

Advanced Laboratory as Liberal Education

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Abstract

The first semester advanced physics laboratory course has been structured in a way that permits students to receive credit for an interdisciplinary course in the liberal education program of Southeast Missouri State University. It achieves this by integrating the disciplines of physics, engineering physics, mathematics, written communication, and oral communication. As a result, students can complete a course requirement for a major or a minor in physics or engineering physics and simultaneously complete part of the general education requirement of the University. In this paper, we will describe the course, PH345/UI330 Experimental Methods I, our general education curriculum called University Studies, and how this course satisfies the objectives of both a major or minor in physics or engineering physics and the objectives of the University Studies Program.

I. Introduction

Students are often surprised upon entering industry or graduate school by how much skill is required in areas that most of them spent little effort developing in undergraduate school. Such skills include self education and research on a topic, designing and conducting an experiment based on that research, and presenting the results of such efforts in writing and orally. My own experience was very much this way when I entered industry after undergraduate school. Although I had completed degrees in physics and electrical engineering, I had done very little experimental design, I had never learned to solder, and I had done very little formally to develop my communication skills. This caused considerable stress during my first few months on the job. When I began teaching and had the opportunity to participate in revising a two-course sequence in advanced physics lab, I was eager to try to create a laboratory sequence that prepared students more adequately for professional life after graduation than my own undergraduate education had prepared me. The course sequence that was developed not only meets our own programmatic needs, but the first course also meets the objectives for an interdisciplinary course in our University Studies Program¹. Fortuitously, it fits very well with the outcomes listed in ABET Engineering Criteria 2000² Criterion 3 as well.

This paper will describe the first course in the lab sequence, PH345/UI330 Experimental Methods I, how it fits into the University Studies Program, and how it fits with the objectives of ABET Engineering Criteria 2000.

II. Course Description

The advanced laboratory sequence consists of two courses that operate in essentially the same manner. Students in both our physics and engineering physics programs typically take this sequence in their junior year. As such, it serves as a building block for the engineering physics students who take the capstone design sequence in their senior year or for those students beginning undergraduate research with a faculty member. Only the first course of the sequence, PH345/UI330 Experimental Methods I, is part of the University Studies Program. The two course numbers refer to the fact that students may register for UI330 if they wish to receive University Studies credit or PH345 if they do not.

The objectives of the course are to:

- A. Improve laboratory skills
- B. Provide opportunity for open-ended and creative investigation of phenomena of interest in physics and engineering
- C. Develop initiative in scientific investigation
- D. Develop skills in experimental design, data acquisition, data analysis, and detailed comparison of experimental results to theory
- E. Develop written and oral communication skills used in conducting experimental work and in presenting scientific results

These objectives are addressed by students conducting a series of six experiments after introductory topics such as error reduction, analysis, and propagation; data analysis and fitting; resources for research; keeping a lab journal; and ethical issues are covered.

Each experiment is allocated two weeks, which consists of ten hours formally scheduled in the lab, but the lab is open and available to students at any time during business hours for independent work. All experiments run simultaneously and groups rotate experiments after two weeks. After the first three experiments, each student prepares a formal written report on some aspect of one of the experiments in the format of an article in a letters journal. The instructor chooses precisely which experiment and what aspect of it in such a way that each student writes a unique paper. They also prepare an oral presentation of their work such as they would give at a professional conference.

Before beginning each experiment, students receive a brief handout that contains a few questions that must be answered experimentally. For example, students may be asked to determine the beam divergence of a HeNe laser and the frequency spacing of its longitudinal modes. The handout also describes the equipment available for the experiment and lists a few general references. Students must then conduct outside research on the topic of the experiment in order to design an experiment to answer the questions posed in the handout. They are required to find and read at least two references, one of which must be a journal article pertinent to the experiment. They have considerable freedom as to exactly what aspect of the posed questions or what variation of the question they will investigate. The lab journals are reviewed at the beginning and end of each lab period at which time the instructor discusses with the students how their work is progressing. Lab journals are graded at the conclusion of the experiment. The lab journals form the basis for the formal written and oral reports. Great emphasis is placed on the design of the experiment in terms of making certain that thoughtful measurements are made

that minimize error and that the experimental situation matches the theory used to describe it. Great emphasis is also placed on comparing experimental results to theory. As with experimental work in an industrial or graduate school setting, good results usually take several iterations of data acquisition and analysis.

During those introductory lectures, about one period is devoted to ethical issues. Prior to that class, students must locate on the web and read the Code of Ethics of the National Society of Professional Engineers. They also must locate on the web and read several statements on ethical issues published by the American Physical Society. The code and statements are briefly discussed and then some relatively simple scenarios are described in which students are asked to identify any potential ethical issues raised in the scenario. They are then asked to apply the code and statements to suggest possible courses of action, which course of action might be best, and why.

Guest lecturers from the English Department and the Speech Department provide the instruction on communication skills near mid term and near the end of the semester. They conduct workshops during scheduled lab time in which they provide feedback to help students with their written papers and their oral presentations. In their workshops, guest faculty discuss issues such as audience analysis, organization, grammar and tone, ways to maintain audience attention, use of visual aids, etc. Students work through several iterations of their reports with feedback from the guest faculty and the course instructor before the final versions are presented for grading. The oral presentation is made to the students and faculty of the entire Physics Department during Common Hour, the noon hour on Wednesdays reserved for University-wide programs as well as departmental activities such as this. Since this audience consists of students ranging from beginning freshmen to seniors, as well as faculty, the talk must be structured and presented in a way that freshman can understand it and still at a level appropriate for juniors and seniors in physics and engineering physics.

After the second three experiments, students again write a paper and present their results. Lab groups are changed at mid term to provide more opportunity for students to develop team skills by learning to work with people of various abilities, personalities, and work habits. Since the second course in the lab sequence operates in the same manner as UI330, students complete four journal style papers and four technical presentations by completing both courses. By then, their written and oral communication skills have improved considerably, as well as their confidence in making oral presentations.

Students are also encouraged to present one of their papers at the Annual Southeast Student Research Conference held each April on campus. The talks must be modified for this presentation because the audience for any session of this conference consists of students and faculty from a variety of departments across campus rather than only from the Physics Department. This provides another good opportunity for students to develop their oral communication skills by making their presentation much more tutorial and general in nature.

This course structure and philosophy have several major benefits when compared with a more traditional lab course that consists of numerous, closed-ended experiments with a formal lab report for each. First, it fosters a more realistic understanding by students of experimental work

than the traditional lab course. Things do not always go smoothly in the lab, in fact, they usually do not. But that does not mean that one quits, waits for the lab period to end, and gets the data from a friend in another lab group. Rather, it means that one finds a way around the problem. This is a new way of thinking for many students, and it represents a much more mature attitude toward lab. Second, this approach fosters independent experimental and research skills in the student to a much greater extent than the traditional lab course. Each lab group may investigate aspects of the particular phenomenon under study that are of interest to them, rather than each group conducting exactly the same experiment on a given phenomenon. Since multiple avenues of investigation are available for each experiment, each lab group has, to a large extent, a unique laboratory experience related to each phenomenon. Ownership for what is done in the lab belongs to the group. Early in the semester, the instructor routinely answers some questions with “it’s up to you, it’s your experiment.” After the first experiment, questions such as “how many data points should we take?” or “do we have to measure this or that?” are replaced with discussions of the best way to make a particular measurement and what are the potential advantages or drawbacks to that approach. Third, this approach fosters much more creativity in experimental design than a traditional lab. Since no explicit experimental procedures are given, students must devise the best way to answer the question at hand experimentally. Fourth, students have the opportunity to develop written and oral communication skills to a much greater extent than in a typical lab course. The traditional approach to lab is for students to write short “formal reports” for each lab following a format usually prescribed by the instructor. In UI330, students are given several samples of papers taken from letters journals published by the American Institute of Physics (AIP) or the Institute of Electrical and Electronic Engineers (IEEE). Their papers are to be of similar length and tone. Students also benefit from instruction and critique by the guest English and Speech faculty members. Finally, lab groups function much more as teams because the variability in members’ backgrounds requires that various team roles be assumed by lab group members in order for the lab group to be successful. Student reaction and feedback in the course has been quite positive to date. Although a bit hesitant in the beginning, students generally come to appreciate the freedom to pursue their own ideas and interests with each experiment.

III. University Studies Program

The University Studies Program is a skills-based program that consists of forty-eight hours of course work. It includes a three-hour freshman seminar, three hours from each of twelve categories of courses, six hours of interdisciplinary courses, and a three-hour interdisciplinary senior seminar. Table I shows the distribution of courses required. The University Studies Council rigorously reviews courses submitted for inclusion in the University Studies Program to be sure that they are built around the University Studies Objectives listed below and that interdisciplinary courses are truly interdisciplinary. They also frown on a course attempting to significantly address too many of the objectives. The Council consists of faculty representatives from each of the six colleges at the University and the Dean of University Studies. Approval usually takes two or three iterations of submission and revision based on the recommendations of the Council. Such was the case with UI330 Experimental Methods I (the course justification document is eleven pages long), but it is now approved and available as a choice for one of the interdisciplinary courses.

TABLE I
STRUCTURE OF THE UNIVERSITY STUDIES PROGRAM
SOUTHEAST MISSOURI STATE UNIVERSITY

PROGRAM THEME: UNDERSTANDING AND ENHANCING THE HUMAN EXPERIENCE

I. First Year Introductory Course 3 hours

II. The 100-200 Level Core Curriculum:

THEME: ACQUISITION OF KNOWLEDGE:

GAINING PERSPECTIVES ON THE INDIVIDUAL, SOCIETY AND THE UNIVERSE

The core curriculum is separated into three perspectives with four categories of courses in each perspective. One course is required from each of the twelve categories.

100-200 Level Core Curriculum 36 hours

Perspectives on Individual Expression	Perspectives on Natural Systems	Perspectives on Human Institutions
Artistic Expression 3 hours	Behavior Systems 3 hours	Development of a Major Civilization 3 hours
Literary Expression 3 hours	Living Systems 3 hours	Economic Systems 3 hours
Oral Expression 3 hours	Logical Systems 3 hours	Political Systems 3 hours
Written Expression 3 hours	Physical Systems 3 hours	Social Systems 3 hours

III. The 300-400 Level Interdisciplinary Curriculum:

THEME: INTEGRATION OF KNOWLEDGE: LIVING IN AN INTERDEPENDENT UNIVERSE

Each student takes two 300-level courses that integrate two or more categories of the core curriculum.

300 Level Interdisciplinary Courses 6 hours

Each student also takes a 400-level senior seminar that integrates two or more perspectives of the core curriculum and that requires students to demonstrate the ability to do appropriate interdisciplinary scholarship and present it in both oral and written forms.

400 Level Senior Seminar 3 hours

TOTAL 48 hours

The University Studies Program is based on the following nine objectives:

1. Demonstrate the ability to locate and gather information
2. Demonstrate capabilities for critical thinking, reasoning, and analyzing
3. Demonstrate effective communications skills
4. Demonstrate an understanding of human experiences and the ability to relate them to the present
5. Demonstrate an understanding of various cultures and their interrelationships
6. Demonstrate the ability to integrate the breadth and diversity of knowledge and experience
7. Demonstrate the ability to make informed, intelligent value decisions
8. Demonstrate the ability to make informed, sensitive aesthetic responses
9. Demonstrate the ability to function in one's natural, social, and political environment

In order to qualify as an interdisciplinary course, a course must integrate at least two of the categories shown in Table I. UI330 successfully integrates Physical Systems and Logical Systems from Perspectives on Natural Systems and Written Expression and Oral Expression from Perspectives on Individual Expression. An interdisciplinary course must also address at least Objectives 1, 2, 3, and 6 at a significant level, which means that the objective is addressed by all four aspects of the course; namely, course content, teaching strategies, student assignments, and student evaluation. UI330 does this and it also addresses Objectives 4, 5, 7, 8, and 9 to some extent, which means that the objectives are addressed in at least two of the aforementioned four course aspects.

From the course description above, it should be reasonably clear how Objectives 1, 2, and 3 are significantly addressed in this course, but now let's look at how Objective 6 is significantly addressed and how Objectives 4, 5, 7, 8, and 9 are addressed to some extent.

Objective 6 deals with the integration of knowledge and experience. For students in this course, this means they must draw upon their previous courses to function in the course. It is addressed at the significant level because all four aspects of the course - content, teaching strategies, student assignments, and student evaluation - are addressed. As for content, physics and engineering are interdisciplinary because of the substantial mathematical content and because of the importance of clear communication of technical ideas to both technically literate and more general audiences. The quantitative nature of this course requires the use of physical, mathematical, and numerical analysis. The emphasis on communication also requires students to draw on knowledge and experience from formal courses in written and oral communication. Although primary emphasis is on communicating to audiences of peers, students are encouraged to present their experimental work to a more general audience by participating in the Southeast Student Research Conference. As for teaching strategies, the instructor discusses various analysis techniques during the first week of the class. He then continually discusses with students how closely their experiment satisfies the assumptions of the theory being used to model it. Perhaps a different or modified theory should be used, or perhaps a different analysis technique would be more appropriate. The students must draw from both mathematics and physics to be successful in this effort of matching theory and experiment. Moreover, they must communicate their ideas effectively, both orally and in writing. As for student assignments, students must include theoretical discussions of the phenomenon under study and then must use mathematical

and numerical analysis to compare their experimental results to the theory. Students must make use of mathematical software such as a spreadsheet or Mathcad for most of these comparisons. This is done for each experiment in their lab journals, for both of their formal written reports, and for both of their oral presentations. These reports must also effectively communicate their work on each experiment. Finally, as for evaluation of student performance, the grade for the lab journals and written reports is partly determined by the extent to which the results are properly compared to theory and discussed. Students are also graded on their oral presentations. The criteria for grading the lab journals, written formal reports, and oral presentations include technical content and correctness, organization, clarity, sound reasoning, and effective presentation.

Objective 4 deals with understanding human experiences and relating them to the present. Some of the experiments conducted in this course have historical significance. One example is measuring the speed of light. As students conduct their research, the historical importance of an experiment is uncovered. The instructor also brings it up informally to help prompt this aspect of the research during the experiment. Including discussion of the historical significance of a particular experiment in the research notes in the lab book and in any formal papers or talks positively influences the student's grade. So, although not addressed significantly, this objective is addressed to some extent.

Objective 5 deals with understanding various cultures and their interrelationships. Again, because many of the experiments conducted in this course are closely related to topics in modern physics, students during their research discover that physics and engineering are truly global activities. Contributions were made from scientists and engineers from various cultures worldwide. The instructor once again brings this fact out during informal discussions while experiments are being done. Including discussion of this aspect of the topic in the research notes in the lab book and in any formal papers or talks positively influences the student's grade. So, again, although not addressed significantly, this objective is addressed to some extent.

Objective 7 deals with making informed, intelligent value decisions. Valuing is the ability to make informed decisions after considering the ethical, moral, aesthetic, and practical implications. This objective is addressed to a greater extent than the previous two because so many decisions that are made during the course of an experiment involve values typical of the engineer or scientist. Since multiple alternatives must be considered at nearly every stage in the design and conduct of the experiment, some set of values must guide how the limited resources of time, skills, and equipment will be used to accomplish the experimental objectives. In this context, the instructor can discuss how cutting corners or incorrectly interpreting data raises potential risks to public safety or reduces public confidence in science and engineering in general. Environmental impact is often an appropriate topic for discussion in this context. It is in support of this objective also that the instructor can raise additional ethical issues. For example, are there ethical and moral issues related to how technology based on phenomenon being investigated in the lab is applied? Having worked in the defense industry, such questions abound, and they are raised in informal discussions during the course of selected experiments.

Objective 8 deals with making informed, sensitive aesthetic responses. A concern for beauty is a universal characteristic of human culture. Beauty in physics usually relates to the degree to

which the theoretical description of a phenomenon uses elegant mathematics and actually explains what is going on physically. Students must wrestle with elegant and sophisticated theory in their research for several experiments in this course. Beauty in engineering usually relates to minimizing the complexity of a system while meeting specified design objectives. Students must design the simplest, most efficient experiment possible in order to answer the experimental questions in the allotted time. They must also fit experimental results with theory. The better the match between the two, the more aesthetically pleasing this is to the physicist or engineer. As with these other less significant objectives, the instructor raises such issues informally with the students, but not to the extent that one could say it is a significant aspect of the course.

Finally, Objective 9 deals with functioning in one's natural, social, and political environment. The existence of mankind depends on countless interrelationships among persons and things. Students must learn to interact responsibly with their natural environment and with citizens of their society and world. Interaction with their natural (i.e. physical) environment is intrinsic to the course. The essence of physics and engineering is to understand and then manipulate the natural environment for the benefit of human beings, while minimizing the impact of such manipulation. Working successfully in groups and having a well-developed set of laboratory skills is intrinsic to the social (i.e. professional) environment for most physicists and engineers. In addition, students have opportunity to discuss among themselves and with the instructor issues of social and political concern. Examples might be the proper level of government funding of science and engineering research or the quality of laboratory equipment at a state university. Because the atmosphere of this course is intentionally designed to simulate that of a professional technical environment, this objective is addressed to a greater extent than some of the others as well.

Because the University Studies Program is skills based rather than content based, prerequisites for the interdisciplinary courses must be kept to a minimum. The prerequisites for UI330 are completion of the Logical Systems requirement, which is College Algebra or higher mathematics, and completion of either an algebra-based introductory physics sequence, the first course of which satisfies the Physical Systems requirement, or a calculus-based general physics sequence. Although UI330 is primarily intended for students majoring in physics or engineering physics, students with other majors, such as chemistry, math, or computer science occasionally take it after completing the algebra-based introductory physics sequence in order to obtain a minor in physics. Incidentally, physics and engineering physics majors take the calculus-based general physics sequence, but they must satisfy their Physical Systems requirement with General Chemistry because the first general physics course is not a part of the University Studies Program. Since backgrounds can potentially vary from one student to another, expectations for the sophistication of the physics and engineering is based on the mix of individual student backgrounds that constitute each lab group. This is true for both majors and non-majors because our upper-level major courses are offered on a two-year cycle, and the backgrounds of our majors differ depending upon which upper-level courses they have completed. This variability in background actually strengthens the course because the lab groups are formed in a manner that helps students develop the team building skills necessary for success in the lab and after graduation as well. And, because the lab groups are changed at mid term, students must continually work at team building.

IV. Connection with ABET Criterion 3 a-k

Although the advanced lab sequence was developed before ABET Engineering Criteria 2000 was published, the structure of the courses clearly supports many of the outcomes listed in Criterion 3. Table II lists the outcomes of Criterion 3 for reference.

TABLE II
ABET Criterion 3 Outcomes

- a. an ability to apply knowledge of math, science, and engineering
- b. an ability to design and conduct experiments, as well as to analyze and interpret data
- c. an ability to design a system, component, or process to meet desired needs
- d. an ability to function on multi-disciplinary teams
- e. an ability to identify, formulate, and solve engineering problems
- f. an understanding of professional and ethical responsibility
- g. an ability to communicate effectively
- h. the broad education necessary to understand the impact of engineering solutions in a global and societal context
- i. a recognition of the need for, and an ability to engage in life-long learning
- j. a knowledge of contemporary issues
- k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

With only minor modifications to the lab courses, we were able to address Outcomes a, b, g, i, and k at a significant level. Further, we were able to address Outcomes c, d, e, f, and h to some extent. Compare Outcomes f, h, and j with the University Studies Objectives 4, 5, 6, 7, 8, and 9. There is considerable overlap.

As was the case with the University Studies Objectives, the outcomes that are significantly addressed are quite apparent. Outcomes a and b are clearly integral to the course content because students come to the course with a background in math, science, and engineering that they must apply. They are required to design and conduct open-ended experiments and to collect, analyze, and interpret data as a major component of the course. Outcome g regarding effective communication is also clearly integral to the course content because of the emphasis placed on written and oral reports. The emphasis on communication skills is one of the major reasons the course was accepted for the University Studies Program as an interdisciplinary course. Outcome i is integral to the course because students must conduct self education on the topic of the experiment in order to understand the phenomenon under study and to be successful in the lab. By having to do this, they learn to understand the need for and the value of life-long learning. Finally, Outcome k is significantly addressed because of the requirement to collect and fit data and to compare it to a theoretical model. This typically involves using computerized data acquisition followed by data analysis using software such as spreadsheets or MathCAD.

Perhaps not as apparent are the outcomes that are only addressed to some extent. Outcome c is addressed to some extent because the experimental design sometimes requires genuine creativity on the part of the lab group. For example, measuring the speed of light was mentioned earlier.

There are several possible ways of doing this, all of which require students to design and build some part of the experimental apparatus. Although simple designs are usually involved, this aspect of the course does prepare students well for our capstone design sequence in their senior year. Outcome d is addressed somewhat because the work of the lab group is a team effort even though the teams are usually only two students. And, because the students come to the course with varying levels of background preparation, including some students who are not physics or engineering physics majors, the lab groups often have an aspect of being multi-disciplinary. Outcome e is addressed somewhat because exactly how to make various measurements and exactly how to analyze the data obtained from those measurements certainly involves identifying, formulating, and solving engineering problems. Outcome f is addressed somewhat because professional and ethical issues are discussed in the introductory work at the beginning of the course and then later in connection with selected experiments. Finally, Outcome h is addressed somewhat because some of the experiments raise interesting questions due to their historical significance or ethical significance. Such questions are discussed informally during lab. Outcome j is not really addressed in this course.

UI330 is one of the few courses in the curriculum where addressing Outcomes f, g, h, i, and j can be readily and naturally incorporated. The second lab course along with the capstone design sequence are two others.

V. Summary and Conclusion

In summary, we have developed an advanced physics lab course that incorporates written and oral communication to a sufficient extent to qualify it as an interdisciplinary course in our University Studies Program. In order to qualify, the University Studies Council consisting of faculty representatives from each of the colleges of the University had to be persuaded that the course significantly addressed University Studies Objective 6 dealing with integration of the breadth and diversity of knowledge and experience as well as that it purposely addressed University Studies Objectives 4, 5, 7, 8, and 9 to some extent. The course description and these Objectives, when compared with the outcomes of ABET Engineering Criterion 3, show that the course addresses Outcomes a, b, g, i, and k to a significant extent and Outcomes c, d, e, f and h to some extent. Students realize early in this course that those skills they had tried to avoid developing in the early part of their curriculum must be developed for success in this course as well as for success as physicists and engineers after graduation.

Bibliography

1. University Studies Handbook, Southeast Missouri State University. Also see <http://ustudies.semo.edu> .
2. Engineering Criteria 2000, Accreditation Board for Engineering and Technology, Baltimore, MD, 2000.

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