Experiences in the Integration of Digital Signal and Image Processing Research into the Undergraduate Electrical Engineering Curriculum*

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Abstract

Through the integration of research into the undergraduate electrical and computer engineering curriculum, students are invited to think abstractly and to stimulate their innate creativity. This paper discusses some of the successes and challenges involved in introducing undergraduate students to the joys and frustrations of signal and image processing research. Experiences are described from work supported in part by National Science Foundation Faculty Early Career Development (CAREER) grant number MIP-9624849, entitled "A Career Plan for the Integration of Image Processing Education and Research." Research-based projects were included in several required and elective courses taught by the principal investigator, including Computer Aided Measurement and Controls; Communications Engineering; Digital Image Processing; Discrete Real-Time Filtering; Capstone Senior Design; and Independent Study. Some of the projects attempted by the students included a hybrid Discrete Cosine/Wavelet Transform for still image coding; the super-resolution enhancement of image sequence frames and multiple camera images; multispectral image segmentation via vector quantization; the subband decomposition of digital audio; the automated recognition of musical notes captured by a microphone connected to a sound card; the development of a desktop videoconferencing system for distance learning; and the design of a telerobotic rover controlled via the World Wide Web. All design and research-related projects required considerable supervision by the instructor, and obviously some projects were more successful than others. Regardless, the students enjoyed studying problems that were not necessarily well-defined, and in all cases they learned a great deal about the process of research and development. Brief descriptions of the projects are provided, along with comments from student evaluations. The instructor provides a reflection on these experiences, both favorable and unfavorable.

1. Introduction

The National Science Foundation (NSF) has been active in motivating successful researchers to return to the classroom so that they may share their experiences with undergraduates. The Presidential Young Investigator (PYI) Program, which awarded grants based solely on research prowess, has recently evolved into the Faculty Early Career Development (CAREER) Program, which supports junior-level faculty members seeking to integrate their education and research activities at the undergraduate and graduate levels. Proposing original ideas in education and research integration is relatively simple; actually implementing these concepts in the classroom can be extremely challenging and highly time consuming, while at the same time professionally and personally rewarding. This paper discusses experiences, both favorable and unfavorable, in the integration of education and research activities at the

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undergraduate level. Since the author's area of expertise lies primarily in the realm of digital signal and image processing, the injection of research opportunities into the curriculum was limited to regular teaching assignments and more informal student advisement related to these topics. Several advantages and disadvantages of this teaching mode are provided, in which student evaluation comments are used to assess the utility of education/research integration.

This paper is organized as follows. Section 2 describes background information regarding education/research integration, including project categories and research productivity ratings as defined by the author. A number of research and design-oriented projects are listed in Section 3, representing undergraduate research projects supervised at least in part by the author. Student evaluations and instructor reflections on this mode of teaching are provided in Section 4, while a brief conclusion and the author's own evolution of signal and image processing education/research integration are presented in Section 5.

2. Integration of Education and Research

There are many required and elective courses in which education and undergraduate research can be effectively integrated. Generally, these courses should have some flexibility in their syllabi, such that design and research projects may be substituted for a final exam. It may be inappropriate to incorporate research activities into a first or second course on linear circuit theory, for example, simply because the material is new to the students, and the problem-solving skills acquired by studying classical textbook problems are critical for success in upper-division courses within the electrical and computer engineering curriculum. Traditional design-oriented classes are highly conducive to the integration of education and research. The author has incorporated signal and image processing research activities into the following four regular teaching assignments at the University of North Dakota:

- EE 304–Computer Aided Measurement and Controls
- EE 411–Communications Engineering
- EE 456–Digital Image Processing
- EE 521–Discrete Real-Time Filtering

Each of these courses is directly related to signals and systems, the author's general area of expertise, so that he felt confident in his ability to advise undergraduate research projects in these topics.

In addition to regular teaching assignments, there are many informal teaching opportunities that arise in which undergraduate research opportunities can be injected into the curriculum. Most notably, capstone design courses can easily be utilized for research-related projects, provided that the instructor is willing to devote a significant amount of time to advising the student team members. At the University of North Dakota, the author has supervised several research projects in EE 480/481–Capstone Senior Design, as well as EE 490–Independent Study. Obviously, the time commitment will be high for both the instructor and the students when they are working on projects with loosely-defined specifications; unfortunately, this is typically the case for research problems. The National Science Foundation highly encourages undergraduate research during the summer months by supporting students through the Research Experience for Undergraduates (REU) program. Successful research projects have been initiated by the author through the REU program, and this has provided several young researchers with wonderful opportunities for exposure to the entire research experience – conducting experiments, documenting research findings, presenting the results at conferences, and networking.

A definite disadvantage of introducing research activities to all students is that some individuals are naturally more interested in a particular subject matter than others. Research requires a huge commitment from the students and the instructor, and success often results due to the passion for a particular subject rather than innate intelligence. An instructor must carefully choose research projects tailored to the students' interests and abilities. Granted, not all research projects are successful; in fact, most initial attempts at solving a difficult problem are not fruitful. However, by selecting projects which are (1) interesting and exciting to a group of students, and (2) challenging but not beyond their capabilities allows the students to feel that they learned a great deal, whether or not their hypotheses were proven correct. For this reason, the author provides a list of research and design-oriented projects to the students, rather than allowing the students to work on projects of their own choosing. These lists generally contain relatively simple problems for course final projects, and much more challenging problems for capstone design, independent study, and graduate-level research. As expected, talented students are encouraged to attack the more difficult (and often more interesting) problems, and less interested students are given projects which will help improve their understanding of the essential course material. The next section describes a number of projects, possessing varying degrees of difficulty as well as varying levels of success, conducted by students under the author's supervision.

3. Research and Design-Oriented Project Descriptions

This section provides descriptions of design and research-related projects conducted primarily by undergraduate students, along with several graduate students enrolled in the courses. Due to paper length constraints, the abstracts have not been included in the conference proceedings; interested educators may study a complete electronic version of the article at the Web site `http://nyquist.ee.und.nodak.edu/~rschultz/papers/Asee99-2632-Schultz.pdf`. The abstracts were written for the project reports by the students, with limited editing required by the instructor. Undergraduates' names are underlined in the abstract heading, while graduate students' names are not underlined. In all cases, the project supervisors' names appear in parentheses. Each project abstract has been placed under the course heading for which it was assigned, and the projects are categorized as (1) research, (2) design, or (3) research and design-oriented. A research project is defined as a project that attempts to solve an open problem; in other words, researchers throughout the world have attacked that particular problem in the past, and no definitive solution exists. A design-oriented project is considered to be more well-defined than a research project, in that a set of procedures may be followed to arrive at an acceptable solution, but there are several possible avenues that may be pursued. A project that is both research- and design-oriented involves a problem that is highly open-ended, but once an acceptable solution has been found, software and hardware development may be required to implement the results.

Research productivity ratings have been assigned to the projects, corresponding to the subjective quality of the results. These ratings, in decreasing order of research productivity, include (1) publishable, (2) highly successful, (3) successful, (4) moderately successful, and (5) unsuccessful. Design projects are typically rated lower than research projects, since results that are not novel are usually not considered to be of publishable quality. A low rating does not imply that the project was not a useful learning experience – it simply means that the project did not generate research results that may be considered for future publication in a conference proceedings or archival journal. Research failures provide a great deal of insight into the solution of difficult problems encountered in the past and challenging problems that will be encountered in the future, and therefore every attempt at solving a particular problem only enhances the researcher's intuition.

3.1. Projects in EE 304–Computer Aided Measurement and Controls

Computer Aided Measurement and Controls is a required sophomore-level course in C/C++ text-based programming, practical digital signal processing concepts, the development of instrumentation systems, and National Instruments LabVIEW graphical programming. Since this is a course intended for an inexperienced audience, the research-related laboratory assignments are rather well-defined. The intent of these projects is to provide an early introduction to research and design-oriented problems that have many possible solutions. These projects were given as regular laboratory assignments during the fall 1996 and fall 1997 semesters.

INTRODUCTION TO DIGITAL SIGNAL PROCESSING
Semesters: Fall 1996 and Fall 1997
Project Category: Research and Design
Rating: Not Applicable

INTRODUCTION TO DIGITAL IMAGE PROCESSING
Semesters: Fall 1996 and Fall 1997
Project Category: Research and Design
Rating: Not Applicable

IMPLEMENTATION OF A DIGITAL FILTER USING MICROSOFT VISUAL C++ AND NATIONAL INSTRUMENTS LABVIEW
Semesters: Fall 1996 and Fall 1997
Project Category: Research and Design
Rating: Not Applicable

3.2. Projects in EE 411–Communications Engineering

Communications Engineering is a course in classical communications theory – signals, linear systems, modulation, and noise – offered as an electrical engineering elective course to juniors, seniors and graduate students. Projects are assigned on modern communication topics that cannot be covered in-depth during the lectures. The following final projects were implemented during the spring 1996 and fall 1997 semesters.

EXAMINATION OF THE LOSSLESS COMPRESSION OF MEDICAL IMAGES
<u>Chaun Cox</u> (Richard R. Schultz)
Semester: Spring 1996
Project Category: Research
Rating: Moderately Successful

WAVELETS AND THE WORLD
<u>Joel Haugen</u> (Richard R. Schultz)
Semester: Spring 1996
Project Category: Research
Rating: Moderately Successful

AMPLITUDE AND PHASE MODULATION USING THE MOTOROLA MC68HC11
<u>Allison Sawrey and Anna Muller</u> (Richard R. Schultz)
Semester: Fall 1997
Project Category: Design
Rating: Successful

MPEG AUDIO COMPRESSION
Jason Block and Brian Pedersen (Richard R. Schultz)
Semester: Fall 1997
Project Category: Design
Rating: Successful

QUANTIZATION AS A COMPRESSION METHOD
Michael J. Carman (Richard R. Schultz)
Semester: Fall 1997
Project Category: Research
Rating: Publishable

3.3. Projects in EE 456–Digital Image Processing

Digital Image Processing is an electrical engineering elective offered to juniors, seniors, and graduate students, covering the fundamentals of image acquisition, multidimensional signal processing via student-developed software, and data export. Several upper-division computer science majors were enrolled in the course; despite having little background in systems theory, they tended to excel due to their programming proficiency. The following final projects were assigned to students during the fall 1996 and spring 1998 semesters.

CALIBRATION AND INTEGRATION OF LOW-QUALITY DIGITAL IMAGES USING MULTIPLE CAMERAS
David A. Anderson, Allan Narveson, and Chad Raap (Richard R. Schultz)
Semester: Fall 1996
Project Category: Research
Rating: Moderately Successful

HYBRID DISCRETE COSINE/WAVELET TRANSFORM
Mike Pelarski, Peter Boes, Mark Sayler, and Chris Karalus (Richard R. Schultz)
Semester: Fall 1996
Project Category: Research
Rating: Moderately Successful

IMAGE SEGMENTATION VIA MORPHOLOGICAL FILTERING
Michael J. Carman and Cale J. Coughlan (Richard R. Schultz)
Semester: Fall 1996
Project Category: Research
Rating: Publishable
[Author's Note: A paper based on this work appeared in the Midcontinent Institute's Third Annual Undergraduate Research Conference and Competition Proceedings, *(Minot, ND), February 28 through March 1, 1997.]*

SURVEILLANCE VIDEO SEQUENCE ANALYSIS THROUGH MULTIFRAME RESOLUTION ENHANCEMENT
Li Meng, Debin Chen, Kevin Rada, Kirk Eisenbeis, and Don Wiebelt (Richard R. Schultz)
Semester: Fall 1996
Project Category: Research
Rating: Publishable

DEVELOPMENT OF THE IMAGEPRO SOFTWARE APPLICATION FOR HUTCHINSON TECHNOLOGY, INC.
Mary Nass, Katherine Reuss, Brian Rootes, and Xinxiang Zhou (Richard R. Schultz)
Semester: Spring 1998
Project Category: Design
Rating: Highly Successful
[Author's Note: The four undergraduates are employees of Hutchinson Technology, Inc., enrolled in EE 456–Digital Image Processing during the spring 1998 semester as distance education students through the University of North Dakota's Corporate Engineering Degree Program.]

MICROSOFT NETMEETING AND CONNECTIX QUICKCAM VC
John Sievila (Richard R. Schultz)
Semester: Spring 1998
Project Category: Design
Rating: Successful
[Author's Note: The undergraduate was enrolled in EE 456–Digital Image Processing during the spring 1998 semester as a distance education student through the University of North Dakota's Corporate Engineering Degree Program.]

MPEG VIDEO COMPRESSION
Jeff Barsness and Nathan Eckel (Richard R. Schultz)
Semester: Spring 1998
Project Category: Design
Rating: Successful

3.4. Projects in EE 480/481–Capstone Senior Design

Capstone Senior Design is a two-semester sequence that requires electrical engineering seniors to work on project teams under the supervision of a faculty member. Projects may be selected by either the students or the faculty, but the author prefers to select a research-oriented project for the students that he feels comfortable supervising. Although this limits the variety of available projects, it also improves the chances that the students will be successful in their goals for the year.

DESIGN OF THE TELE-ROBOTIC ADVENTURES WEB-CONTROLLED ROVER FOR THE DAKOTA SCIENCE CENTER'S VIRTUAL MUSEUM
Melissa L. Kurtz, Allison D. Sawrey, and Brian D. Pedersen
(Steve Lindaas, Richard R. Schultz, George Bibel, Arnold F. Johnson, and Charles A. Wood)
Semesters: Spring 1998 and Fall 1998
Project Category: Research and Design
Rating: Publishable
[Author's Note: This work was presented at the 1999 National Conference on Undergraduate Research, (Rochester, NY), April 8-10, 1999.]

MULTISPECTRAL SEGMENTATION OF THE VISIBLE HUMAN PROJECT DATA SET VIA VECTOR QUANTIZATION
Michael J. Carman, Aaron Douglas, and Dawn Willett (Richard R. Schultz)
Semesters: Fall 1997 and Spring 1998
Project Category: Research
Rating: Publishable
[Author's Note: This work began as a final project in EE 456–Digital Image Processing, and evolved into an EE 480/481–Capstone Senior Design project. A conference article based on this work has appeared in the Proceedings of the 1998 National Conference on Undergraduate Research*, (Salisbury, MD), April 23-25, 1998. In addition, this project received the Second Place Award at the 1998 IEEE Red River Valley Section Paper Contest, (Fargo, ND), on April 24, 1998.]*

SEMI-AUTOMATED LESION DETECTION IN DIGITAL MAMMOGRAMS
Jeremy J. Brewer and Elaina M. Mahrer (Richard R. Schultz)
Semesters: Summer 1998 and Fall 1998
Project Category: Research
Rating: Moderately Successful

SUBBAND DECOMPOSITION AND VISUALIZATION OF DIGITAL MUSIC SIGNALS
Bradley R. Bender and Joe Wheeldon (Richard R. Schultz)
Semesters: Fall 1997 and Spring 1998
Project Category: Research and Design
Rating: Moderately Successful

TELERADIOLOGY: AN APPLICATION FOR RURAL MEDICINE COMMUNICATIONS
Van L. Snyder and Paul J. Pladsen (Richard R. Schultz)
Semesters: Fall 1996 and Spring 1997
Project Category: Research and Design
Rating: Moderately Successful
[Author's Note: A paper based on this work was published in the Midcontinent Institute's Third Annual Undergraduate Research Conference and Competition Proceedings, *(Minot, ND), February 28 through March 1, 1997.]*

TELETEACHING: A VIDEOCONFERENCING SYSTEM FOR DISTANCE EDUCATION
Chad Raap, Doug Rothenberger, and Jason Weishaar (Richard R. Schultz)
Semesters: Fall 1996 and Spring 1997
Project Category: Research and Design
Rating: Publishable
[Author's Note: A paper based on this work was published in the Midcontinent Institute's Third Annual Undergraduate Research Conference and Competition Proceedings, *(Minot, ND), February 28 through March 1, 1997.]*

3.5. Projects in EE 490–Independent Study

This is a variable-credit course offered to interested juniors and seniors in electrical engineering. The abstract titles and ratings are provided below.

3D IMAGING OF THE VISIBLE HUMAN DATA SET
Brian Hawley (Richard R. Schultz)
Semester: Spring 1998
Project Category: Research and Design
Rating: Moderately Successful

DIGITALLY ENHANCED HEARING AID APPLICATIONS
Jeremy J. Brewer and Elaina M. Mahrer (Richard R. Schultz)
Semester: Summer 1998
Project Category: Research and Design
Rating: Highly Successful

GENERATION OF A COMPUTER GRAPHICS INTRODUCTORY SEQUENCE FOR THE UND SCHOOL OF ENGINEERING AND MINES PROMOTIONAL VIDEO USING 3D STUDIO MAX
Michael J. Carman (Richard R. Schultz)
Semester: Spring 1998
Project Category: Design
Rating: Highly Successful

3.6. Projects in EE 521–Discrete Real-Time Filtering

Discrete Real-Time Filtering is an electrical engineering elective offered primarily to seniors and graduate students. Theoretical and practical concepts in digital signal processing and discrete filter design in the z-transform frequency domain are covered in this course. The discrete filters are designed using MATLAB, and then implemented as real-time applications using the Texas Instruments TMS320C31 Digital Start Kit (DSK). The final projects were implemented during the spring 1998 semester; note that Master's-level students completed several of the course projects.

CREATING REVERBERATION EFFECTS WITH THE TEXAS INSTRUMENTS TMS320C31 DIGITAL STARTER KIT
Michael Enstad (Richard R. Schultz)
Semester: Spring 1998
Project Category: Design
Rating: Highly Successful

STOCK MARKET EXTRAPOLATION UTILIZING SINGULAR VALUE DECOMPOSITION TECHNIQUES
Kyle J. Erickson (Richard R. Schultz)
Semester: Spring 1998
Project Category: Research
Rating: Unsuccessful

SUBBAND CODING OF AUDIO SIGNALS
Ames Grisanti (Richard R. Schultz)
Semester: Spring 1998
Project Category: Research and Design
Rating: Highly Successful

3.7. Projects Support by the National Science Foundation Research Experience for Undergraduates Program

Several students have conducted research during the summer months through support from the National Science Foundation REU Program. This is a very effective method of providing undergraduates with an extensive, well-rounded research experience. For highest research productivity, it is best if the project goals are defined before the students begin conducting their research, since 8-10 weeks in the summer is the maximum amount of time available for research and documentation purposes.

IMPLEMENTATION OF A WORLD WIDE WEB-BASED CONTROLLER FOR THE UNIVERSITY OF NORTH DAKOTA SPACE STUDIES TELESCOPE
Chris J. Schmidt and Joseph R. Rydel (Richard R. Schultz and Charles A. Wood)
Semester: Summer 1998
Project Category: Research and Design
Rating: Successful

NONLINEAR FILTERING AND ENHANCEMENT OF DIGITAL ULTRASOUND IMAGERY
Melissa L. Kurtz (Richard R. Schultz)
Semester: Summer 1996
Project Category: Research
Rating: Publishable
[Author's Note: A paper based on this work appearing in the Proceedings of the 1997 National Conference on Undergraduate Research*, (Austin, TX), April 24-26, 1997.]*

SUBZEROCAM: DESIGN OF A WORLD WIDE WEB-BASED DIGITAL CAMERA FOR SUNRAYCE '97
James A. Johnson (Richard R. Schultz)
Semester: Summer 1996
Project Category: Research and Design
Rating: Publishable
[Author's Note: A paper based on this work appeared in the Proceedings of the 1997 National Conference on Undergraduate Research, *(Austin, TX), April 24-26, 1997.]*

SEMI-AUTOMATED LESION DETECTION IN DIGITAL MAMMOGRAMS
Brian G. Giesinger and Elaina M. Mahrer (Richard R. Schultz)
Semester: Summer 1998
Project Category: Research
Rating: Moderately Successful

4. Assessment of the Educational Added Value

Although the instructor was generally satisfied with the quality of the research and design-oriented projects, the students in each of the courses found that the workload was substantial. Comments pertaining to the research-oriented laboratories and projects from the relevant courses were extracted from the student evaluation forms. A sample of these edited comments is provided below:

- "The labs made us think and apply things to real applications." – EE 304, Fall 1996
- "The lab assignments were good for learning the programming language. We experienced electrical engineering work integrated with computers." – EE 304, Fall 1996
- "The labs were very interesting and beneficial in getting a grasp on C programming." – EE 304, Fall 1996
- "Not enough time was given for labs during/near holidays." – EE 304, Fall 1997
- "Reduce the number of lab assignments. We are swamped with work. We do have other engineering classes that require our time also." – EE 304, Fall 1997
- "By doing the projects, we were forced to learn the material." – EE 304, Fall 1997
- "The projects include new and hot topics in modern communication areas. It made us explore communications more deeply, not only restricted to the text book." – EE 411, Spring 1996
- "Project should have been started earlier." – EE 411, Spring 1996
- "I would like to see more current topics in communication covered either by the student or the instructor. I think that the final design project should be better or more clearly defined." – EE 411, Spring 1996
- "More time is needed for projects and [the] second half of class. I felt like we flew through modulation. More time spent on it would have been helpful." – EE 411, Fall 1997
- "ASSIGN PROJECTS SOONER!! Otherwise, the class was great. How about Digital Image Processing II?" – EE 456, Fall 1996
- "I feel too much weight is being put on the final project – the bulk of our work has been with the individual labs #1 through 5. For the final project to have so much weight, it seems we should have spent more time on it." – EE 456, Fall 1996

- “I really learned a lot in this class but there are some things I’m not as happy with…The part I’m unhappy with is the project and the time given to work on it. We are expected to go full boar for one week the second to last week of school on something we know very little about and be able to do presentations and formal papers on it. During that week a lab was due and another test is given, on top of all the other projects, papers, and tests that generally come due towards the end of a semester. I think next time it should be a little more organized [and] thought out.” – EE 456, Fall 1996
- “It is not practical to have a final project of the caliber Dr. Schultz expects and only allow two weeks to complete it…I feel that Dr. Schultz like most instructors doesn’t realize this is not the only class we are taking. With 15 other upper level credits, it is hard to find the time he expects for labs, exams and projects and still do well [in] other courses.” – EE 456, Fall 1996
- “The course was an excellent learning experience, however a lot of material was crammed into only one semester. The course project is a good idea, but there is very little time at the end of a semester to explore the material to any great depth. Perhaps a project that builds throughout the semester would meet the same goals.” – EE 456, Fall 1996

Although the students tend to feel that they had learned a great deal through this teaching mode, even for unsuccessful projects, they were virtually unanimous in their rebellion with respect to workload. However, the overall student evaluations for the relevant courses were certainly more encouraging than the sampled comments. A single quantitative assessment score has been compiled for each course in which education and research were integrated, with the results shown in Table 1. Course evaluations at the University of North Dakota are calculated on a scale from 1 to 5, with 1 representing the highest rating and 5 representing the lowest. The quantitative assessment score shown for each semester was computed by averaging the students’ responses to all questions on the course evaluation form. All evaluation scores were well above average, in which a value of 3.00 represents an average evaluation score. Judging by the student evaluations of the courses in which research and design-oriented final projects were required, the integration of education and research was (seemingly) readily accepted by the students as an effective learning tool. Personal conversations with the students confirmed that they enjoyed the projects, but that they were pressed for time at the end of the semester when the projects were due and oral presentations took place.

Table 1: Integrated Education and Research
Regular Teaching Assignment Student Evaluations

Semester	Assessment Score	Number of Students
EE 304–Computer Aided Measurement and Controls		
Fall 1996	1.66	25
Fall 1997	1.52	35
EE 411–Communications Engineering		
Spring 1996	1.58	6
Fall 1997	1.46	12
EE 456–Digital Image Processing		
Fall 1996	1.65	19
Spring 1998	1.55	8
EE 521–Discrete Real-Time Filtering		
Spring 1998	1.65	9

As far as the perceptions of the instructor are concerned, the integration of signal and image processing education and research was a *qualified* success; *i.e.*, the experiences were highly satisfying, but at a significant cost to the students outside of the specific class in which the research was conducted. Some advantages and disadvantages associated with education/research integration discovered by the author simply through experience are listed below:

Advantages:

- Due to the enormous amount of student contact time required to conduct research and implement advanced design projects with undergraduates, the instructor truly gets to know her or his students, and the students definitely appreciate this personal style of teaching.
- The projects provide hands-on experience, which is simply not attainable through writing a term paper or taking a final exam on the course material. This has long-term benefits to the students with respect to improving critical thinking abilities, unleashing their innate creativity, and appreciating the need for life-long learning.
- Instructors who try to strike a balance between education and research will find that this teaching style is very satisfying, and although not all projects will be successful, some students wish to continue the research after the course. In this manner, education and research integration serves as a recruiting tool, enticing students to work on capstone design projects, independent studies, summer research, and even graduate-level research with the professor. The author has experienced all of these types of project continuations as a direct result of incorporating research into the classroom. As evidenced by the project abstracts available in the previous section, research-oriented publications can result from course projects, as the open-ended problems become more well-defined and additional experiments are carried out.

Disadvantages:

- Every professor has an expertise in a specific area, along with associated prejudices towards particular avenues of research. For example, the author's primary research interest is in the area of super-resolution image sequence enhancement, an extremely narrow subdiscipline within image processing, which is, in and of itself, a narrow subdiscipline within electrical and computer engineering. In addition, the author does not highly regard the research conducted on neural networks, another popular subdiscipline within digital signal processing. For these reasons, the students are often given an incomplete listing of research topics from which to choose, and prejudices held by the instructor are inevitably propagated to the students. Thus, the students are presented with an incomplete view of the research field.
- An instructor's expertise in one area may result in the students conducting a highly successful research project in the associated course. In contrast, an instructor's inadequacies in the background of another field may result in the inability to supervise successful research projects. In the author's opinion, digital image processing projects were for the most part successful due to the instructor's experience in that area, while communications-oriented projects were much less research-oriented due to the instructor having deficiencies in understanding the state-of-the-art.
- Research requires immersion in the background literature to advance the frontiers of knowledge. The author found that it was virtually impossible to make students read relevant conference articles, journal publications, or even modern textbooks. Students tend to migrate towards the World Wide Web to retrieve information and to stimulate creativity, but they do not comprehend that the World Wide Web is not subject to the rigors of peer review. This was a definite problem, as it shifted the workload of acquiring reliable background information from the students to the professor.

- Engineering students generally have high workloads in all of their courses, and asking them to spend a large percentage of their time on one project in a single course may be unfair. Since research is essentially nonlinear with respect to results produced versus time invested, an instructor cannot expect the students to complete a challenging project in one week, one month, or even one semester. Open-ended projects provide students with wonderful opportunities to think and express their creativity; however, undergraduates do not necessarily have the same amount of time as graduate students and professors to circumvent "research roadblocks".
- By far the most disconcerting problem with integrating education and research in the manner portrayed within this article is the assignment of equitable grades to projects of varying degrees of complexity, as well as varying levels of success. Given that not all research avenues prove fruitful, students take a risk when they select a challenging project, while another group may choose a relatively simple research-oriented project that can be implemented quite easily. The grades that are submitted can only be based on the amount of effort that the students have invested in a project, rather than on its success. Grading a wide variety of research projects results in many difficult decisions, since most students expect high grades for success and low grades for failure. The assignment of fair grades to a wide variety of design and research-oriented projects is, seemingly, an impossible task.

In the author's opinion, the intuition and creativity that is stimulated in the students through this teaching mode outweighs the considerable number of disadvantages. However, the time commitment required by both the instructor and the students must not be taken lightly.

5. Conclusions and the Evolution of Education/Research Integration

The integration of education and research into the electrical engineering undergraduate curriculum has been presented as a professionally satisfying, albeit time consuming, task. Design-oriented required and elective courses, capstone design, independent studies, and summer research programs have all been used as vehicles for education/research integration by the author. Of course, not every student becomes excited about the prospect of pushing the technological envelope, so great care must be taken in assigning a project that is interesting to a particular group of students, in which they can make quantifiable progress towards a solution. A number of research and design-oriented projects have been described in this paper, with varying degrees of difficulty and varying levels of success. It is important to impress upon the students that although the desired results are often not achieved for a research project, the knowledge and insight gained by attacking a challenging problem will be useful in future endeavors.

Although much of the formal and informal student feedback regarding signal processing education/research integration was positive, the author has resorted to assigning the students smaller, more well-defined research projects over the duration of a semester. Students still obtain the benefits associated with working on open-ended projects, but by assigning a handful of projects to an entire class, the students can assist each other in solving the inevitable problems that arise. Moreover, grading of the projects becomes more equitable and meaningful, a significant advantage from the instructor's perspective. Integrating teaching and research is personally very satisfying, but it is also extremely time consuming and professionally draining. The workload for both student and instructor is enormous. In retrospect, providing research opportunities to undergraduates has been a valuable experience for the students as well as the professor. As this is essentially uncharted territory, we can only learn how to deliver research experiences to undergraduates through experimentation, while at the same time not compromising their overall education.

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