Engineering Education in an Integrated Setting

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Abstract—This paper serves to give brief overviews of key issues in five case studies in engineering technology stand-alone project based courses within a standard scholastic framework. The courses were offered in a range of scenarios with significant international student participation. The subject material focused on optics, opto-electronics and electronics. Topics covered in this work include: issues with managing scope, issues with adapting to open ended problem solving, and, confusion between method based teaching and guided projects. The main purpose of this paper is to share findings on preparing and delivering project based courses that are developed within a pre-existing system of courses and with a pre-existing limit of facilities.

Keywords—project based courses, stand-alone projects, open-ended problems, case studies, curriculum design, student perceptions, optics, electrical engineering

1 Introduction

We live in a world where the pace of change in engineering is constantly accelerating. As challenging as Engineering Technology Education has been in the past, that challenge is growing. As the time for engineering change becomes shorter than the average cycle time for a post-secondary engineering program, acquiring knowledge and vocational skills through the traditional lecture/lab delivery modality places graduates at risk of being obsolete before they even cross the stage at convocation [1-3].

This suggests a need to shift the emphasis of program outcomes to focus on skills that do not expire, remaining viable in the job market. Such skills would include teamwork development, project management, and self-directed and guided learning. Future graduates must develop skills which allow them to become flexible and adept lifelong learners of engineering technology. This paper covers five case studies of project-based engineering technology courses. These courses were all developed within programs that followed a standard engineering education model (discrete lec-

ture-based and lab-based courses) and as such include possible techniques for the delivery of stand-alone courses within a standard framework. The courses tended to follow the CDIO (Conceive-Design-Implement-Operate) [4] approach to learning and course delivery, using a 'less is more' methodology which builds understanding of core concepts, rather than providing overwhelming exposure to a range of concepts that students may not master or retain after graduating.

A significant issue arising in practical educational environments occurs when students lack sufficient understanding of fundamental concepts in mathematics, physics and engineering. The reality is that these project courses have been required to adjust for this issue by a combination of allowing time for students to understand the concepts and to lay out alternate routes for finishing the course with a less than ideal review of some of the fundamental concepts. The instructor has the role of guide and does not provide all the answers but assists the students in finding the answers to fact-based and procedural questions [3-12]. The courses discussed below follow the basic model of problem based learning in the context of an integrated setting of mixed project based experiential learning courses and standard delivery courses (such as lecture based).

2 Case Studies

2.1 Case A. Memorial University Graduate Course.

Background: A Graduate Course in Digital Logic and State Machines in the Department of Electrical and Computer Engineering at Memorial University in St John's Newfoundland, Canada was developed and delivered. The course was provided for students who may not have the full background in electrical engineering required for advancement in the Master's Program of Electrical Engineering. This course tended to be exclusive to international students. Previous years in the program had shown that some students experience difficulties in the Master's program and had a higher failure rate as a result of insufficient background and/or a lack of comfort in some of the required undergraduate course material. The course in question comprised material from third and fourth year Electrical Engineering courses in digital electronics, state machines, processors and firmware. The students also had the option of taking three complete undergraduate courses. Often this full review would prove to be tedious and redundant for the students. Once offered, the students tended to choose the single accelerated/combined course. The course in question was then developed to review key concepts with participatory discussions of these points and was combined with student projects (processor design, implementation and testing). The case study under discussion involved the module concerning digital logic, state machines and processors.

Methodology: The course was delivered in two main manners. First, participation in class was required of all students. Attendance was taken and required. This was a condition of the fast track option of a shortened single course comprising three standard undergraduate courses. Lectures were undertaken as classroom discussion of top-

ics where students were directed to provide information and complete analyses in stages and in groups. Discussions would revolve around specific problems that the students were given prior to class with the option of reviewing the material in self-study. A key part of these discussions was creating a non-judgmental, relaxed environment that encouraged participation, and noting that the class time was more interesting with significant student involvement. Students were also required to present a solution to a small problem or the method to arrive at a solution. Secondly, each student was required to complete a culminating project, designing, implementing and testing a soft core processor in VHDL or Verilog. The Altera development environment was used with simulation in ModelSim-Altera.

The students were also encouraged to create a rolling set of course notes. This method was supported by the condition that this was the only material that they were allowed to use for the final exam [11].

Outcomes: The students demonstrated clear ability to analyze digital logic during classroom discussions. Despite the challenges presented by English as a second language, students adapted readily to ongoing participation in the discussion groups. As mentioned, this is believed to be a direct result of the intentional creation of a relaxed atmosphere, where all participation is encouraged and valued. More study is required to confirm this. The participation can take several lectures to build up but often results in high levels of participation within the class.

Although each student worked on a soft core processor there are many possible solutions [10].

Issues: The students had difficulties defining the project scope. Projects tended to exceed the written requirements in some areas, causing students to spend more time than required on that aspect while not meeting all of the primary goals. This was conveyed to the students on evaluations of the projects. As scope understanding was determined to be one of the primary deliverables of the course, students were directed to produce evaluations of their own work (after discussions with the course director) and note changes that would occur in the future. This acknowledges that feedback is not useful until it is understood and applied to future work [6].

Student Evaluations of Course:

Primary student comments on the course:

1. The inclusion of problems that the class would work through as a group to illustrate complex problems was valued and supported student absorption of the material.
2. The creation of a soft core processor proved to be challenging and time consuming to many students.
3. Students continued to have issues with scope, complaining that the scope of the projects exceeded the time allocated for the course based on course loads.

2.2 Case B. Hoseo University Senior Year Engineering Design

Background: Two engineering design courses were delivered in English as part of a streaming to advance students into capstone projects in an international competition

setting. Students were all Korean language speakers, in third and fourth year engineering at Hoseo University. The course was directed towards engineering students (Electrical Engineering and sub disciplines such as Display Engineering) and was supported through the Hoseo University School of Venture Business.

Methodology: The courses were both delivered in an interactive setting. Each two hour segment followed the steps: 1. Explanatory lecture of theory with implementation examples. 2. Student implementation of the design or design module. 3. Student testing of the module or full design. Students were actively supervised during implementation and testing with the instructor providing intensive support through secondary examples and question answering. Peer to peer assistance was encouraged.

Both courses had primary technical objectives. The first course involved the design of a hybrid (digital-analog) implementation of a pulsing neuron cell for use as an optical pre-processor. The device processed electrical current from an optical detector and converted this into pulse code modulation. The devices also processed signals through a simple neural network composed of multiple cells. Learning occurred through a complementary digital circuit. The design was primarily implemented and tested in the PSpice circuit simulator environment.

The second course focused on the development of a standard digital image processing and display driver design implemented in the Altera (Quartus) development environment and simulated in ModelSim-Altera.

The courses were delivered in staged combined labs/lectures. The entire course objectives were explained at the beginning and through the course. The delivery was then broken down into manageable stages that were built on in succession. This effectively takes extremely complex and often overwhelming projects and reduces them to manageable components. The ease of each segment is designed to maintain a constant level of ease (or difficulty) but this can shift as some tasks are more involved than others and as each student's abilities comply with some tasks better than others. Often tasks will reappear in succeeding modules but with changing context and increased complexity. This approach has been shown to correlate well with successful solving of real world problems [7]. Each student worked on their own designs but were allowed and encouraged to give and receive peer to peer assistance. Each stage was submitted for evaluation.

Outcomes: Students were universally able to complete assignments. Students who completed rapidly were able to develop mentoring skills. Students demonstrated expertise in real time, and generally were able to complete assignments during class time. Although the software was available for download by the students, the course was structured so that most of the work could be completed during regularly scheduled class hours. This emphasized focus on the material for the given time and encouraged their own work.

Issues: Due to the difficulty of the material and the required depth of background knowledge, significant time was required for the tasks. The 'no person left behind' approach means that slowest student defines the pace. Using this method makes it difficult to create a pure assessment distribution that factors in time constraints. At times, some students would lack focus on the material, making it difficult to keep the entire class in sync.

Student Evaluations of Course:

1. The students were generally positive about the outcomes, in that nearly 100% completed the tasks and were able to reduce a complex problem into manageable parts.
2. The quicker students had some frustration in the pacing. They tended to provide assistance to others but also wanted to work ahead which would throw off the class synchronization.

2.3 Case C. Niagara College, Ontario, Canada. Bachelor of Technology, Photonics.

Background: An advanced physics course in physical optics was delivered. The course was delivered in the fourth year of a four year program in Niagara College's Degree level Optics Program, the Bachelor of Technology Photonics, BATP. Prior to the course being developed and delivered, standard examples of physical optics courses were referenced, which tended to deliver material in a standard lecture form. A primary constraint was the lack of student facilities, as the optics equipment is expensive and specialized. The optical labs at Niagara College are superior with complete optical kits, breadboards, and a selection of lasers. This allowed the course to be switched into a nearly pure applied delivery mode using a lab project based approach. The course material was physical optics but it was determined that the material needed to be limited ('less is more' approach in which several key concepts would be covered in depth) due to time constraints, the point being that it was determined that an applied delivery mode using projects would be more time consuming than a lecture based approach. The trade-off was that student comprehension and retention of key concepts would increase in the applied project based delivery mode scenario.

Methodology: The approach was to provide five to ten hours of specific lectures and approximately sixty hours of project based laboratory time. The bulk of the course was delivered through student development and demonstration of labs. In groups of 2-3, students chose amongst a short list of physical optics topics. They then developed an experiment to demonstrate core principles. The students were then required to train the rest of the class in their particular experiment who in turn complete an experiment using the equipment.

Each topic was delivered as: 1. Introductory lecture on the key concepts of the material with heavy use of diagrams. 2. The development of the experiment. 3. Review of the key concepts found in the experiment. The students were expected to design the experiment but were provided with ongoing support. The course also incorporated a final exam that was implemented as a discussion of the core concepts and explaining some fundamental concepts.

The core topics covered were: 1. Holography, demonstrating complex diffraction, interference, spatial and temporal coherence. 2. Interference with an emphasis on applications such as geometric lens analysis. 3. Spatial frequency analysis with an emphasis on image analysis. 4. Spectral analysis with a breadboard spectral analyzer.

The course used Blackboard as a repository of the student-developed material. The students were encouraged to develop this material as it was the only reference material they were allowed to use for the final exam.

For each project, a core driving objective was used to enable the students to develop knowledge and practices that were required to meet their goals. Each project demonstrated some core ideas but required knowledge of many areas of optics to complete. The method used closely resembles that of a real world environment.

Outcomes: The students were able to develop complex experiments on their chosen topics. The review and examination process was treated as an opportunity to summarize the course material. Each student was required to verbally explain their specific set up and answer a series of short questions on key physical optics points. Students universally acquired applied skills in developing practical experiments and were also able to verbalize key concepts. A significant part of the evaluation process included discussions of a self-assessment nature with the students. This was then put into the context of the larger group and previous cohorts as well as the basic expectations and requirements of the course and program.

Each of the required tasks was done in an environment that was open ended with an acknowledgement that there is more than one solution.

Issues: The time required to develop individual experiments was too long based on the time constraints of the course. This meant that the students were not able to replicate other experiments beyond simple investigations of set ups. Each student group was only able to complete their own experiment in detail and then participate in a demonstration lecture of the other experiments. Students often required prompting to continue developing the experiments as these followed long term timelines rather than labs with limited scope. The students were required to develop time and project management skills. This proved difficult in the context of other challenging courses with hard and staggered deadlines. There was often a tendency to meet short term goals and push back on longer term goals in this environment.

Student Evaluations of Course: Students tended to have a mismatch in expectations. Other theory courses did not use applied exercises so that students tended to be confused by a minimization of rigid lectures. The students tended to have higher expectations of themselves than was reasonable. Many of the students indicated that they expected advanced material that would normally be found in a graduate course. Physical optics is typically a heavily mathematical subject and mathematics is a subject that tends to be delivered as method-oriented and not problem-oriented [11].

2.4 Case D. Niagara College Project Course.

Background: The Photonics Engineering Technology Program at Niagara College, Ontario, Canada includes a capstone project in the final year of the program (year 3). The projects are typically student team efforts and must include an element of photonics (opto-electronics) technology. Projects occasionally pair student teams with industry partners to solve an existing problem. Alternative projects are generated internally by the Photonics Department Faculty, or often result from proposals by the students themselves to solve a problem which they have identified.

Methodology: The course begins by developing a project proposal, and the project plan. It then proceeds with the implementation of the project plan, and concludes with a written project summary and an oral presentation. Project reviews occur continuously throughout the timeline of the project with formal reviews at the midpoint and end of the project. Several variations on the delivery methods of this course have been experimented with throughout the sixteen year history of the program. The most significant, and perhaps difficult, variable for the faculty to gauge and set has been the correct ratio of guided to self-guided study. The faculty recognizes the importance of allowing students to take risks and fail in ways that are not typically condoned in traditional course deliveries.

Students are responsible for setting the scope of their own projects. Faculty provides suggestions to the students to increase the chances of success, and warnings when an ill-defined or too ambitious statement of scope is identified. Except in extreme circumstances, students are given license to ignore suggestions and warnings if they so choose. There have been occasions where such an ignored warning actually resulted in an inspiring success.

Outcomes: This course fosters many of the soft, creative, and critical thinking skills that tend to be underemphasized in the more traditionally delivered technical courses in the first two years of the program. Students develop an appreciation for project management and the importance of scope while managing a project. While most traditional courses in the program are organized as discrete packets of knowledge and skill development with clearly communicated expectations for students, the projects that graduates are expected to participate in are far less clear cut. This course forces students to grapple with open-ended problem solving and develop a realization that there is not always a clear boundary between success and failure. Students are also often forced to face their own limitations in ways in which they have never been challenged. In most traditional courses everything is generally achievable. In the capstone course that is no longer assured.

Issues: A common challenge faced by students in this course is creating an appropriate statement of scope for their project and setting the accompanying goals. After a minimum of two years in the program, passing very difficult traditional classes in the science and technologies, these students typically approach the capstone course with overconfidence. Students making grand statements of scope usually begin with the best of intentions and extremely high motivation. That motivation is however quickly sapped as the students fail to make quick concrete progress towards their goal, or realize that the problem that they have set for themselves is far more complex than they previously thought. Students often fail to perceive timescales, including the effort required to complete unstructured tasks. In the student's earlier classes, failures and successes came quickly and were just as quickly left behind with the introduction of the next topic.

As the term progresses, student effort, and focus, often become directed towards the other more traditional courses as the students prioritize the externally imposed deadlines of the other courses, allowing their project timelines to slide. The students continue to be provided with free rein over the management and direction of their

project, but with faculty warnings. Without such guidance, many students, even those seen to be academically strong, can lose momentum.

The faculty has observed two dominant types of reactions by students who have come to the realization, midway through a project, that their scope is entirely unreasonable. The first results in an observable realization on behalf of the student of the purpose and use of setting scope in a practical sense. These students will re-evaluate their projects, narrowing their project scope to something reasonably achievable (or in some cases abandoning the project in favour of something more reasonable). The second reaction is a breakdown in motivation as seen by a significant lack of effort and progress. Without careful guidance and direct intervention by faculty to set achievable goals for the student, they will effectively abandon all work on the project.

Student Evaluations of Course: Students are often frustrated with the outcomes of the projects from the capstone course. Students can often be confused from having previously completed complex labs but then have difficulty completing open ended tasks. They have little previous exposure in academia to realistic open ended problem solving or the development of skills to cope with such circumstances. Student directed learning is uncommon in the first two years of the program, and often students are confused when presented with a lack of formal structure.

2.5 Case E. Hoseo Students at Niagara College

Background: Undergraduate students in Electrical Engineering from Hoseo University in South Korea travelled to Niagara College in Canada for eight weeks. As part of their training, they participated in a project based course. The course focused on the complete development cycle for constructing a spectrometer.

Methodology: The course covered the design, implementation and testing of a complex opto-mechanical-electronics module (spectrometer). The course was divided into one hour lectures and two hours of labs, twice a week for eight weeks. The lectures covered background theoretical material and preparatory material for the labs. The course included basic optical design (lens and optical system design), opto-mechanical design (for the mount), diffraction (diffraction based spectrometer), laser machining and laser welding (for constructing the mounts), thermal effects (for tolerancing the optical and mechanical designs), photolithography and thin film deposition (for manufacturing gratings) and testing.

Due to limitations in equipment, the students were rotated through tasks in which groups as small as 1-2 students would work on the machines. For example, as only one student could work on the laser welder at a time, the others would work on the laser cutter or an optical test bench or on the optical or mechanical design software.

Although every student worked on the same project simultaneously, they were each responsible for their own physical device. There was also variation between devices as each student individually designed the optics and the mechanical systems. Each student also produced several individual diffraction gratings.

Outcomes: Each student was able to successfully manufacture an individual spectrometer. The course was intended to provide a hands-on experience to support the

theoretical understanding of the material, such as athermalization, tolerancing, laser machining, diffraction and optical and mechanical design.

The students were also being exposed to technical instruction in English, with significant new material. In the opinion of the course instructor, the students exceeded expectations. The students performed enthusiastically on the particularly unique tasks of photolithography, optical test bench examination of diffraction, laser welding and machining.

Although the course was not delivered as an open ended project but rather as an individual effort on a common project objective, it was determined to be a useful exercise given the limitations present. The main limitations were; available equipment time, available instructor time, and available total allocated course hours. The course could be seen as a preliminary run through of a complete project which would be useful when encountering future open-ended projects. The main value was that the students developed skills in the context of a complete project.

Issues: The course was intentionally ambitious, as it was determined that the students had a unique opportunity to cover nearly all tasks associated with the design cycle of a complex opto-mechanical module. As the course progressed, time constraints required simplifications. For example, although each student created their own mechanical drawings, the final design to be laser cut was reduced to a single version.

There was also a significant amount of material covered, so that many of the tasks could not be covered in detail. This was determined to be a reasonable trade-off as the emphasis was placed on a general overview of the design process while at the same time providing valuable experience with many processes.

When trying to balance equipment issues (limited time on machine), sometimes the students would lose motivation.

Student Evaluations of the Course: The students indicated generally positive responses to the course. Recurrent issues included a lack of time on certain machines (laser cutter in particular). Students also had requested more individual instruction on certain aspects, which was a result of time constraints.

3 General Discussion

Identified through numerous program advisory committee meetings, a common complaint from employers is that new graduates in engineering have difficulty implementing open ended projects and projects with vague instructions (on methods). Ideally, employers want goal based employees with enhanced communication skills. Based on the experiences of the authors, through interactions with graduates, industry partners and program advisory committees, it is predicted that there are direct correlations with enhanced job performance for those students who had some exposure to project based learning.

Issues that have been identified here include student related issues such as lack of interest and motivation as well as structural problems such as time limits and practical facilities limitations. However, it has been established that student engagement gener-

ally improves when problems are real as opposed to canned [11]. An excellent model for engineering education includes traditional courses (lecture based) mixed with project courses which serve to reinforce standard course content [8].

An important finding is that with group project courses, it is often difficult to quantitatively determine a spectrum of performance when there are factors such as group dynamics and peer to peer tutoring. With a hierarchy of requirements, the teaching of the task often overshadows precise assessment. Even with individual projects one can never be certain where the solutions come from. From a systemic point, a precise individual assessment may be irrelevant. Teaching of soft skills to the group likely outweighs errors in individual assessment.

4   Conclusions

Successfully conveying the importance of scope to students continues to be a challenge, and has become an outcome of increasing importance for these courses. Students are not alone in commonly miscalculating the time required to complete a particular task. It is not until a person has carried out a particular task or form of work (or they read about it and embrace the data) that they gain an appreciation for the needed commitment of time. The outcome of the project itself, successful or not, is broadly irrelevant in this context as it is experience itself which will eventually build an understanding of scope. An alternative delivery method could involve the use of smaller introductory projects that serve to introduce key concepts.

It is our postulate that students also often have an expectation of too much work based on prior course experience so that when they take a course with limited scope (less is more), or are asked to set their own limits on scope, they are often initially confused. It has been the authors' experience that it can take several courses for the nominal student to realize that managing expectations is an important process both in the learning process and in practical project management. A single capstone course is insufficient. Scope management is a significant life skill, of high value beyond normal education deliverables.

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