AC 2008-636: DESIGNING UNDERGRADUATE ENGINEERING LAB EXPERIENCE TO SATISFY ABET EC2000 REQUIREMENTS

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Designing Undergraduate Engineering Lab Experience to Satisfy ABET EC2000 Requirements

Abstract

Engineering is a practical discipline. It is a hands-on profession where doing is a key element. Practicing engineers use research laboratories and development laboratories to obtain experimental data to guide them in designing and developing a product and/or to determine if a designed product performs as intended. Engineering students, on the other hand, need to go to laboratories to build up essential skills and abilities required for the engineering profession in general, and particularly those required to deal with industrial research and development laboratories.

In January 2002, ABET, with support from the Alfred P. Sloan Foundation, held a 3-day colloquy to explore the issues related to the true goals of students' undergraduate lab experience. The aim was to determine, through consensus, taxonomy of laboratory learning objectives, which could be validated and disseminated throughout the educational community. A final list of 13 objectives was developed as the desired outcomes of a successful lab experience accumulated over an engineering curriculum.

In the present work a practical approach is presented to meet these fundamental objectives. A set of students' learning outcomes for an experimental design course is developed together with a set of assessment rubrics for different types of lab experiments. Also an assessment rubric for the write-up given to the students for a design of experiment is also presented.

The work is complemented by a form to evaluate student's lab experience in an engineering program. The form is used to develop an action plan to improve this lab experience as a case-study of a program preparing for an ABET accreditation visit under EC2000.

Introduction

Since Engineering is a practical discipline and a hands-on profession where doing is a key element, undergraduate engineering laboratories are essential to prepare the future engineers to fit into the profession. In their comprehensive paper on the role of the laboratory in engineering education, Fiesel and Rosa[1] explored the milestones of that role as follows:

- Prior to the creation of engineering schools, engineering was taught using apprenticeship approach. Early engineers had to design, analyze, and build their own creations through learning by doing.
- From the earliest days of engineering education, laboratories have been an essential part of any engineering curriculum. Prior to the emphasis on engineering science in the early seventies most engineering instruction took place in the laboratory.

- While engineering programs became more theoretical in the seventies, industry continued to require individuals who possessed more practical skills. Many institutions developed programs in engineering technology.
- Around 1980, ABET became the organization responsible for engineering and technology accreditation. With clearly defined boundaries between engineering and technology, it became clear that engineers were not adequately prepared in laboratory techniques.
- By late 1990s ABET EC2000 appeared, requiring institutions to develop mission and objectives for each program, to develop outcomes that could be periodically assessed, and to continuously improve programs' offerings.

The new EC2000, referred to engineering laboratories as a significant part of engineering education in 4 places; Design of experiment (3b), Use of modern tools (3k), Facilities (new criterion 7), and Support (new criterion 8). Outcome 3.b, in particular, states that engineering programs must demonstrate that their students attain: *an ability to design and conduct experiments, as well as to analyze and interpret data."*

ABET EC2000 presented a paradigm shift in dealing with engineering laboratories. Students have to design their own experiments instead of only conducting recipe-type experiments and dealing with collected data. In doing this, the students can achieve several outcomes and be prepared for the profession.

For an engineering program seeking ABET accreditation, several questions related to undergraduate laboratories need to be answered:

1. Why is it important for professional engineers to be able to design and conduct experiments? To which extent can the undergraduate lab experience simulate the professional engineering practice?
2. What are the fundamental objectives that could be met through the lab experience?
3. How can an engineering program introduce elements of design of experiment in the curriculum without overwhelming both students and faculty?
4. How can the students' lab work be assessed to measure the achievement of learning objectives related to lab experience and to outcome 3.b in particular?
5. How can a faculty member assess the write-up he/she prepares and gives to the students for a design of experiment component in a lab course?
6. How can the engineering program evaluate the student's lab experience in the curriculum and develop an action plan for further improvements?

The present work aims at addressing these open-ended questions and proposes some possible answers.

Experience of Introductory Physics Courses

The experience of the "Scientific Abilities Project" developed by the Rutgers Physics and Astronomy Education Research Group[2] is interesting. The project is sponsored by the National Science Foundation program "Assessing Student Achievement" (NSF-ASA). The goal of the project is to help students develop some of the abilities used by scientists and engineers in their work. These abilities include:

- an ability to represent knowledge in multiple ways;
- an ability to design experiments to investigate new phenomena, test hypotheses and solve experimental problems;
- an ability to collect and analyze experimental data;
- an ability to devise and test relationships and explanations, and
- an ability to evaluate reasoning and experimental design.

Etkina *et al*[3] describe the process they follow in teaching introductory physics courses as a system that engages students in processes similar to the ones that scientists use to construct and apply knowledge. In their system:

1. Students start each conceptual unit by analyzing patterns in experimental data. (Observational Experiments)
2. They use multiple representations of the data to construct explanations or mathematical relationships. (mathematical models)
3. They test their models, predict the outcomes of new experiments, perform the experiments, and revise their models if the outcomes do not match the predictions. (Testing Experiments)
4. Finally, they apply revised models to solve problems both mathematically and experimentally. (Application Experiments – which are similar to most of our engineering experiments)

In this approach the 3 types of experiments are defined as follows:

1. ***Observational Experiment:***
   It is an experiment that students perform to investigate a new phenomenon. The students do not make predictions or have expectations about its outcome. They need to collect data, analyze them and find a pattern in the data. They then need to explain the reasons for the pattern (if applicable), and/or construct a qualitative or quantitative relationship.

   Example: Design an experiment to determine if there is a relationship between pressure and temperature of an unknown gas when its volume is kept constant.

2. ***Testing Experiment:***
   Students use an explanation or relationship to make a prediction of the outcome of the experiment. They decide on additional assumptions, perform the experiment, and record the outcome. Taking into account theoretical assumptions & experimental uncertainties, they know that: when prediction agrees with experimental outcome, it only means that the explanation/relationship cannot be rejected. Otherwise, they have to either reject the explanation/ relationship, or reconsider the assumptions they have made.

   Example: Design an experiment to test the following rule: an object always moves in the direction of the net force exerted on it.

3. ***Application Experiment***

It is an experiment that typically involves solving a practical problem or determining an unknown quantity by performing experiments. Students need to solve these experimental problems using at least two different methods and then compare the results. Often they need to perform additional experiments or make informed estimates to determine some physical quantities.

Example: Design at least two independent experiments to determine the coefficient of static friction between your shoe and the sample of carpet provided.

Labs in the Engineering Profession

Practicing engineers use research laboratories and development laboratories. In ***Research Laboratories*** they seek broader knowledge that can be generalized and systematized, often without any specific use in mind. They carry on what is called *Observational experiments* and *Testing Experiments.* They also go to ***Development Laboratories*** *t*o obtain experimental data to guide them in designing and developing a product. The lab is used to answer specific questions about nature that must be answered before a design and development process can continue. In this case they carry on the so called *Application Experiments*. They also go to these development laboratories to determine if a design performs as intended. Measurements of performance are compared to specifications, and these comparisons either demonstrate compliance or indicate where and how changes need to be made. In this case they carry on the so called *Testing Experiments.*

Engineering students need to go to laboratories to build up essential skills and abilities required for the engineering profession in general, and particularly those required to deal with industrial research and development laboratories. The important question is: what are the skills and abilities (i.e. outcomes) that can be developed in the students through their undergraduate lab experience? In other words: what are the fundamental objectives of an undergraduate laboratory experience, i.e. what are the observable (measurable) students actions that serve as evidence of knowledge, skills and attitudes acquired in a lab course?

Fundamental Objectives of Engineering Lab Experience

In January 2002, ABET, with support from the Alfred P. Sloan Foundation, held a 3-day colloquy (with 52 participants) to deal with the above mentioned issues. The goal was to determine, through consensus, taxonomy of laboratory learning objectives, which could be validated and disseminated throughout the educational community. A final list of 13 objectives was developed (see Feisel and Peterson[4]).

In fact those fundamental objectives are the desired outcomes of a successful lab experience accumulated over an engineering curriculum and can be stated as follows:

By completing the laboratories in the engineering undergraduate curriculum, the student will be able to:

1. ***Instrumentation:*** Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.
2. ***Models:*** Identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.
3. ***Experiment:*** Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.
4. ***Data Analysis:*** Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.
5. ***Design:*** Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.
6. ***Learn from Failure:*** Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
7. ***Creativity:*** Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
8. ***Psychomotor:*** Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
9. ***Safety:*** Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.
10. ***Communication:*** Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
11. ***Teamwork:*** Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
12. ***Ethics in the Lab:*** Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
13. ***Sensory Awareness:*** Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Introducing Design of Experiments in Engineering Curricula

Taking into consideration the above mentioned fundamental objectives and the experience of introductory physics, the author proposed the following approach to introduce deign of experiments in engineering curricula. The approach could be gradually applied while minimizing the expected faculty load. It was successfully used to improve the lab experience in several engineering programs in King Abdulaziz University during the last couple of years.

- Lecture students on: instrumentations in the lab, modern tools, safety, accuracy, uncertainties, anomalous data, hypothesis, etc.
- Gradually replace some of your classical lab experiments by experimental design projects.
- Keep some old-fashioned experiments with recipe-like instructions to train the students on using lab equipment.
- Form by the beginning of the semester students' cooperative teams. Each team, composed of 3 to 5 students of heterogeneous abilities, should develop and follow specific team norms. Team work and assessment tools should permit the development of social skills, positive interdependence, individual accountability, face to face interaction, and group processing.
- Ask for a team design report & specify tasks to be reported (see previous examples and rubrics).
- Ask the students to prepare and deliver professional oral presentations to communicate their ideas.
- Change experiments each semester. Specify a code of ethics in the lab (including reporting information objectively and interacting with integrity) and punish severely non ethical behaviors.
- Avoid demonstrations carried out by the instructor or the lab technician and observe the students doing.
- Allocate 30-40% of the grade to individual work (oral presentations, final examinations, and on-job observations that measure psychomotor skills).
- Prepare assessment rubrics that build on the particular type of experiment to be designed (observation, testing, or application). You need to add other elements to cover the tasks you are asking for (e.g. report writing, safety precautions, theoretical background, team working, etc).
- Let the students self assess their report using the same rubrics before submission.
- Allow resubmission (once) with reduced maximum grade if a student or a team fails to reach your expectations (that could be a score of 3) in any of the critical items that you <u>clearly</u> specify in the rubric. Otherwise the work is unacceptable.
- Allocate some bonus points to creativity if you consider it as one of your learning objectives.

Assessment Rubrics

A rubric is a set of categories that define and describe the important components of the work being completed, critiqued, or assessed. Each category contains a gradation of levels of completion or competence with a score assigned to each level and a clear description of what criteria need to be met to attain the score at each level. [5]

Rubrics are descriptions of how the standards set in performance criteria can be met, at varying levels of quality. Rubrics can be used to discriminate between many levels of performance (for example, 'excellent,' 'good,' 'fair,' 'poor,' 'unacceptable') or few levels of performance (e.g., ‘pass’ or ‘fail’). Rubrics can include a scale of points to be awarded across a continuum of performance levels, or can be intended to bin samples into descriptive categories.[6]

Well-written rubrics clearly define components necessary to demonstrate levels of achievement of performance criteria, and are supplemented with specific indicators or examples of what would constitute the various levels of performance to be determined. Well-written rubrics focus on identifying the presence or absence of demonstrable items, avoiding overly broad or vague terms that are difficult to directly demonstrate (e.g., ‘appreciate,’ ‘understand’) or that are very likely to be interpreted in different ways by different reviewers (e.g., ‘appropriate,’ ‘adequate’).[6]

Based on several rubrics available from different engineering institutions, including those of the Rutgers Physics and Astronomy Education Research Group[2], the author prepared assessment rubrics for each of the 3 types of observational, testing and application experiments. Appendix A contains an assessment rubric for the design of an application experiment. This type of experiments is the type commonly used one in undergraduate engineering laboratories. Other rubrics could be found on the KAU Academic Accreditation Unit website[7].

Appendix B contains an assessment rubric to evaluate the write-up of a design experiment. The write-up should contain the main elements of the design and exclude the recipe-type instructions. The write-up should demonstrate that the instructor is able to:

- Identify suitable type of experiments
- Deal with fundamental objectives as desired outcomes of students lab experience
- Write a concise project brief
- Write clear guidelines for the students to reach the level of learning associated with each fundamental objectives
- Write clear, measurable, learning objectives
- Specify clear, reliable, and objective assessment criteria of students work

Evaluation of the Lab Experience in the Curriculum

Appendix C contains a survey that was used to evaluate student’s lab experience in the engineering programs in King Abdulaziz University. The form evaluates the lab experience in 3 distinct areas:

- Students and Learning
- Instructors and Instruction
- Facilities and Safety

The results of the survey, when first used, indicated the weak as well as the strong points of the undergraduate lab experience of KAU students as shown in Fig 1. The results reflect the weak points of the classical recipe type experiments where the students are unable to deal with faulty equipment, experimental uncertainties, and open ended problems. They also reflect some issues related to equipment maintenance and their logistics. The results were successfully used to develop an action plan to improve lab experience in several engineering programs preparing for an ABET accreditation visit under EC2000.

		Score out of 5
Critical Problems	Preventive maintenance tasks and calibration tasks are scheduled regularly and service manuals for all the equipment are in place and ready to be used.	1.67
	The write-ups given to the students are not recipe-like instructions. They do represent open ended problems that allow for creativity and independent thinking.	1.73
	Students are able to identify unsuccessful outcomes caused by faulty equipment, construction or process and could re-engineer effective solutions.	1.73
	Students accept and deal positively with experimental uncertainties.	1.79
	Non conventional instructional methods (e.g. active cooperative & problem based learning) are used.	1.85
	Corrective maintenance (repair upon failure) is reported and carried out with limited paper work and within reasonable downtime.	1.85
Strong Points	Theory, background and concepts are introduced before tackling testing or application experiments.	4.09
	Lab experiments in courses containing lab component are well integrated with course material.	3.27
	Safety guideline are available and could be easily found by the students.	3.19
	Labs are kept clean and tidy and are organized such that students can work comfortably and safely.	3.12
	The quality of equipment is adequate and permits exposing the students to modern engineering. tools.	3

Fig. 1 Results obtained from the survey used to evaluate the lab experience for the first time

Conclusion

Several questions related to designing a successful undergraduate engineering lab experience to satisfy ABET EC2000 requirements were discussed. Different types of experiments suitable for engineering students and their fundamental learning objectives are identified. A simple approach to design, introduce, assess, and evaluate these experiments is outlined. Several assessment rubrics are presented as well as a survey to evaluate the lab experience and prepare a corrective action plan, if applicable.

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APPENDIX A
Assessment Rubric for the Design of an Application Experiment

	Scientific Ability	0	1	2	3	NA
		Missing	Inadequate	Needs Improvement	Adequate	
1	Is able to identify the problem to be solved and define the objectives of the experiment.	No mention is made of the problem to be solved.	An attempt is made to identify the problem to be solved but it is described in a confusing manner, objectives are not relevant, objectives contain technical/ conceptual errors or objectives are not measurable.	The problem to be solved is described but there are minor omissions or vague details. Objectives are conceptually correct and measurable but may be incomplete in scope or have linguistic errors.	The problem to be solved is clearly stated. Objectives are complete, specific, concise, and measurable. They are written using correct technical terminology and are free from linguistic errors.	
2	Is able to find relevant theory and previously published theoretical and experimental data and to use them to explain the expected outcomes of the experiment.	No theory or previously published data is included.	Theory and previously published data are irrelevant or contain conceptual or mathematical errors.	Theory and previously published data are relevant and well written with equations and some discussions but are not used to explain the expected outcomes of the experiment.	Theory is well written with equations and discussion relevant to the experiment. Published data are included and correctly used to explain the expected outcomes of the experiment.	
3	Is able to identify variables to be measured.	Dependent and independent variables are not correctly identified.	Dependent and independent variables are identified as well as the range of some of them.	dependent and independent variables are identified as well as the range for both of them.	Dependent and independent variables are identified as well as the range for both and the appropriate increments for measurements.	
4	Is able to identify appropriate available sensors, instrumentation and/or software tools to measure physical quantities.	Failure to identify appropriate tools and instrumentation or some of the chosen measurements cannot be made with the available equipment.	The list of appropriate tools and instrumentation is incomplete, the selection is not justified, or no details are given about how they will be used (range and appropriate number of data points to capture the phenomenon).	A complete list of appropriate tools and instrumentation is present with incomplete justification or with vague or incomplete details about how they will be used (range and appropriate number of data points to capture the phenomenon).	A complete list of appropriate tools and instrumentation is present with complete justification. All details about how tools and instruments will be used are provided and clear (range and number of data points are optimized to capture full response of system within equipment limitations).	
5	Is able to design a reliable experiment that solves the problem.	The experiment does not solve the problem.	The experiment attempts to solve the problem but due to the nature of the design the data will not lead to a reliable solution.	The experiment attempts to solve the problem but due to the nature of the design there is a moderate chance the data will not lead to a reliable solution.	The experiment solves the problem and has a high likelihood of producing data that will lead to a reliable solution.	
6	Is able to deal responsibly with safety and environmental issues related to experimentation as a technological process.	No mention is made to safety or environmental issues related to the designed experiment.	Measures to deal with safety and environmental hazards are vague, incomplete, or insufficient	Measures to deal responsibly either with safety issues or with environmental hazards are presented	Measures to deal responsibly with both safety issues and environmental hazards are presented.	
7	Is able to identify sources of experimental uncertainty.	No attempt is made to identify experimental uncertainties.	An attempt is made to identify experimental uncertainties, but most are missing, described. vaguely, or incorrect.	Most experimental uncertainties are correctly identified.	All experimental uncertainties are correctly identified.	
8	Is able to evaluate specifically how experimental uncertainties may affect the data.	No attempt is made to evaluate experimental uncertainties.	An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect.	Most experimental uncertainties are evaluated correctly, though a few contain minor errors, inconsistencies, or omissions.	All experimental uncertainties are correctly evaluated.	
9	Is able to minimize experimental uncertainty.	No attempt is made to minimize experimental uncertainty.	An attempt is made to minimize experimental uncertainty, but most major sources of uncertainty are not addressed or are addressed inappropriately.	Effective steps are taken to minimize most major sources of uncertainty, but one major source is not addressed.	Effective steps are taken to minimize all major sources of experimental uncertainty.	
10	Is able to record and represent data in a meaningful way.	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible.	All important data are present, but recorded in a way that requires some effort to comprehend.	All important data are present, organized, and recorded clearly.	
11	Is able to analyze data appropriately.	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.	
12	Is able to make a judgment about the results of the experiment.	No discussion is presented about the results of the experiment.	A judgment is made about the results, but it is not reasonable or coherent.	An acceptable judgment is made about the result, but the reasoning is flawed or incomplete.	An acceptable judgment is made about the result, with clear reasoning. The effects of assumptions and experimental uncertainties are considered.	

	Scientific Ability	0 Missing	1 Inadequate	2 Needs Improvement	3 Adequate	NA
13	Is able to evaluate the results by means of an independent method.	No attempt is made to evaluate the consistency of the result using an independent method.	A second independent method is used to evaluate the results. However there is little or no discussion about the differences in the results due to the two methods.	A second independent method is used to evaluate the results. Some discussion about the differences in the results is present, but there is little or no discussion of the possible reasons for the differences.	A second independent method is used to evaluate the results. The discrepancy between the results of the two methods, and possible reasons are discussed. A percentage difference is calculated in quantitative problems.	
14	Is able to identify the shortcomings in an experimental design and suggest specific improvements.	No attempt is made to identify any shortcomings of the experimental design.	An attempt is made to identify shortcomings, but they are described vaguely and no specific suggestions for improvements are made.	Some shortcomings are identified and some improvements are suggested, but not all aspects of the design are considered.	All major shortcomings of the experiment are identified and specific suggestions for improvement are made.	
15	Is able to choose a productive mathematical procedure for solving the experimental problem .	Mathematical procedure is either missing, or the equations written down are irrelevant to the design.	A mathematical procedure is described, but it is incomplete, due to which the final answer cannot be calculated.	Correct and complete mathematical procedure is described but an error is made in the calculations.	Mathematical procedure is fully consistent with the design. All quantities are calculated correctly. Final answer is meaningful.	
16	Is able to identify the assumptions made in using the mathematical procedure .	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	Most assumptions are correctly identified.	All assumptions are correctly identified.	
17	Is able to determine specifically the way in which assumptions might affect the results.	No attempt is made to determine the effects of assumptions.	An attempt is made to determine the effects of some assumptions, but most are missing, described vaguely, or incorrect.	The effects of most assumptions are determined correctly, though a few contain errors, inconsistencies, or omissions.	The effects of all assumptions are correctly determined.	
18	Is able to communicate the details of an experimental procedure clearly and completely.	Diagrams are missing and/or experimental procedure is missing or extremely vague.	Diagrams are present but unclear and/or experimental procedure is present but important details are missing.	Diagrams and/or experimental procedure are present but with minor omissions or vague details.	Diagrams and/or experimental procedure are clear and complete.	
19	Is able to behave with highest ethical standards.	No references are mentioned and the role of each team member is not explicitly stated.	The list of references is incomplete or does not appear in a standard professional format but the role of each team member is explicitly stated.	A standard professional list of references is used to credit work from other sources but the role of each team member is not explicitly stated.	A standard professional list of references is used to credit work from other sources and the role of each team member is explicitly stated.	
20	Is able to work effectively in teams.	No team meeting minutes or team peer-to-peer assessment is attached.	Team peer-to-peer assessment is presented. Team meeting minutes are missing or do not show assignments of roles, tasks, and responsibilities.	Team peer-to-peer assessment is not presented. Team meeting minutes is presented and shows assignments of roles, tasks, and responsibilities.	Team peer-to-peer assessment is presented. Team meeting minutes are presented and show assignments of roles, tasks, and responsibilities.	
21	Is able to make and justify a reasonable conclusion.	No attempt is made to state or justify a conclusion.	A conclusion is stated, but its justification is either absent, missing major steps, or containing major mistakes.	A conclusion is stated and justified, but it is inconsistent with the results of the student's analysis, or it is incomplete.	A conclusion is stated and justified, and is consistent with the results of the student's analysis.	
22	Is able to communicate his work in concise way.	No attempt is made to state or write an executive summary.	An executive summary is stated, but it is either very long or very short.	The executive summary has a reasonable length and format but some elements are missing (background, problem definition, relevant theory, experimental approach, results, and conclusions).	The executive summary has a reasonable length and format and contains all of the following: background, problem definition, relevant theory, experimental approach, results, and conclusions.	

Definition: *An experiment that typically involves solving a practical problem or determining an unknown quantity by performing experiments. Students need to solve these experimental problems using at least two different methods and then compare the results. Often they need to perform additional experiments or make informed estimates to determine some physical quantities.*

Example: *Design at least two independent experiments to determine the coefficient of static friction between your shoe and the sample of carpet provided.*

APPENDIX B
Assessment Rubric for the Write-Up of a Design of Experiment

	Scientific Ability	0 Missing	1 Inadequate	2 Needs Improvement	3 Adequate
1	Is able to identify suitable type of experiments.	No mention is made of the type of experiment to be designed.	An attempt is made to identify the type of experiment but the type selected is not suitable for the experiment.	The selected type of experiment is suitable but is not the optimal one.	The optimal type of experiment is selected.
2	Is able to deal with fundamental objectives as desired outcomes of students lab experience.	No mention is made to fundamental objectives.	some of the Fundamental objectives mentioned could not be reached in the experiment.	A limited number (less than 6) of fundamental objectives that could be reached (by fulfilling customer requirements) are mentioned.	A large number (6 or more) fundamental objectives are cited and could be reached (by fulfilling customer requirements).
3	Is able to write a concise project brief.	Project brief is either very long, very short or badly formatted.	Project brief has suitable length and format but it vague, misleading, or conceptually wrong.	Project brief has suitable length and format. It is clear, precise, and technically sound but contains some linguistic errors.	Project brief has suitable length and format. It is grammatically correct, clear, precise and technically sound.
4	Is able to write clear guidelines for the students to reach the level of learning associated with each fundamental objectives.	Guidelines are missing or misleading.	Guidelines are not sufficient to address all desired outcomes specified in the learning objectives.	A complete list of appropriate guidelines is present but with vague or incomplete details about how they should appear in the final students report.	A complete list of appropriate tools and instrumentation is present with complete details about how they should appear in the final students report.
5	Is able to write clear, measurable, learning objectives.	Learning objectives are missing.	The specified learning objectives are not measurable or could not serve as evidence of knowledge, skills, and attitudes acquired after successfully completing the exercise.	Some of the specified learning objectives are not measurable, linguistically incorrect or could not serve as evidence of knowledge, skills, and attitudes acquired after successfully completing the exercise.	All cited learning objectives are measurable, linguistically correct and could serve as evidence of knowledge, skills, and attitudes acquired after successfully completing the exercise.
6	Is able to specify clear, reliable, and objective assessment criteria of students work	No mention is made to assessment criteria or methodology.	Assessment criteria are vague, unreliable, or opinion based.	Assessment criteria are clear, reliable, objective, but do not cover all skills to be measured, or contains some linguistic errors.	Assessment criteria are clear, reliable, and objective. They cover all skills to be measured and are free from linguistic errors.

APPENDIX C
Survey Used to Evaluate Undergraduate Lab Experience

	To which extent do you agree that in the lab activities in your department:	Not at all	Somewhat	Moderately	Reasonably	Highly	Ext. highly
Students and Learning		**0**	**1**	**2**	**3**	**4**	**5**
1	Students have hands on experience and do not rely on demonstrations carried out by lab instructor						
2	Students normally work in: equally participating, reasonably sized, and long lasting teams of heterogeneous abilities						
3	Oral and written communication skills are developed and assessed						
4	Non ethical issues (such as copying lab reports and sharing experimental data) are avoided						
5	Students demonstrate acceptable skill levels in analysing and interpreting results						
6	Students have awareness of safety issues related to lab environment						
7	Students accept and deal positively with experimental uncertainties						
8	Students are able to identify strengths & limitations of theoretical models as predictors of real world behaviours						
9	Students are able to identify unsuccessful outcomes caused by faulty equipment, construction or process and could re-engineer effective solutions						
10	Students have exposure to modern measuring equipment, sensors, data acquisition and data analysis software and hardware						
Instructors and Instruction		**0**	**1**	**2**	**3**	**4**	**5**
1	The write-ups given to the students are not recipe-like instructions. They do represent open ended problems that allow for creativity and independent thinking.						
2	Instructors are present during the whole lab session. Engineers and TAs only have a supportive role						
3	Theory, background and concepts are introduced before tackling testing or application experiments						
4	Assessment tools are not limited to lab reports and individual exams. They also include on job assessment and observations						
5	Course learning objectives are defined for lab courses and courses containing lab component and include students' abilities to design experiments						
6	Lab experiments in courses containing lab component are well integrated with course material						
7	Non conventional instructional methods (e.g. active cooperative & problem based learning) are used						
Facilities and Safety		**0**	**1**	**2**	**3**	**4**	**5**
1	The quality of equipment is adequate and permits exposing the students to modern engineering tools.						
2	Lab spacing is adequate as well as the number of students per experimental setup.						
3	Corrective maintenance (repair upon failure) is reported and carried out with limited paper work and within reasonable downtime						
4	Preventive maintenance tasks and calibration tasks are scheduled regularly and service manuals for all the equipment are in place and ready to be used						
5	Labs are kept clean and tidy and are organized such that students can work comfortably and safely.						
6	Security and safety procedures are developed and implemented including safeguard of doors and windows, safety of electric connections and high pressure ducts, safe handling of chemicals hazardous materials and preventive measures against fires						
7	Lab utilization is optimized to handle undergraduate teaching, BS projects, and research.						
8	Experiments are revised and modernized each semester according to currently available resources in the lab and to prevent the students from copying old reports.						
9	A plan of modernization is in place for new equipment, supplies, and furniture						
10	All lab equipments are properly maintained and calibrated.						
11	Inventory of equipment, tools, and furniture in the lab is organized and documented with standardized forms and paperwork						
12	Safety guideline are available and could be easily found by the students						
13	Capabilities and areas of applications of major lab equipments are clearly documented to be used in the design of experiments as well as BS projects.						