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Teaching signals and systems through portfolios, writing, and independent learning

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I. Introduction

This paper describes an integrated approach to outcome-driven instruction and assessment of a continuous-time signal and system analysis course at the sophomore level. A set of seven course outcomes was established: four relating to traditional topics in frequency domain analysis of signals and systems, and three relating to broader educational outcomes, including effective communication, reflection on learning achievement, and learning independently. These seven outcomes were then used to structure the course, and to provide a focused basis for assessment of learning and continuous improvement.

A significant component of the course involved independent student project work; each student completed three projects, each of which involved learning advanced topics not discussed in class. Each project also involved substantive use of Matlab and Simulink software, which the students were also expected to learn independently. Finally, each project culminated in a writing assignment in which the students were challenged to consider what they had learned, how new material fit into their previous knowledge base, and how this learning process related to their own personal learning styles. Taken together, these three projects formed a course portfolio for the students to discuss with their academic advisors after completion of the course.

In order to help students learn to convey technical concepts and ideas effectively, all course homework assignments and exams also featured essay-type questions. Some of these questions challenged students to explain technical concepts in their own words; others were focused more on reflection of learning, as in the project assignments. Rubrics for evaluation of the writing were used so that the results would be both consistent and also be directly aligned with the course educational outcomes. In-class "minute papers" were used as a tool to help students practice writing, to solicit immediate feedback regarding student comprehension, and to encourage students to think critically about their learning during the course.

Elements of the projects, homework assignments, and exams were associated with the course outcomes, and student learning was evaluated using rubrics designed for each outcome and was validated by another faculty member. The results of this assessment were then used, along with student evaluation data, to formulate specific improvements for future offerings. They also provided a rich source of data for assessment of some of the more challenging criteria of ABET EC2000: the ability to communicate effectively, and the ability to engage in lifelong learning.

II. Course-Based Outcomes Assessment

Since 1970, WPI has featured an undergraduate program that places emphasis on project work and educational outcomes. The degree requirements consist primarily of substantial student projects, and there are nominally no required courses in the students' majors. The student projects therefore play significant roles in institutional and programmatic accreditation and in assessment of learning outcomes for continual improvement. Nonetheless, WPI students spend a great deal of their time taking courses, and so the activities in these courses should be aligned with educational goals and evaluated accordingly. Current efforts in the Electrical and Computer Engineering Department are focusing on course-based assessment, both to enhance student learning and to augment accreditation evidence provided by the project requirements.

Although no specific courses are required, a set of "core courses" is taken by almost all ECE students. These courses have become the focus of course-based assessment efforts, and are used in conjunction with project outcomes to demonstrate achievement of the ABET EC2000 Criteria. They include an introductory circuits course, a course on electrophysics, an introductory computer engineering course, an introductory microelectronics course, a course on embedded systems, a design course, and the subject of this paper: EE 2311, Continuous-Time Signal and System Analysis. The overall course assessment strategy involves development of sets of educational outcomes for each core course: typically, between four and eight outcomes are associated with each course. These outcomes form the basis for course assessment and continuous improvement of student learning; additionally, when taken together, they sufficiently address those EC2000 Criteria not already covered by project work and other activities, and provide supporting evidence for the rest of the criteria.

III. An Overview of the Course: Content, Challenges, and Opportunities

The material addressed in EE 2311 is fairly typical of introductory signal and system analysis courses in curricula that present continuous-time analysis separately from and before discrete-time analysis. The main topics of the course are:

- Description and classification of signals and systems
- Singularity functions
- Impulse response and convolution
- Trigonometric and exponential Fourier series
- The Fourier transform and some of its applications
- The Laplace transform and some of its applications

The course meets 35 hours during WPI's 7-week term, and has no formal laboratory component. Students are expected to invest about 15 to 20 hours per week, including class time, into the course.

Historically, this course has proved to be challenging for both instructors and students. The material is largely abstract and highly conceptual, and requires strong mathematical skills as well as comprehension of the meaning behind the mathematics. In essence, the students are being introduced to the notion of thinking and working in the frequency domain. Although this is a common and important paradigm for electrical engineers, students typically struggle--at least initially--with the mathematical techniques, the conceptual underpinnings, or both. Furthermore, there are a number of techniques, such as convolution, the determination of Fourier series and their spectra, and the determination of Fourier transforms and their spectra, which demand considerable time and practice to master. Finally, modern treatment of this material requires that students become familiar with mathematical modeling tools such as Matlab and Simulink. All of this can result in a "packed" course with little time for reflection, discussion, and review. Due to these considerations, the motivation existed to make some changes to the course to allow deeper understanding and more time for discussion and absorption of the material.

Along with the motivation for change, the course was seen to present significant opportunities for students to achieve some broad educational outcomes beyond mastery of the material. The abstract nature of the material lends itself well to written work: challenging the students to express their understanding of the concepts in writing could reveal their mastery of the ideas, and help them develop the ability to demonstrate their understanding in this form. The abundance of applications of frequency-domain techniques, such as filtering and modulation, provides the opportunity for students to explore applications on their own, simultaneously testing their grasp of the fundamentals and providing them with experience in learning independently. Learning computer tools is also well-suited to independent learning, as the ability to learn new computer applications is a fundamental skill needed by engineers and researchers. Additionally, the need to provide accreditation evidence for such educational outcomes as communication skills and the ability to learn independently further motivates the development of assignments that cause students to demonstrate these abilities.

The course design was, therefore, reconsidered with the following objectives in mind:

- To provide "more space" in the course curriculum by reducing the amount of material explicitly discussed in class;
- To challenge students to learn both computer tools and advanced applications independently;
- To challenge students to express their ideas in writing, both for the purposes of demonstrating understanding of the material and for the process of reflecting on it;
- To design assignments which would provide direct evidence of broad educational outcomes such as effective technical communication and the ability to learn independently.

IV. Addressing the Challenges with Project Portfolios, Writing, and Independent Learning

A fundamental tenet of project-based learning is that educational outcomes can be more effectively and efficiently achieved by transferring responsibility to students for their learning. Given this and WPI's project orientation, the inclusion of project work in the course was a natural consideration. A set of three "Discovery Projects" was developed to achieve all of the objectives listed above. The projects were written in tutorial form to step students through the processes of learning and applying new material and tools.

- Discovery Project I focuses on learning about analog filters as an application of frequency-domain analysis of signals and systems. The primary goals of this project were for students to characterize different types of filters; to use Bode plots for filter analysis and specification; to understand the reasons for filtering and to design simple filters to solve specific problems; and to perform basic operations in Simulink and Matlab.
- Discovery Project II focuses on the vector-signal analogy as a framework of understanding for signal decomposition. The primary goals of this project were for students to understand the motivation and use of orthonormal basis sets; to recognize and characterize signal correlation; and to develop further Matlab skills by generating signal decompositions using a orthonormal basis set such as Walsh functions.
- Discovery Project III focuses on amplitude modulation as an application of Fourier analysis. The primary goals of this project were for students to understand the need for modulation, to learn about the time and frequency domain characteristics of amplitude modulated signals, to learn about coherent and noncoherent detection using product and envelope detectors, and to use Simulink to model a complete AM transmission and reception system.

Taken together, these three projects were presented to the students as their "course portfolio" of accomplishment. Although traditional homework assignments and exams were still integral parts of the course, the Discovery Projects were featured elements, worth 30% of the final grade. Each project included a significant writing assignment challenging students to respond, in essay form, to a question which would both test their understanding of the material and would cause them to reflect on what they had learned. The project reports, in which the students answered a series of 10 questions, were graded on format and appearance as well as on technical accuracy and writing quality.

In order to provide students with practice in developing technical and reflective writing skills, written work was also incorporated into each homework assignment. Finally, in order both to assess student achievement in these areas, and to provide accountability and motivation for the students, material from the Discovery Projects was featured significantly in the closed-book, closed-notes exams, as were writing assignments: typically, 40% of each exam consisted of short essay questions in which students were expected to explain their understanding of concepts in their own words.

V. Developing and Assessing Educational Outcomes

After consultation with other faculty who teach the course, and with the department's assessment coordinator, two sets of educational outcomes to be measured for the course were established: one set dealing with technical content to be permanently associated with all offerings of the course, and a second, covering broader program-level educational outcomes, and specific to this offering. These broader educational outcomes are already addressed in WPI student project requirements, so their inclusion was left to the discretion of the course instructor, who can tailor the set of course outcomes based on interest, strengths, and educational philosophy.

The following outcomes were established for all offerings of EE 2311: Students who pass EE 2311 will be able to:

1. Characterize signals and systems using commonly-accepted terminology
2. Relate frequency-domain descriptions of signals and systems to their characteristics in the time domain.
3. Use frequency-domain techniques to solve input/output problems for linear, time-invariant systems.
4. Use computer software tools to model signals and systems and to solve associated problems.

The following additional outcomes were established for this offering of EE 2311: Students who pass EE 2311 will also be able to:

5. Convey effectively ideas and concepts through writing.
6. Apply existing knowledge and utilize educational resources in order to learn new concepts and tools on their own.
7. Reflect constructively on educational experiences, and assess critically the value of those experiences.

Although the primary intent of this experiment was to enhance student learning and skill development, its value in assessment for accreditation was considered also. Outcomes 5, 6, and 7 were chosen for their relevance to ABET EC 2000 and to the educational goals and mission of WPI, and also because they are commonly held to be difficult to achieve and measure in technical programs. We decided to use writing assignments and independent project portfolio work to determine their effectiveness in enhancing and demonstrating student achievement of the broad educational outcomes involving communication, development of lifelong learning skills, and self-awareness. If successful, this model could be used to encourage course instructors to augment the "basic" course outcome list with offering-specific broader outcomes consistent with their own educational methods and course content.

Each of these seven outcomes was mapped to a particular exam, homework, or project component by which its achievement could be directly measured. These specific assignments were graded using standardized rubrics, and the grades for each student were separately recorded in addition to the standard course grade information. In order to allow comparative analysis, student grades for each outcome were mapped into a 5-point scale:

0: Student did not attempt the assignment
1: Student demonstrates serious misconceptions or substantial errors
2: Student demonstrates some understanding but also misconceptions or errors
3: Student demonstrates good understanding and ability, with some minor errors
4: Student demonstrates mastery of the material

VI. Results and Analysis

This course was delivered in the new format for the first time from October to December of 2000. Data was collected with respect to each of the seven course outcomes by separately recording student performance on specific assignments in exams and projects; homework assignments were judged to be ineffective for data collection, since students would frequently elect to submit incomplete assignments.

Of the 155 students registered for the course, 135 took the final exam and so were judged to have "completed" the course. Of these, 125 received passing grades. Table 1 shows the percentage of passing students who performed at level "3" or "4" in each of the seven outcomes. All 125 passing students achieved at least four of the outcomes at level "3" or "4"; 96% achieved at least five outcomes; 88% achieved at least six; and 62% achieved all seven outcomes.

Table 1: Percentage of passing students performing at level "3" or "4" for each course outcome

EDUCATIONAL OUTCOMES RELATED TO COURSE CONTENT	% at "3" or "4"
1. Characterize signals and systems using common terminology	79
2. Relate frequency domain descriptions to time domain characteristics	72
3. Use frequency domain techniques to solve i/o problems for LTI systems	90
4. Use computer software tools to model and solve problems	61
BROADER EDUCATIONAL OUTCOMES	% at "3" or "4"
5. Convey effectively ideas and concepts in words	86
6. Apply knowledge and skills to learn new concepts & tools on their own	94
7. Reflect constructively on educational experiences and assess value	95

It is worth noting that some students who passed the course did not attempt all of the assignments used to measure these outcomes--typically when the assignment was part of a homework or project activity. Given the significant amount of work in the course, this may at times have been a rational resource allocation decision on the part of the students. For example, outcome 4 was measured by student performance on a problem in Discovery Project 3; this problem required the students to design, simulate, and evaluate a coherent AM receiver. Only 75% of the students attempted to do this with any level of seriousness; of these, 84% were able to achieve at level "3" or "4". By comparison, at least 94% of students attempted each of the other six outcomes. An analysis of student achievement with respect to the number of outcomes attempted showed that 77% of passing students achieved a level of "3" or "4" on all outcomes they attempted; 92% failed to achieve no more than one outcome, and 98% failed to achieve no more than two outcomes.

It is interesting to note that outcome 2, which relates to abstract understanding, was not achieved as often as outcome 3, a procedural application of the abstract material in outcome 2. This is not surprising, and indicates the need to emphasize conceptual understanding. It is also worth noting that students performed quite well on Outcomes 5, 6, and 7, which deal with broad educational outcomes not typically associated with engineering courses; this provides encouraging evidence that such outcomes can reasonably be achieved in engineering courses.

These data provide insight into aspects of the course that might warrant redesign or modification, and they also suggest improvements to be made in the assessment process. For example, the relatively low level of achievement on outcome 4 could indicate that not enough instructional emphasis was placed on learning and applying Matlab and Simulink. Interestingly, however, students performed very well overall on outcome 6, which broadly assesses their ability to learn new concepts and tools, but not so on outcome 4, which asks them to apply those very same tools to the new concepts in an integrative fashion. This may indicate limits to students' abilities to achieve higher-level learning outcomes on their own. At the same time, the number of students not attempting that outcome makes clear the need for measurements to focus on assignments that all students are likely to complete.

It is, of course, pertinent to ask how high these levels of achievement should be. One can argue that passing a course should be contingent upon achieving all educational outcomes for the course. Such a grading approach is possible, and has been used for one of the other core courses in the WPI ECE curriculum. However, it required significant restructuring of assignments, grading rubrics, and course logistics so as to allow students opportunities for remediation, and also necessitated more elaborate sets of course outcomes and assessment efforts.

A content analysis of qualitative comments on student course evaluations revealed a high level of student satisfaction with the Discovery Projects, which emphasized these broader outcomes. Some representative student comments follow:

- "The Discovery Projects were among the best assignments I've done."
- "The Discovery Projects were a great challenge, but I felt so good when I could figure them out on my own."
- "I felt like what I was learning was actually useful, and I could see how it could be applied."
- "Overall, the Discovery Projects were the best and hardest part of the course. They added greatly to my understanding of the material."
- "The emphasis on applying knowledge to problems that were unlike examples from class demanded that I truly understand the concepts and not just plug in numbers."
- "It wasn't all math and finding formulas; you had to know the theory on a few levels of abstraction to really know what was going on."

The quantitative student evaluation results were overall highly favorable; as is shown in Table 2, they exceeded the levels of satisfaction the same instructor had received for the same course in the past, despite the fact that the projects added a significant workload to an already challenging course, and also despite a significantly larger number of students in the course. The column labeled "stimulated interest" indicates the percentages of respondents who either agreed or strongly agreed with the statement "The instructor stimulated my interest in the subject material." The next column gives the percentages of students agreeing or strongly agreeing with the statement "The instructor used evaluations which were good measures of the material covered."

The final column is a measure of overall student satisfaction covering 14 different aspects of the course organization, content, delivery, and effectiveness

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Table 2: Comparison of student course evaluation data without and with projects

Offering	Total students	Responses	Stimulated interest	Evaluations good measures of material	Overall satisfaction
1998 (no project)	63	57	93%	91%	99%
2000 (with project)	135	116	97%	98%	100%

VII. Conclusions and Future Work

This paper has described how a student project portfolio and other writing assignments were incorporated into a course to address a number of educational objectives: student learning of more material, inclusion of modern computer tools, and achievement of broad educational outcomes including independent learning, written communication skills, and student reflection on learning outcomes and their value. Outcomes assessment was used to explicitly track the level of achievement of each student with respect to each of seven predefined learning outcomes.

Despite an increase in expectations for the students and inclusion of significant amounts of new material, student satisfaction as measured by course evaluation statistics increased. Interestingly, student achievement of educational outcomes was greatest for some of the broadest educational outcomes, such as effective communication, learning to learn, and critical reflection on learning, suggesting that such outcomes can readily be achieved and measured in engineering coursework. Comprehension of abstract ideas lagged behind students' abilities to procedurally apply the material, suggesting the need for more attention to conceptual understanding. Although student ability to learn about new tools and ideas on their own was high, their ability to apply the new material was lower. This may, however, simply reflect the need for more careful placement of achievement measures. Overall, the educational outcome data provide foci for improving student learning in subsequent offerings of the course, and also provide a rich source of data for assessment and continuous program improvement.

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Nick Arcolano will graduate with a BS in Electrical Engineering and a minor in International Studies in May 2001. He has worked on curriculum development for the past two years, and was the author of the Discovery Projects and assessment plan for the course described in this paper. Nick won WPI's Two Towers Award for the outstanding member of the junior class, is a member of numerous honor societies, and has served as president of his fraternity.