Designing Effective Electrical Engineering Laboratories Using Challenge-based instruction that Reflect Engineering Process

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I. Introduction

In electrical engineering, physical lab courses should provide a multi-facet environment that enables students to apply concepts and principles to design, synthesize and analyze electrical circuits and systems, and gain practical "hands-on" experience, knowledge, and skills and give students "a feel" for problem solving. However, students are often ill prepared to perform the labs and few resources are available for students to learn how to perform necessary lab procedures. This can lead to an over dependence on the instructor for information, which can result in frustration for both students and instructor. A lot of lab time is often spent waiting for instructor assistance, which can result in student loss of interest, motivation, and focus on the lab and its objectives. Also, students may have little or no understanding of how and where the lab concepts and principles can be applied in real world problems. Therefore, an alternative approach to physical lab instruction is desirable. Innovations in technology provide several ways to improve lab instruction. For example, students could prepare for labs through on-line pre-lab tutorials and quizzes that explore the lab principles and test instruments to be used. Web-based tutorials and resources can be made available during the lab itself, helping students to sustain their own inquiry without much assistance from the lab instructor. Anchoring lab experiments to realistic challenges can enable students to understand the practical applications of concepts and principles covered in different labs. Carrying out studies to explore these possibilities for improved instruction can lead to more effective laboratory learning in electrical engineering education.

A study at Vanderbilt University has been exploring the potential of organizing the content of electrical engineering labs around realistic challenges. The challenges provide a context for performing lab experiment, which should help students apply the concepts from the labs to other problems. Before coming to the lab, students are given a challenge and asked to generate ideas about potential solutions and to identify what more they need to know to solve the challenge. Also, they prepare for the lab by reviewing web-based learning resources (e.g. tutorials, on-line test of basic concepts, components, and procedures for using equipment). These materials help familiarize students with the expectations of the lab. In the lab, computer-based instruments by National Instruments replace conventional bench-top ones. Workstations are connected to the Internet enabling student's immediate access to the web-based resources. Now students can guide their own inquiry by accessing these resources as needed, rather than continually asking for instructor assistance.

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This paper describes the new innovative challenge-based lab environment, and presents comparative evaluations of instructor and student attitude. Affective or reactive type evaluation was used. The results show positive affective reactions and satisfaction with the challenge-based lab experience compared with traditional labs. Initial evaluations also indicate that challenge-based lab instruction changes instructor in-lab workload compared with traditional labs. The paper discusses the implications of these results on challenge-based lab instruction in engineering education.

II. Background

In the learning sciences and education, there is much discussion on situated cognition that is based on learning experiences that reflect the complexity of the real world settings where the knowledge and skills will be used[1]. Studies in cognitive psychology and education suggest that unless learners understand how to use knowledge as a problem-solving tool, they may represent a problem at a superficial level, or they may not recognize the problem when it occurs in a novel situation[2]. If instruction is designed in a context that helps the learner situate learning in an approximation of the real world, there is the potential to overcome the tendency for knowledge to remain inert[3]. A method for organizing resources around learning activities, such as a lab setting, was developed by Schwartz et al[4]. Schwartz and colleagues produced a software shell, STAR (Software Technology for Assessment and Reflection) Legacy Cycle, to help people visualize and manage inquiry in a manner that centers on learner, knowledge, assessment, and community[5]. The STAR Legacy Cycle provides a framework for inquiry and it is organized around challenges. After each challenge, learners generate their own ideas. Next they are able to consult resources relevant to the challenges, including the ability to hear ideas from experts. Learners eventually are given opportunities to "test their mettle" and revise before going "public". The STAR Legacy Cycle is designed to help balance the features of learner, knowledge, assessment and community centered-ness.

A. The STAR Legacy Cycle

Instruction in lab courses requires the use of a variety of basic teaching skills, including lesson planning, encouraging complex thinking, and encouraging student participation. However, lab courses have elements that differ from other teaching forums. Designing lab "learning environments should be linked to issues that are specifically important in the processes of learning, transfer and competent performance"[5]. Questions about what are taught, how it is taught, and how it is assessed should be important in labs. "How it is taught" refers to the teaching methods and strategies used. Modern learning theory shows that different kinds of learning goals require different instructional methods to achieve them. Different types of teaching and learning methods can be either successful or not successful depending on the goals of learning and the prior knowledge and skills learners bring to the learning task[6].

Wiggins & McTighe[7] propose a design method for creating learning environments. They suggest that effective course design should first begin with the learning goals, that is, what do we want students to know and be able to do? After the learning goals, the second thing is to determine is how to assess student progress toward these set goals. Thirdly, what instructional methods are best suited to enable students to learn effectively and to accomplish the set goals. This "Working

Backwards" method assumes that these three design steps are continuously evaluated. The main idea behind this design method is that the teaching methodologies employed would be determined by the learning goals.

The How People Learn (HPL) Design Framework by Bransford, Brown and Cocking[5] highlights a set of four overlapping lenses that are useful for analyzing the quality of various learning environments. These environments can be investigated at levels ranging from individual courses to programs as a whole. The "lenses" used for assessment categorize learning environments by their dominant focus, whether learner, knowledge, assessment, or community. Learner-centered environments pay attentions to the knowledge, skills, attitudes, and beliefs that learners bring to a course. Based on the learners' strengths, interests, preconceptions, misconceptions, and so forth, learners learn about themselves.

Knowledge-centered environments focus on helping students learn in ways that lead to understanding and subsequent transfer. The environment is conceived after determining what learners ought to know and be able to do when they have completed the course. The course is designed to provide the foundation knowledge, skills, and attitudes needed for successful transfer.

Assessment-centered courses emphasize feedback and revision. What is assessed must be congruent with the learning goals of the students. Two main types of assessment are used. Formative assessment is a source of feedback to improve the instructional and learning process. Summative assessment measures what students have learned at the end of some set of learning activities.

Community-centered environments allow learners to be part of a community where they learn from one another and continuously attempt to improve. Here the classroom and the school are communities where students feel that they belong. They can learn to use technology to access resources. Working together in the learning environment helps students to develop lifelong learning skills.

Figure 1 shows the four overlapping lenses that are useful for analyzing the quality of various learning environments.

It is apparent that the "Working Backwards" strategy of Wiggins& McTighe[7] meshes with the HPL Framework by Bransford, Brown and Cocking[5]. The Working Backward strategy starts with a knowledge-centered component, since its first step is to determine "what we want our students to be able to know and do at the end of a course or learning experience. This is setting the learning goal. The second step is taken by asking "what kinds of evidence will show us that we are getting there", the knowledge-, assessment- and learner-centered lenses overlaps in the HPL. The third step in the Working Backwards method is taken by asking "What instruction methods will allow us to accomplish our goals", the learner-, community-, assessment-, and knowledge-centered lenses overlaps in the HPL.

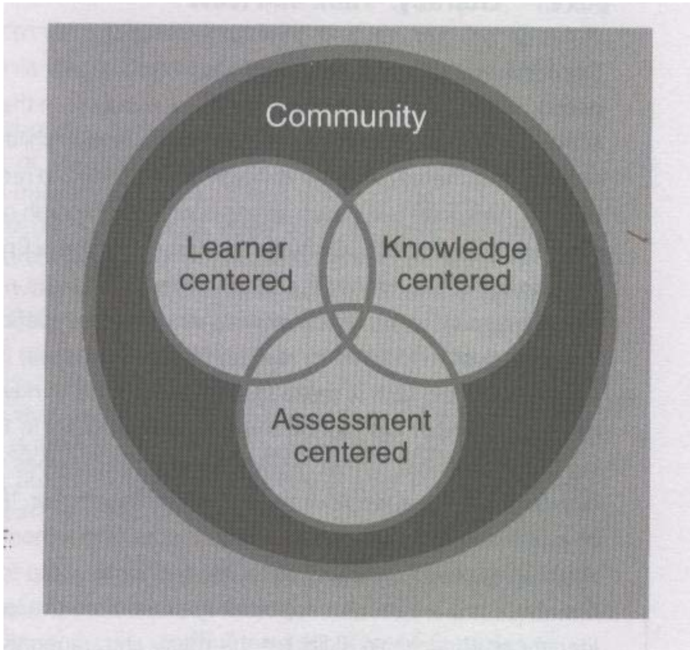

Figure 1. The overlapping lenses used for analyzing the quality of learning environments

Both the "Working Backward" strategy and the HPL framework could be used to develop a learning environment for physical lab courses. If the lab-learning environment is put in the HPL framework, the learner-, community-, assessment- and knowledge-centered lenses overlap. The Working Backward and HPL strategies could potentially re-organize and restructure the tradition lab learning process. With the aid of appropriate learning technologies and pedagogical methods, an innovative lab model could be devised.

Much has been discussed in education about situated cognition that is based on learning experiences that reflect the complexities of the real world settings where the knowledge and skills will be used [2]. By designing instruction in a context that helps the learner situate learning in an approximation of the real world, the potential for knowledge to become inert is avoided[3]. Laboratory learning ideally reflects real world settings and is inquiry based and anchored around key concepts.

Schwartz et al.[4] produced a software shell, the STAR Legacy Cycle, to help people visualize and manage inquiry in a manner that is learner, knowledge, assessment and community centered. The STAR Legacy Cycle provides a framework for inquiry. Solving important problems, assessing progress, and revising when necessary play a prominent role in the Legacy Cycle. The environment can also be easily adapted to fit local needs, in part because it is easy to add and delete various resources. The software is organized around challenges. After each challenge, learners generate their own ideas. Next they are able to consult resources relevant to the challenges, including the ability to hear ideas from experts. Students eventually receive opportunities to "test their mettle" and revise before going "public." The STAR Legacy is designed to help balance the features of learner, knowledge, assessment and community centeredness. The STAR Legacy Cycle structure is shown in Figure 2, which was used in developing the EECE 213 labs.

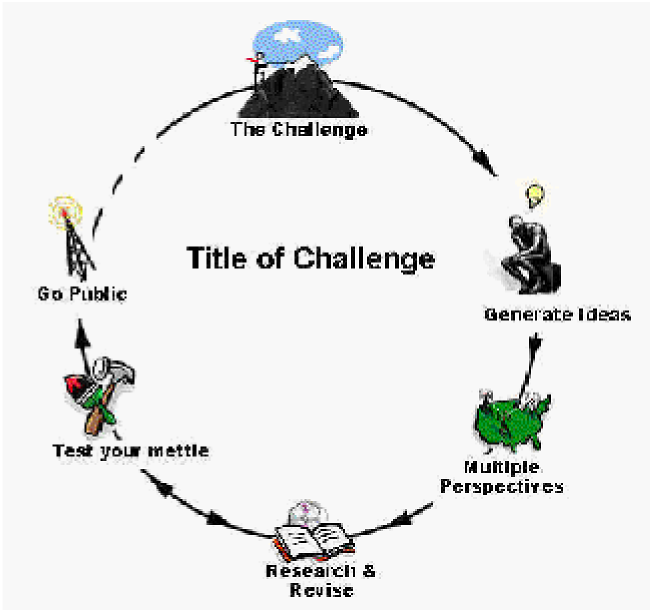

Figure 2. The STAR Legacy Cycle

B. Significance and relevance of The STAR Legacy Cycle to the engineering practice

In order for engineering lab courses to be developed following the challenge-based STAR Legacy Cycle, it is necessary to relate the cycle to the engineering process. The cycle was first developed to organize instruction and manage learning activities and resources in a classroom setting. It has never been implemented in engineering lab course design[8]. So an objective of this study has been to evaluate the appropriateness of the Cycle in a practical engineering lab course.

Analyzing the cycle for significance and relevance to an engineering process revealed that it coincided with the engineering project development process. Establishing this relationship was been a major outcome which would provide the basis for designing physical lab courses in engineering education.

Figure 4 shows the relationship between the STAR Legacy Cycle and the engineering project development process. Figure 4 can be simplified to suit any engineering project developmental process. For the purposes of the study and the labs involved, Figure 4 has been left in this general form. The activity-to-activity correspondence between the two cycles in Figure 4 would help students understand the relevance of the new lab design.

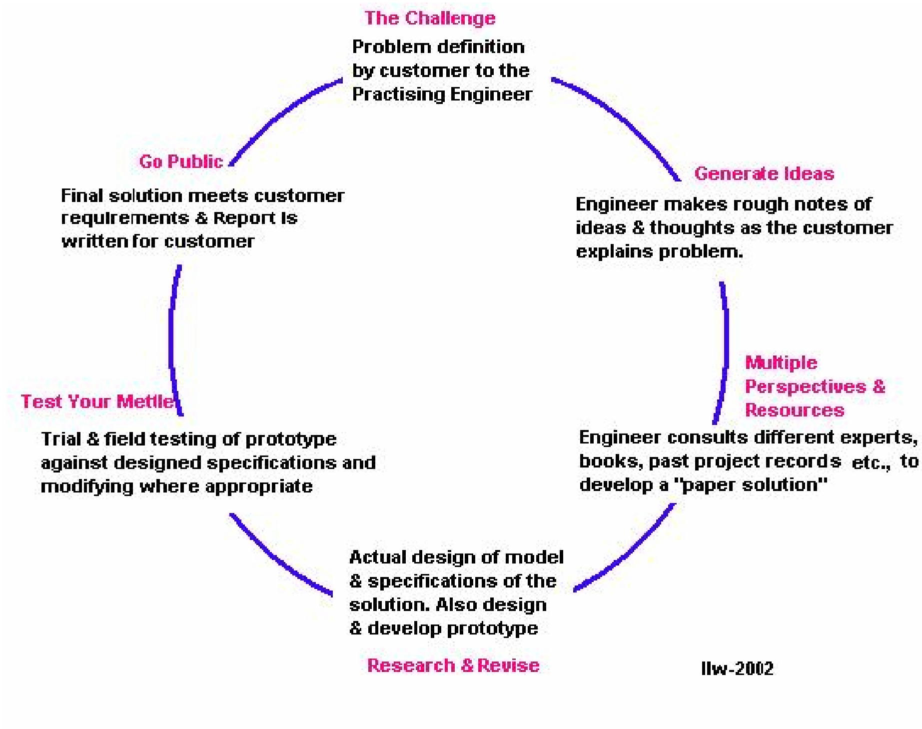

Figure 4. The relationship between the STAR Legacy Cycle and engineering process

III. Traditional Electrical Engineering 213 Circuits Labs at Vanderbilt

In Electrical Engineering at Vanderbilt University, the course EECE 213 Network Theory I is a requirement for sophomore engineering students in biomedical, computer, and electrical engineering programs. This 4-hour course has nine physical circuits labs. These labs have been taught in the traditional method for years to demonstrate the application of electrical concepts and principles to design, synthesis, and analysis of basic electronic circuits. The aim has been to give students necessary practical experience and knowledge. A lab manual contains brief description of each lab, short pre-lab exercises, and experimental procedures. During lab classes, the Teaching Assistant (TA) gives a group introduction, answers questions, and is available to help with individual problems. After completing the lab procedures, the traditional practice has been that students write up on the outcomes in their lab notebooks, and submit the notebook for grading as they left the lab. Assessment of students' learning in the lab is based on the interpretation of their lab notebook entries.

A previous study into student learning in the same EECE 213 labs reported a number of problems with traditional lab instruction[11]. Students were often unfamiliar with the contents of labs, electronic components and materials, and test instruments. Two other related studies reported that student knowledge and understanding of basic electrical concepts were often disjointed and "in pieces"[11]. Student misconceptions often resulted because of their lack of proper understanding of basic electrical concepts. This resulted in students having difficulties applying the concepts correctly to solve circuit problems.

In this study, it became necessary to confirm these student deficiencies. A survey was carried out every term during the years 2000, 2001 and 2002, before labs were started to determine the background of students enrolled for the EECE 213 labs. The results showed that many students had little prior knowledge of basic electrical circuit concepts and no practical competencies in basic electronic circuits, materials, and test instruments (see Table 1). A follow up written test on basic circuit concepts and practical knowledge pertinent to the labs confirmed the student weaknesses in prior knowledge and practical competencies (see Table 2). After the first three labs, another survey to determine student difficulties in those labs showed that students had problems in many areas of the three labs (see Table 3). These surveys and the written test confirmed previous findings that a lot of students were ill prepared to perform the EECE 213 labs. Many students had little understanding of the basic electronic components (i.e., capacitors, inductors, resistors, operational amplifiers) and materials like breadboards. They had difficulty realizing correctly the physical circuit from a circuit schematic diagram. Many students had no prior experience on common test instruments like the HP54501A digitizing oscilloscope, the Tektronix CFG250 function generator, power supplies and other equipment. Many did not know how to use the oscilloscope to display waveforms correctly, how to take accurate measurements, how to process measurements, or how to interpret results and determine the operational characteristics of test circuits. Apart from the limited information in the lab manual, no other resource was available to help students prepare and learn how to perform necessary lab procedures.

The traditional lab environment is inherently instructor-centered where the lab instructor becomes the resource center and sole source of assistance for conceptual and procedural difficulties that students may. Students often got bogged down with procedural and practical difficulties that distract them from the concepts and objectives of the labs and prevented deeper inquiry. Much of the instructor time in the lab is spent addressing student procedural and practical problems than in conceptual discussions. This over dependence on instructor assistance often resulted in decreased interest, motivation, and students completing lab grudgingly[1].

Also, while the objectives of the lab are often listed in the manual, no effort is made to anchor lab concepts to real world settings that would demonstrate the application of the concepts and principles of the lab. Therefore, many students simply follow and complete lab procedures in order to fulfill course requirements without any real understanding and appreciation of where the concepts are applied.

The enforcement of the lab notebook entries as the required form of presentation in the traditional labs, do not meet ABET Engineering Criteria 2000 that aims to develop formal presentation and technical report writing skills. The assessment of learning in lab fails to adequately evaluate "practical" competencies gained from the activities and interactions. The grading is criteria-based because the outcomes of the experiments are known. Therefore the assessment basically rewards for "getting it right" and penalizes for "getting it wrong". Studies have shown that when formative assessment resources are added to a course, students achieve at higher levels than without them[5].

Asynchronous learning methods aim to make learning resources accessible at anytime from anywhere, and such methods have not been investigated for implementation in physical electrical engineering labs. Such methods can be incorporated in lab course designs to make available learning resources for access on a “needs basis”. “Just in time, in context” information can be made available to assist student preparation “before lab”; as an alternative information resource “during-lab”; and for “after-lab” access to assist student review and write up.

IV. A technology-enhanced, challenge-based physical circuits labs at Vanderbilt

Lab instruction and learning issues highlighted here raises the question; How can innovations in learning technologies and new outcomes in the learning sciences improve instruction and learning in engineering lab courses?

ABET Engineering Criteria 2000, which focuses on student outcomes, requires faculty of engineering disciplines not only to develop methods and measures for evaluating their programs, but also to use the results to improve the instruction and learning process[9]. The goal is to ensure that graduates have the knowledge and skills described in Engineering Criteria 2000 as they enter engineering practice as well as continual improvement and innovation of the educational system by faculty[10] (www.abet.org/EAC/eac2000.html). These requirements also apply to physical lab courses that form a vital part of an accredited engineering program.

Based on the results of the surveys and test (see Tables 1, 2 and 3) the following lab innovations were developed, evaluated, and organized into a technology-enhanced, challenge-based, physical learning environment for the EECE 213 circuits labs.

A. Computer-based instrumentation

In 1998, the Department acquired the National Instruments VirtualBench (NI VB) software and hardware for evaluation but had not been used. NI VB is a stand-alone, software-based, ready to use suite of instruments. It has a 2-channel oscilloscope, Function Generator, digital multimeter, and other instruments. The NI VB instruments are connected to the physical world through a BNC2120 interface board whose terminals are programmed as input or output terminals of the instruments. The BNC2120 interfaces between the outside world and the NI VB instruments via a data acquisition board (NI DAQ Board) installed in the computer.

In 2001, a comparative evaluation was carried out to determine student attitude and satisfaction between the NI VB instruments and the conventional bench top instruments. The class was divided in two groups. For the first four labs, one group used the conventional instruments while the other used NI VB. Then for the next five labs, the two groups switched instrument type. Then a self-reporting evaluation was conducted to measure student attitude and satisfaction on the use of both NI VB and conventional instruments. The evaluation results showed that students favored computer-based NI VB instruments over the traditional bench top instruments (see Tables 4 and 5. Based on this evaluation, the Department replaced the conventional bench top instruments in the EECE 213 circuits lab with computer workstations. All six stations in the lab were equipped with a Gateway Pentium II PC with the NI VB Version 2.1.1.1 software and the associated hardware.

B. Web-based lab courseware and learning resources

In the traditional lab method, apart from the limited information in the lab manual, there were no resources available for students to learn how to perform necessary routine and lab procedures. No lab resources were available for students to learn:

- About physical electronic components and how to use them properly;
- How to correctly realize physical circuits from schematic diagrams;
- The proper use materials like the breadboard and construct circuits on it;
- How to use electronic test instruments and make accurate measurements;
- To analyze and evaluate measurements; and
- How to determine important performance parameters of circuits.

Such lack of sufficient resources has lead to an over dependence on lab instructors for information, which often results in frustration for both students and instructors. This over dependence on lab instructors for routine procedures and information could be reduced with the aid of technology. Asynchronously accessible web-based tutorials as well as help facilities, demonstrations, and other learning resources on concepts, components, materials, and lab procedures could be developed and made available through the Internet. Such sources of information would be available for "just in time, in context" access during "before lab" preparations, "in lab" assistance, and "after lab" consultations. Students would self-learn new concepts and self-correct misconceptions at all stages of the lab experience. This would prepare students for the labs, address conceptual and procedural difficulties, improve lab efficiency, improve understanding, redefine the workload of lab instructors, and improve the lab learning process. These hypotheses would need to be tested.

Web-based lab courseware, tutorials and other learning resources pertinent to the EECE 213 circuit's labs were designed and developed and made available on the Lab's website (http://eecs.vanderbilt.edu/courses/ee213)

The EECE 213 Lab website includes the major elements of good web-based course design. It has two sides. On the student side, there is asynchronous access to lab course materials, instructions, and tutorials. The instructor side is accessible by the instructor to develop, update and upload learning materials. Other facilities like pre- and post- lab tests; feedbacks, instructor evaluation, student surveys, student performance evaluation, and on-line submission of formal lab reports could easily be added.

Evaluations were carried out to determine student attitude and satisfaction with web-based "just in time, in context" tutorials and learning resources. The results are shown in Table 6.

C. Challenge-based lab design using the STAR Legacy Cycle

After the computers and computer-based instrumentation in the lab, Internet access, development of the lab courseware and other learning resources, the STAR Legacy Cycle was used to design the lab instruction around challenges and organize the lab activities. The existing nine traditional circuits labs in EECE 213 were redesigned using the Working Backwards strategy[7]. Lab activities were organized using the Cycle, which reflects the project development process in engineering. Organization of instruction was done to achieve a balance between learner-, knowledge-, assessment-, and community-centeredness[5]. The HPL framework was useful in determining the methods to introduce challenges, help students generate ideas, embed assessment, and in designing multiple learning activities to foster deeper understanding.

The STAR Legacy Cycle was divided into the three segments that make up the total lab learning experience. They are:

1. Before Lab
   - Challenges
   - Generating Ideas
   - Multiple Perspectives and Resources (On-line Pre-lab tests, web-based tutorials and learning resources)
   - Research and Revise (Pre-lab design and evaluation)

2. During Lab
   - Test Your Mettle (experiment)

3. After Lab
   - Go Public (formal lab report)

The web-based tutorials and other learning resources are asynchronously accessible during Before Lab, During Lab, and After Lab activities.

When design the lab instruction, the main objectives of each lab were anchored to realistic electrical engineering problems in "The Challenge" (problem definition) of the STAR Legacy Cycle (see Figure 2). To tap students' intuition and to enable sustained and focused inquiry, students are asked to generate ideas on how they would address the problem presented in the challenge. This is the "Initial Thoughts" stage of the Cycle. The "Perspectives and Resources" stage of the Cycle presents opinions of experts on the challenge, definitions, and other resources to help students prepare. On-line pre-lab tests were designed to prepare students on the lab materials and the tests were linked to the "Perspectives and Resources" of the cycle in each lab. Different web-based tutorials and learning resources pertinent to the lab are hyper-linked to the "Perspectives and Resources". The prototype design of a possible solution to the challenge problem occurs in the "Research and Revise "stage of the Cycle. Here the pre-lab design calculations and theoretical performance analysis take place. Also, evaluations are done to ensure that the theoretical performance parameters meet the requirements defined in the challenge problem definition. The "Test Your Mettle" stage of the Cycle takes place during the lab class where the students build their designed circuits and follow experimental procedures to test it and make practical measurements. The measurements would be analyzed and the results compared with designed values and evaluated to check if the practical solution meets the requirements of the challenge problem. The "Go Public" stage of the cycle is where the formal technical report writing takes place. To satisfy ABET requirements in report presentations, the new challenge-based labs requires students to submit formal lab reports based on the industry standard. The traditional lab method required students' lab log notebook entries to be submitted for assessment.

Web-based tutorials and learning resources are used throughout the lab process to provide "just in time, in context" information to students. The hypothesis is that this would enable students to review and self learn concepts as well as self correct misconceptions as they proceed. Also, "just in time, in context" information would improve the learning process in the lab.

Evaluations were carried out to determine student attitude and satisfaction with the new challenge-based lab design. The results are shown in Table 7.

V. Evaluation

Evaluation of engineering courses usually focuses on the cognitive knowledge gained by students. However, the major thrust of this paper is to introduce to engineering education a new technology-enhanced, challenge-based lab environment that has the potential to address problems inherent in the traditional lab method. Therefore, the evaluation here is attitudinal. The primary question to be addressed is: Do students and lab instructors have positive perceptions and attitudes toward the new technology-enhanced, challenge-based lab environment? The evaluation process consisted of self-reporting attitudinal surveys of students and lab instructors, and audio and manual recording of interactions between instructor and students.

A. Student prior knowledge and practical competencies, and difficulties in the lab

Before the labs got started, students enrolled for the EECE 213 labs were surveyed to assess their prior knowledge and practical competencies in different areas. The survey was followed by a written test. For the survey, an affective or reactive type instrument was used because positive reactions would indicate a student having prior knowledge and practical competencies. The results are in Table 1. The sample size N was 191 students enrolled in Spring 2000, Fall 2000, and Spring 2001 semesters.

Table 1. Results of student prior knowledge and practical competency evaluation.

	Competencies	**Mean**	**S. D.**
A	**Test Instruments**		
1	Understanding & operating the features on the scope correctly	2.84	1.11
2	Displaying, measuring and interpreting the wave forms on the scope	2.87	1.03
3	Measuring the amplitude of signals using the oscilloscope	2.79	1.08
4	Measuring the phase angle between signals using the oscilloscope	2.41	1.16
5	Measuring the frequency of signals using the oscilloscope	2.73	1.19
6	Setting the correct amplitude and frequency of signals on the Function Generator	2.67	1.23
7	Understanding the controls & operating the features on the power supply	2.74	1.19
8	Understanding the controls & operating the features on the LCR bridge	2.57	1.19
9	Understanding the controls & operating the multi-meter to read voltages	2.83	1.28
10	Understanding the controls & operating the multi-meter to read current	2.86	1.27
11	Understanding the controls & operating the multi-meter to read resistance	2.89	1.33
B	**Components**		
1	Understanding resistor color codes and determining the values	2.99	1.40
2	Understanding the rating of resistors and its practical significance	2.85	1.19
3	Understanding the codes of capacitors and determining the values	2.78	1.14
4	Understanding the rating of capacitors and its practical significance	2.64	1.10

C	**Use of Breadboard**		
1	Understanding the matrix of rows and columns and their interconnections	2.73	1.49
2	Assembling components and constructing circuits in it	2.97	1.45
3	Trouble shooting when circuits did not operate	2.96	1.37
D	**Using different cables**		
1	Understanding coaxial cables and using them in the lab	2.53	1.31
2	Understanding colored cables and using them in the lab	2.50	1.27
3	Understanding different connectors and using them in the lab	2.52	1.25
E	**Assembling Circuits**		
1	Understanding and interpreting circuit schematic diagrams in the lab	2.95	1.23
2	Interpreting & physically assembling circuit from the schematic diagram	3.02	1.32
3	Troubleshooting & correcting errors in the circuit when it does not work	3.04	1.25
F	**Taking Measurements and Interpreting Data**		
1	Interpreting measurements on the scope	2.72	1.10
2	Plotting measured data	2.80	1.10
3	Interpreting circuit response graphs	2.74	1.05
4	Determining and extracting parameters of interest from the plots	2.70	1.11

Sample size N = 191 students enrolled in Spring 2000, Fall 2000 and Spring 2001.
Response scale: 1 = Strongly disagree, 2= disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree

The results in Table 1 indicate an overall weakness in the student prior knowledge and competencies when they come to start the EECE213 labs. The results showed consistency across the three semesters, which suggests that the combined results in Table 1 are stable.

In order to formatively confirm the results in Table 1, an in-class prior knowledge and competency test was administered after the survey at the beginning of Lab #1. The test was multiple-choice and required simple calculations and reasoning. The test was taken by 93 students that were randomly selected. Table 2 shows the percentage of correct and incorrect answers.

Table 2. Results from students' prior knowledge and practical competency test.

	Question	**% Correct**	**% Incorrect**
Q1	The impedance of a capacitor is:	53	47
Q2	How is the impedance of a capacitor related to frequency?	70	30
Q3	How is the impedance of capacitors related to their capacitance value?	66	34
Q4	How will you convert from pico-Farad (pF) to microfarads (μF)?	34	66
Q5	The phase angle in RC circuits is a function of frequency. What is the maximum phase angle obtainable?	48	52
Q6	The cutoff or break frequency, ω_c, can be express in terms of R and C. Which relationship is correct?	68	32
Q7	What is the significance of the cutoff or break frequency (ω_c) in low pass filters?	39	61
Q8	The "half power" magnitude is defined as the point at which magnitude of Vo is:	47	53
Q9	How would you convert frequency in rads/sec to frequency in Hertz?	59	41
Q10	For a low-pass RC filter, one "time constant" is defined as the time taken for the capacitor to charge up to:	33	67

Q11	The time constant of a series RC circuit is determined by:	61	39
Q12	The impedance of an inductor is:	52	48
Q13	The impedance of an inductor is a function of frequency. How is it related?	68	32
Q14	How does the impedance of an inductor related to the value of inductance?	68	32
Q15	The phase angle in an inductive circuit is a function of frequency. In a purely inductive circuit, the maximum phase angle obtainable is:	54	46
Q16	In an LR circuit, the cutoff or break frequency, ω_c, can be express in terms of L and R. Which is correct?	46	54
Q17	The time constant of a series LR circuit is calculated as:	55	45

Sample size N = 93 students

Table 2 shows that many students lacked prior knowledge and competency in basic circuit concepts and practical skills. These results seem to agree with the results in Table 1. Both Table 1 and Table 2 provide information to instructors on the areas where most students are weak. Instructors can use this information to provide assistance to students in those areas.

B. Student difficulties in the circuits' labs

There was a need to determine exactly the difficulties students faced as a result of their weaknesses in prior knowledge and competencies. This was done using a self-reporting evaluation after the completion of Lab #3. Students were asked to assess and evaluate the difficulties they had in different areas of activities in the first three labs. The students then rated the level of difficulty they perceived themselves to have experienced in each of the listed areas during the first three labs. The evaluation used was an affective or reactive type instrument.

Table 3 shows the results of the students' assessment of the level of difficulty in the first three lab. The 28 items listed are activities that students would participate in while carrying out a lab. For this analysis, assessment of the evaluations from 75 students in the Spring 2001 class was used.

Table 3. Difficulties faced by students in the first three labs in EECE 213.

ID	**Lab activities**	**Mean**	**S. D.**
1	Understanding & operating the features on the scope correctly	2.80	1.00
2	Displaying, measuring and interpreting the wave forms on the scope	2.91	0.95
3	Measuring the amplitude of signals using the oscilloscope	2.44	1.02
4	Measuring the phase angle between signals using the oscilloscope	2.20	0.97
5	Measuring the frequency of signals using the oscilloscope	2.37	0.98
6	Setting the correct amplitude and frequency of signals on the FG	2.79	1.12
7	Understanding the controls & operating the features on the power supply	2.49	1.23
8	Understanding the controls & operating the features on the LCR bridge	2.47	1.29
9	Understanding the controls & operating the multi-meter to read voltages	2.43	1.29
10	Understanding the controls & operating the multi-meter to read current	2.23	1.13
11	Understanding the controls & operating the multi-meter to read resistance	2.52	1.15
12	Understanding resistor color codes and determining the values	2.76	1.09
13	Understanding the rating of resistors and its practical significance	2.68	1.09

14	Understanding the codes of capacitors and determining the values	2.75	1.01
15	Understanding the rating of capacitors and its practical significance	2.99	1.13
16	Understanding the matrix of rows and columns and their interconnections	2.13	1.21
17	Assembling components and constructing circuits in it	2.20	1.17
18	Trouble shooting when circuits did not operate	2.96	1.29
19	Understanding coaxial cables and using them in the lab	3.28	1.34
20	Understanding colored cables and using them in the lab	3.79	1.23
21	Understanding different connectors and using them in the lab	2.55	1.04
22	Understanding and interpreting circuit schematic diagrams in the lab	2.35	1.03
23	Interpreting & physically assembling circuit from the schematic diagram	2.84	0.94
24	Troubleshooting & correcting errors in the circuit when it does not work	2.77	1.03
25	Interpreting measurements on the scope	3.03	1.03
26	Plotting measured data	2.83	1.08
27	Interpreting circuit response graphs	2.64	1.10
28	Determining and extracting parameters of interests from the plots	3.16	1.05

N = 75 students. Response scale: 1 = Not at all difficult, 2 = somewhat difficult, 3 = Difficult, 4 = Very difficult, 5 = Extremely difficult

Table 3 shows that many students did face difficulties in the 28 areas; the level of difficulty varied from area to area. These results present important information to instructors about the specific areas in which they could provide assistance to prepare students better beforehand. One way would be to provide web-based tutorials and video demonstrations on "how to do things". As part of this study, the results in Table 3 were used to develop web-based tutorials. The tutorials are used by students for before-lab preparations, during-lab access, and after-lab use (for data analysis and formal report writing).

C. Computer and use of computer-based NI VB instruments in the circuits labs

The Spring 2001 class carried out four labs using conventional bench top instruments and then the next five labs using computer-based instruments (NI Virtual Bench 2.1.1 and hardware). A self-reporting evaluation was done to assess students' perceptions, attitudes, satisfaction and views, after they had used both the conventional bench top instruments and computer-based instruments in the lab. The evaluation used was an affective or reactive type instrument. Table 4 shows the results of the student assessments.

Table 4. Student assessment on the use of computer-based instruments

	Statement	**Mean**	**S. D.**
S1	"Computer based instruments are user friendly and easier to use compared to conventional bench top instruments."	4.05	0.81
S2	"It took me far less time to learn and familiarize myself how to use the features of the computer-based instruments compared to conventional bench top instruments."	3.49	0.99
S3	"Using computers and computer based instruments allowed me immediate access to online tutorials and other resources when I needed them without leaving the station and saved a lot of time."	3.99	0.90
S4	"Using computers allowed me access tutorials to review and self correct myself on things I did not know and unsure of (misconceptions) to do labs."	3.88	0.87
S5	"The combined computer, computer-based instruments and on-line tutorials and resources provided a good learning environment in the lab."	3.94	0.83

S6	"I am satisfied with my learning experience provided by the combination of computers, computer-based instruments, and online tutorials/resources."	3.73	0.88
S7	"From my experience so far, I would recommend that the combination of computers, computer based instruments and online tutorial/resources be introduced in other labs as well."	3.97	0.71

Sample size N= 77 students (Spring 2001 class), Response scale: 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; 5 = strongly agree.

In Table 4, student assessment of statements S1 and S2 shows that they experienced the computer-based instruments as more user friendly and easier to operate than conventional bench top instruments. Students also agreed that it took less time for them to learn and become familiar with the features of computer-based instruments as compared to conventional bench top instruments. It appears that students prefer computer-based instruments to conventional ones. One reason for this could be that students are most computer literate and feel comfortable operating computer-based instruments. They can easily access on-line facilities when required. With physical instruments, whenever students encounter problems, they must wait for TA assistance.

Question: Did the combination of computer-based instrumentation, web-based lab courseware and learning resources accessible at any time, save lab time that would otherwise have spent waiting for assistance?

This question can be answered by analyzing statement S3 in Table 4. Students agreed that using the computers and computer-based system allowed them immediate access to web-based tutorials and other resources whenever they needed them, without putting the lab on hold to wait for TA attention. The students agreed that this saved them a lot of time. During the labs themselves, it is a common sight to see windows opened on computer monitors displaying tutorials and help facilities as well as the lab procedures, as the students carried out their experiments. Frequently, TAs could point students to the web-based tutorials to answer their questions without having to wait for TA assistance. The URL address of the EECE 213-lab web site is always on the board in front to assist students.

The web-based lab procedures have been designed so that key terms, components, and materials mentioned in the procedures are hyper-linked to tutorials that explain and demonstrate them.

Question: Did the combination of a computer-based system, web-based lab courseware and learning resources accessible at any time, allow self-learning new things and during-lab self-correction of misconceptions?

In order to answer this question, student assessment of statement S4 in Table 4 was evaluated. The students agreed that the computer-based system allowed them access to tutorials and web-based materials to review old concepts, self-correct misconceptions, and self-learn new things they did not know or were unsure about during the labs. The EECE 213 course is structured such that the concepts of the first few labs are not covered until after students have done those labs. For this reason, the web-based tutorials and the TA are the only sources of information about concepts on which the labs are based.

Question: Does the combination of computer, computer-based instrumentation, web-based lab courseware, and other learning resources accessible at any time provide a good lab environment for students and do the students feel satisfied with the experience?

Students own responses to an opened ended evaluation provided a lot of positive feedback. Some of these responses have been randomly selected and are shown in Table 5.

Table 5. Positive and supportive views on computer-based instruments (Spring 2001)

1	Computer-based instruments were easier to use. Controls were easier to identify. (SG.)
2	It was good to be able to work from any computer. (AS.)
3	Computer-based instruments with on-line lab procedures and lab resources provided a convenient environment where they can all be open in different windows at once. (BS.)
4	The results were quicker and immediate and easier to read. (CH.)
5	Less number of physical equipment, less inter-connections to be made, and less troubleshoot instruments if something does not work. (MK)
6	Computer-based instruments were simpler to use and measurements and measurements were done quicker and easier. (EM.)
7	With the computer-based instruments, the panels are easier to use and navigate. (MM.)
8	The computer-based instruments are easier to set up and to use compared to the traditional instruments. Having on-line tutorials access is nice. (CS.)
9	The computer is a familiar working environment and using computer-based instruments was easier and user friendly. (LB.)
10	More flexible, easily portable as you would only carry a disk to install the instruments in another computer at another location, better interface and more visual options (SC.)

Question: Based on experiences with students in the lab, what perceptions do TAs have of how the computer-based instruments, web-based tutorials, and help resources have affected students?

In order to answer this question, an evaluation was carried out with the TAs that were teaching the different Lab Sections. The evaluation used was an affective or reactive type instrument. Table 6 shows the results of this TA evaluation.

Table 6. TA assessments of how the computer, computer-based instruments, web-based tutorials/resources impacted students in carrying out their labs.

	Statement	Mean ± S.D.
S1	"Generally, students found computer-based instruments user friendly and easier to use prepared to conventional bench top instruments"	2.67 ± 1.15
S2	"Generally, it took students far less time to learn and familiarize themselves on how to use the computer-based instruments compared to the conventional bench top instruments."	3.67 ± 1.53
S3	"Computers and computer-based instruments allowed students immediate access to on-line tutorials and other resources when they needed them without leaving the station and saved them a lot of time"	4.33 ± 0.58
S4	"Using computers allowed students to access on-line tutorials to review old concepts, self-learn new things, and self-correct misconceptions while doing the labs. This saved time a lot of time and effort in explaining many times."	4.33 ± 0.58
	"The combined computer, computer-based instruments, on-line	

S5	tutorials/resources provided a good learning environment in the lab."	4.00 ± 0.00
S6	"I am satisfied with the students learning experience provided by the combination of computers, computer-based instruments, and on-line tutorials/resources."	4.33 ± 0.58
S7	"From my experience so far, I would recommend that the combination of computers, computer-based instruments, and on-line tutorials/resources be introduced to other lab as wells."	4.33 ± 0.58
S8	Positive outcomes in using the combination of computers, computer-based instruments, and on-line tutorials/resources.	
S9	Problems or negative outcomes in using the combination of computers, computer-based instruments, and on-line tutorials/resources	

N = 3, Scoring: 1 = S/disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = S/agree

The results in Table 6 show that TAs had positive assessments of how the computer, computer-based instruments, and web-based tutorials and resources helped students in the conduct of the labs. The TA's assessments appear to agree with the students' assessments. However, the TA's assessment of statement S1 did not match up with the student assessment. The TAs in general did not think the computer-based instruments user friendly and easier to use than the conventional bench top instruments. By way of contrast, students stated that the computer-based instruments were more user friendly and easier to use prepared to conventional bench top instruments.

D. Challenge-based lab design using the STAR Legacy Cycle

<u>Question</u>: How did students assess the new challenge-based physical lab instruction?

An evaluation was carried out with the Spring 2001 class after they had completed the challenge-based Lab #4. This evaluation was designed to measure student attitudes and perceptions on a challenge-based lab. The evaluation used was an affective or reactive type instrument. The results are shown in Table 7.

Table 7. Student assessments of new challenge-based lab instruction

Statement	Strongly disagree %	Disagree %	Some what %	Agree %	Strongly agree %
"The challenge-based lab increased my ability to analyze the performance of a simple RLC resonance circuit"	5	14	65	15	2
"The challenge-based lab increased my ability to design a receiver system to tune over a wide range of frequencies and select a specific frequency"	2	20	54	23	2
"After this challenge I can explain why a series RLC circuits selects a specific frequency"	2	38	37	12	11
"After this challenge-based lab I can explain how well a parallel RLC circuit in parallel selects a specific frequency"	2	42	34	14	9

"The challenge-based lab allowed me to think critically about an actual engineering problem and allowed me to organize my own thoughts on how to solve it"	0	9	60	28	3
"After this lab I am confident I could teach someone how to analyze a tuning circuit using lab equipment and graphing paper"	8	38	34	18	2
"I felt more aware of the goals of the actual laboratory experiments during this challenge-based lab compared to other labs I have taken"	9	22	45	25	0
"The challenge-based lab experience felt less like a procedure and more like my experiment to explore a tuned circuit"	8	34	46	12	0
"After the web-based tutorials and challenge-based activities, I felt more prepared for this lab experience than my other labs I have attended"	2	22	57	18	2
"The issues related to the challenge helped me think about the goals of the lab"	2	11	43	40	5
"The issues related to the challenge helped me think about what to include in my lab report"	3	12	46	32	6
"I found it easier to write my lab report for this challenge-based lab compared to other reports I have written"	3	32	32	29	3

Sample size N= 77 students (Spring 2001 class), Response scale: 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; 5 = strongly agree.

The results in Table 7 show that the majority of student assessments fell into the "somewhat agree, agree, and strongly agree" ratings in response to many of the evaluation statements. This shows that a lot of students saw the significance of the new challenge-based lab instruction design and has a positive attitude towards it. During lab classes students did comment positively on how the new challenge-based labs made them more aware of the application of concepts covered. They also felt that having the web-based tutorials and learning resources available for access any time was a major help to them.

VI. Summary of results.

The purpose of this study was to investigate student attitudes, perceptions, acceptance, and satisfaction of a new web-based, resource-rich, technology-enhanced, physical lab-learning environment in engineering education. No previous study has been done on web-based, resource rich, technology-enhanced, physical lab learning environments in engineering education.

The study revealed that engineering students in the EECE 213 course and labs have demonstrable weaknesses in their prior knowledge of basic electronics and circuits. They also lack practical skill competencies. This result was surprising because students would have taken the course EECE 112, which lays the basic electronics and circuits foundation for courses like EECE 213 to build on.

Both students and TAs reacted positively to the combined used of computers, computer-based instruments, web-based tutorials and learning resources. On the whole students are computer literate, and they felt the computer-based system was user-friendly and easy to get to know and operate. Students and TAs expressed satisfaction with the immediate availability of web-based tutorials and other resources during the lab to assist students with their inquiries. These resources took some pressure off the TAs in the lab, as students consulted the web-based tutorials for many of their procedural queries. With the web-based resources accessible at any all times, there was no need to stop the lab and wait for TA help. By contrast, the traditional method of teaching labs invites such interruptions.

The study showed that the majority of student had positive views towards the challenge-based lab instruction. The new model has the potential to improve the lab learning experience. One example is that the challenge-based instruction anchors lab concepts to real world engineering applications. From that students can understand how lab concepts are used in the real world and how different concepts relate to each other. It is important for students to see the practical significance of lab activities.

Both students and TAs expressed satisfaction with the outcomes of the different lab innovations that were introduced and implemented. This new lab environment has been used since the Spring 2001 term by different classes of students and TAs. Therefore, it can be said that students, TAs and the Department, have accepted the system.

The Dean of the School of Engineering at VU, faculty and staff members, as well as visitors to Open-house demonstrations have expressed their positive reactions to the developments that have taken place in the EECE 213 lab environment. The EECS Department has now replaced the NI VB system in the lab with the state-of-the-art ELVIS system from National Instruments. Approval has been given by the Department to extend the work to the EECE 235 Electronics labs. This demonstrates the Department's satisfaction with the outcome of the new lab-learning environment. This investment may also signal the direction the Department envisions for its lab programs.

VII. Conclusions

The results in Tables 1 and 2 confirm earlier studies that engineering students taking the circuits labs in the EECE 213 Network Theory I course, have major deficiencies in prior knowledge and competencies relating to elementary electronic concepts and basic practical circuit skills. As a result of these deficiencies students faced varying degrees of difficulty in many areas of the labs (Table 3).

Results from student assessment of computer-based instruments and expressed student views show that they were satisfied with these instruments and preferred them to conventional bench top instruments. Also, students expressed satisfaction with that the combined computer, computer-based instruments, and web-based lab course ware and other learning resources provided a good lab-learning environment.

Results from TA assessment of computer-based instruments and their expressed views showed that, like students, show they were satisfied with them and preferred them to conventional bench top instruments. TAs agreed that the combined computer, computer-based instruments, web-based lab courseware and other learning resources provided a good lab-learning environment for students.

Results from both student and TA assessment of the new challenge-based lab instruction show that they were satisfied with the new design and approved of it. Both students and TAs recommended similar environments for other lab courses.

Overall, both students and TA have assessed the different innovations of this new integrated, technology-enhanced, challenge-based, physical lab environment favorably. The new environment has the potential to address some of the issues inherent in the conventional lab courses in engineering. The Department of Electrical Engineering and Computer Science has approved implementation of this new lab-learning environment. Other lab courses are now being redesigned in the Department.

VIII. Recommendation

Based on the results presented here and others yet to be reported, this new lab-learning environment has demonstrated its potential to address learning issues in traditional engineering lab courses. The challenge-based lab instruction method is based on the important engineering project development cycle (process). Therefore, it would be safe to recommend that this lab model be considered for implementation in physical lab courses in engineering education.

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