimental theory, principles and procedures, and therefore, no new materials focusing on experimental principles were developed.

Presentation Slides: For each lab experiment, a set of conference-quality class presentation slides using PowerPoint have been developed and are posted on MyCourses each quarter. The presentation slides were first used in 2007-2 by all the lab instructors. Based on the feedback from the instructors and the students, minor modifications were made in 2007-3 and 2008-1.

Step-by-step Instructions: For each equipment or instrument used in the lab, step-by-step instructions for the use of the equipment or instrument were developed, and posted on MyCourses. Beginning 2008-1, we are not posting the instruction sets on MyCourses. Instead, a hardcopy of each instruction set has been laminated and placed next to the equipment or instrument.

Data Sheet: For each experiment, a single-page data sheet was developed. Each student is provided a hardcopy of the data sheet before each experiment. On the data sheet, each student records the names of his/her group members, equipment and specimen details, and data that needs manual recording. At the end of the lab, students are required to obtain the signature of the instructor, and the data sheet must be submitted as part of the lab report.

Lab Report Template: A complete lab report for the first experiment was developed and posted on MyCourses as a template. For each subsequent experiment, lab report instructions and a spreadsheet template have been integrated into the class presentation slides to improve the quality of lab reports submitted by students.

Multiple-Choice Questions: To assess student learning and its consistency from one section to another, a set of ten multiple-choice questions were developed for each experiment. In 2007-2 and 2007-3, students submitted their answers in a hardcopy form as part of their lab report. Beginning 2008-1, this is implemented as an online quiz in MyCourses. This will permit us to tabulate the student responses so that we may identify concepts that a significant number of students are not learning, and also to monitor consistency of student learning from one section to another.

Student Surveys: To assess students' perceptions of the quality of the lab course, its instructional objectives and materials, laboratory facilities and organization, and instructor's presentation, a set of ten survey questions were developed. In 2007-2 and 2007-3, students submitted the survey for each lab experiment as part of their lab report. Beginning 2008-1, this is implemented as an online quiz on MyCourses (rather than a Survey because students are given 5% credit on each lab report if they submit the survey). This will allow us to monitor the quality of instruction in each lab section.

Background of Student Instructors: Lab instructors are either upper-division or graduate students who have taken the course earlier. Approximately four weeks before each quarter begins, the faculty coordinator selects the student instructors based on a combination of academic performance, laboratory skills, personality and availability. Typically, half of the instructors are returning students who have taught this or another sophomore lab in the past, and the other half are teaching a lab course for the first time.

Training of Instructors: In the week prior to each lab experiment, student instructors as a group are provided two hours of training in experimental principles and procedures, hands-on use of equipment and instruments by the faculty coordinator. In this training session, we also identify where an equipment or instrument could malfunction, and how to fix it. Often one or more student instructors have a prior conflict when this training is scheduled, and the faculty coordinator accommodates such conflicts by offering additional one-on-one training sessions. The training sessions also provide an opportunity to the faculty coordinator to obtain feedback from the student instructors on prior week's experiment.

Grading Elements and Grading Rubrics: To ensure that individually graded items demonstrate consistent measurement of each course objective (assessment rubric AR4), a uniform grading policy was developed. In the Materials Science Lab, there are eight experiments with ninth experiment as a demonstration only. There is an in-class quiz in the 4th, 7th and 10th week of the quarter. The grading scheme for the course is presented in Table 3 below:

Table 3: Graded Items and Grading Policy

Item	Points	Total Points	% of Grade
G1. Lab Reports (best 7 of 8 labs)	7 * 75 points	525 points	52.5%
G1a. Abstract and Cover Page	10 points each		
G1b. Signed Data Sheet	20 points each		
G1c. Spreadsheet & Graphs	25 points each		
G1d. Discussion and Conclusions	20 points each		
G2. Multiple Choice Questions	7 * 20 points	140 points	14.0%
G3. Student Survey	7 * 5 points	35 points	3.5%
G4. Three In-class Quizzes	3 * 100 points	300 points	30.0%

Multiple Choice Questions

Multiple-choice questions (MCQ) allow us to evaluate students' understanding of key experimental principles, procedures and results. The questions have a format similar to "Concept Inventory" that is being used by a number of instructors in other core courses such as Statics[2,3], Mechanics[4], and Dynamics[5]. Beginning the 2008-1 term, MCQ set for each experiment has been implemented as an online quiz. Student performance data on these quizzes will permit us to:

(a) identify one or more key concepts that a large number of students missed; this is rectified by improving instructional materials and delivery.
(b) monitor the consistency of instruction across the lab sections; this is remedied by providing better training to the lab instructor.

Table 4 lists one question covering a key concept from each lab that most of the students answered correctly in the 2008-1 term. Column "N" indicates the number of responses, and "%" column shows the percentage for easier comprehension. Correct answers are shown in bold in the "Key" column. In the online quiz system, the responses are randomized.

Table 4: Key Question from each lab that most students answered correctly in 2008-1

L#/Q#	Multiple Choice Question from each lab	Key	N	%
L1/Q9	In tensile testing of metallic materials, **uniform** plastic deformation **begins** when the applied stress equals	N	52	100
	(A) Elastic Limit	**A**	48	92
	(B) Ductility	B	0	0
	(C) Tensile Strength	C	2	4
	(D) Elastic Modulus	D	2	4

L2/Q9	In Rockwell hardness measurements on **either** of the **two steel** specimens, the hardness near the failure edge was found to be **higher** than along the grip surface because of	N	52	100
	(A) Strain Hardening	**A**	52	100
	(B) Preipitation Hardening	B	0	0
	(C) Grain Size Hardening	C	0	0
	(D) None of the choices shown	D	0	0
L3/Q8	For lattices with **BODY-CENTERED** point arrangement and a crystal basis of **one atom per point**, the **permitted** x-ray reflections are from planes that have Miller indices where	N	52	100
	(A) any h or k or l is permitted	A	2	4
	(B) only if h + k + l = even number is permitted	B	1	2
	(C) only if h and k and l are either all odd numbers or all even numbers is permitted	**C**	46	88
	(D) none of the choices shown	D	3	6
L4/Q5	In the AISI 4140 steel specimens tested in the lab, as the **indentation hardness** of specimen **increases**,	N	53	100
	(A) the impact toughness in the ductile regime increases	A	1	2
	(B) the impact toughness in the ductile regime decreases	**B**	49	92
	(C) the impact toughness in the ductile regime remains about the same	C	3	6
L5/Q5	In **precipitation hardening**, **obstacles** to dislocation motion are	N	50	100
	(A) other dislocations	A	0	0
	(B) solute atoms	B	1	2
	(C) grain boundaries	C	8	16
	(D) harder second phase particles	**D**	41	82
L6/Q10	In full annealing of plain carbon steels, the **Rockwell** hardness of the resulting microstructure **increases**	N	52	100
	(A) with increasing carbon content of the steel	**A**	43	83
	(B) with decreasing carbon content of the steel	B	3	6
	(C) none of the choices shown	C	6	12
L7/Q6	In continuous cooling of **4340** austenite to room temperature, the following microstructure **can** form	N	51	100
	(A) 100% Bainite	A	3	6
	(B) 50% Bainite and 50% Pearlite	B	1	2
	(C) 100% Pearlite	C	2	4
	(D) 50% Bainite and 50% Martensite	**D**	45	88
L8/Q4	An **anodic** site is where	N	51	100
	(A) oxidation reaction occurs	**A**	49	96
	(B) reduction reaction occurs	B	2	4
	(C) electrons are consumed	C	0	0
	(D) none of the choices shown	D	0	0

The data in Table 4 indicates that across all sections almost all students answered that particular question correctly in each of the eight labs. This indicates extremely little variation overall, and no significant variation among sections.

Table 5 lists one question covering a key concept from each lab that many students answered incorrectly in the 2008-1 term. Column "N" indicates the number of responses, and "%" column shows the percentage for easier comprehension. Correct answers are shown in bold in the "Key" column. Preliminary analysis of incorrect answers suggests that the course instructor may need to explicitly link the theoretical concepts to the experiment students are doing in the companion lab.

Table 5: Key question from each lab that many students answered incorrectly in 2008-1

L#/Q#	Multiple Choice Question from each lab	Key	N	%
L1/Q4	During elastic and uniform plastic deformation, at a **given applied load**, the **true strain**	N	53	100
	(A) is always larger than the engineering strain	A	13	25
	(B) is always smaller than the engineering strain	**B**	34	64
	(C) could be smaller or larger than the engineering strain	C	6	11

L2/Q1	In **Brinell** Hardness Testing, the hardness number is calculated using	N	52	100
	(A) the surface area of the indentation	**A**	38	73
	(B) the projected area of the indentation	B	13	25
	(C) the depth of the indentation	C	1	2
L3/Q5	In a K-alpha **doublet** diffraction peak of a metallic phase, the **K-alpha-2** line	N	52	100
	(A) is always at a higher angle than the K-alpha-1 line	**A**	33	63
	(B) is always at a lower angle than the K-alpha-1 line	B	14	27
	(C) may be at a higher or lower angle than the K-alpha-1 line	C	5	10
L4/Q8	In plain carbon steels, as the carbon content **increases**	N	53	100
	(A) the impact toughness in the ductile regime increases	A	5	9
	(B) the impact toughness in the ductile regime decreases	**B**	44	83
	(C) the impact toughness in the ductile regime remains about the same	C	4	8
L5/Q9	In **solution treatment** step during precipitation hardening,	N	50	100
	(A) the alloy is heated to a temperature **below the solvus** temperature	A	4	8
	(B) the alloy is heated to a temperature **above the solidus** temperature	B	16	32
	(C) the alloy reaches an **unsaturated** single solid phase state	**C**	30	60
	(D) all of the choices shown	D	0	0
L6/Q5	Slow cooling of **hypoeutectoid** austenite produces a microstructure composed	N	52	100
	of:	**A**	23	44
	(A) proeutectoid ferrite plus eutectoid ferrite plus eutectoid cementite	B	2	4
	(B) proeutectoid cementite plus eutectoid ferrite plus eutectoid cementite	C	23	44
	(C) proeutectoid ferrite plus eutectoid ferrite plus pearlite	D	4	8
	(D) proeutectoid cementite plus eutectoid ferrite plus pearlite			
L7/Q10	**Austenite** to **Pearlite** transformation in steels	N	51	100
	(A) is controlled by nucleation and growth processes	**A**	17	33
	(B) is a diffusionless phase transformation	B	8	16
	(C) is a strain hardening phenomenon	C	6	12
	(D) none of the choices shown	D	20	39
L8/Q7	To reduce **corrosion rate** (see your textbook),	N	51	100
	(A) anode to cathode surface area ratio should be large	**A**	30	59
	(B) anode to cathode surface area ratio should be small	B	13	25
	(C) anode to cathode surface area ratio is irrelevant	C	8	16

Student learning was addressed through three in-class quizzes in the fourth, seventh, and tenth week of the quarter. In 2007-2, a one-way analysis of variance for each quiz across the three sections indicates no significant difference in quiz scores (p-values > 0.05). In 2008-1, the analysis of variance showed no significant difference across the six sections for quiz #1 (p-value > 0.05). On both quiz #2 and #3, only one section performed significantly worse than the other sections. Among the remaining five sections, no pairwise comparisons were significant. So, it appears that the instructional consistency across the multiple lab sections has been achieved.

Student Surveys

Student surveys after each lab experiment provide data about students' perceptions of the quality of (a) instructional design, (b) instructional materials, (c) experimental equipment and organization, and (d) instructional delivery. This data will help us improve students' lab experiences and satisfaction.

Table 6 lists cumulative responses from all the student surveys from 2007-2 and 2008-1 terms. Column "N" indicates the number of responses, and "%" column shows the percentage for easier comprehension.

Table 6: Cumulative Data from Student Surveys (Quarters: 2007-2 & 2008-1)					
Materials Science Lab (0304-344); Quarters: 2007-2 & 2008-1		**Q:2007-2**		**Q:2008-1**	
Sum of ALL LABS		**N**	**%**	**N**	**%**
1. How well have the **lab objectives** been fulfilled?	N	242	100	402	100
(A) ALL objectives were met	A	83	34	242	60
(B) MOST objectives were	B	144	60	144	36
(C) FEW objectives were met	C	15	6	12	3
(D) Lab objectives have not been stated	D	0	0	4	1
2. How much have you **learned** in this lab ?	N	242	100	402	100
(A) I learned a LOT	A	77	32	142	35
(B) I learned a MODERATE amount	B	137	57	211	52
(C) I learned VERY LITTLE	C	28	12	36	9
(D) I already knew this material	D	0	0	13	3
3. How was the instructor's **presentation** ?	N	242	100	402	100
(A) ALL major points were presented effectively	A	99	41	194	48
(B) MOST major points were presented effectively	B	109	45	178	44
(C) FEW major points were presented effectively	C	32	13	27	7
(D) Needs significant improvement	D	2	1	3	1
4. What is your opinion of the **PowerPoint slides** ?	N	241	100	402	100
(A) ALL major points were presented effectively	A	64	27	168	42
(B) MOST major points were presented effectively	B	82	34	192	48
(C) FEW major points were presented effectively	C	81	34	32	8
(D) Needs significant improvement	D	14	6	10	2
5. What is your opinion about the **equipment, supplies and room** ?	N	237	100	401	100
(A) Well organized, neat and equipment worked well	A	167	70	341	85
(B) Well organized, neat but equipment malfunctioned	B	59	25	44	11
(C) Inadequate organization but equipment worked well	C	9	4	11	3
(D) Inadequate organization AND equipment malfunctioned	D	2	1	5	1
6. How was instructor's **handling of lab procedures**?	N	242	100	402	100
(A) Highly systematic, well organized	A	139	57	270	67
(B) Moderately well organized	B	98	40	125	31
(C) Inadequate organization	C	4	2	6	1
(D) Confusing, unsystematic	D	1	0	1	0
7. How do you feel about **lab report requirements** ?	N	241	100	402	100
(A) Work was relevant, amount was right	A	193	80	329	82
(B) Work was relevant, amount was too much	B	29	12	64	16
(C) Report requirements were not relevant to the lab	C	8	3	5	1
(D) More substantive assignment would be helpful	D	21	9	4	1
8. Were the multiple-choice **questions clear** ?	N	240	100	402	100
(A) ALL questions were clear	A	67	28	109	27
(B) MOST questions were clear	B	106	44	191	48
(C) TWO to FIVE questions were vague or ambiguous	C	54	23	71	18
(D) FIVE or more questions were vague or ambiguous	D	13	5	31	8
9. Were the multiple-choice **questions relevant** to the lab ?	N	240	100	401	100
(A) ALL questions were relevant to this lab	A	89	37	157	39
(B) MOST questions were relevant to this lab	B	110	46	166	41
(C) TWO to FIVE questions were NOT relevant to this lab	C	15	6	60	15
(D) FIVE or more questions were NOT relevant to this lab	D	26	11	18	4
10. **Overall**, what is your opinion of this lab experience ?	N	242	100	401	100
(A) Successful	A	56	23	225	56
(B) Successful but needs minor improvements	B	144	60	134	33
(C) Adequate but can be improved significantly	C	35	14	30	7
(D) Inadequate and requires a major revision	D	7	3	12	3

From a chi-square analysis for each question across sections in 2007-2, we can conclude that student satisfaction was not statistically different (p-values > 0.05) for fulfillment of lab objectives (Q1), instructor presentation (Q3), equipment (Q5), and instructor's handling of lab procedures (Q6). There were some statistical differences in student satisfaction across the three sections on the remaining six questions. Based on feedback we received from students in 2007-2, several PowerPoint slides in each lab were modified in 2008-1. This resulted in greater student satisfaction, as seen in Table 6.

The author is unable to determine why students find that a significant number of questions in the MCQ sets were either unclear or irrelevant or both.

Concluding Remarks

1. Preliminary assessment of data from multiple-choice questions, quizzes and student surveys indicates that instructional consistency across all the lab sections has been achieved.

2. Students' understanding of key materials concepts can be considerably improved with better coordination between the class lectures and lab instruction.

3. We held several workshops on this project for six other lab instructors and coordinators in the department. Our longer term goal is to persuade these instructors to develop high-quality instructional materials for their lab courses. Thus, the success of this project could lead to a larger activity of department-wide or even college-wide adaptation and implementation of our ideas.

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