

VERTICAL COURSE INTEGRATION THROUGH DESIGN PROJECTS

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Abstract – This paper describes two, two-course sequences that are vertically integrated through design projects. This integration allows students to learn more effectively, to more easily make connections between topics, and to learn other important skills. Vertical integration is a good solution when horizontal integration is not feasible. The results of these sequences have been very positive, so the plans for the near future are to expand them to include more courses.

INTRODUCTION

One of the challenges of engineering and technology education is the packaging of knowledge into individual courses. While such a system is logistically advantageous, it makes it more difficult for students to establish connections between various topics and to see the ‘big picture’ of engineering. Many schools have approached the problem by creating integrated experiences during the first or second years of curricula. While this approach has been extremely successful, it is difficult to achieve without the cooperation of supporting departments such as math and physics.

For smaller programs where engineering and technology students do not comprise the majority of the service teaching load for math or physics programs such an approach may not be feasible. The Engineering Technology (ETec) Department at Western Washington University (WWU), which offers degrees in Manufacturing (MET), Plastics (PET), and Electronics (EET) Engineering Technology, as well as Industrial Design (ID), Industrial Technology (IT), and Technology Education (TechEd), is in such a situation.

The solution to this quandary has been to move towards a vertical integration of classes through the use of continuous design projects. Projects are begun in one class and then continued through one or more following classes. These projects allow students to draw connections as they continue to develop their own design concepts into more sophisticated designs as they obtain new knowledge. As of this time two projects have been implemented across two classes, each with very positive results, and plans are underway to expand these projects to include almost all program classes in three majors, MET, PET and IT, during student’s first two years.

This paper discusses the projects that have been implemented as well as the learning objectives they address and the outcomes assessment during the first three years of this project. In addition, this paper will summarize plans for a more completely integrated curriculum for programs in the ETec Department at WWU.

Student Learning Outcomes

The ETec Department began developing its outcomes assessment strategy in 1998 [1],[2]. To start this effort, faculty in the ETec Department developed a list of desired student learning outcomes. Table I shows these department student learning goals. ETec Department faculty agreed that each of these skills is important for student success after graduation. All issues in Table I must be addressed in each curriculum, preferably more than once. The challenge, however, is to address all of these issues without sacrificing the technical aspects of the various curricula.

TABLE I
SKILLS THAT CONSTITUTE THE ENGINEERING TECHNOLOGY DEPARTMENT
DESIRED STUDENT LEARNING OUTCOMES

▪ Analytical Ability	▪ Oral Communication
▪ Teamwork	▪ Written Communication
▪ Project Management	▪ Visual Communication
▪ Business Skills	▪ Creative Problem Solving
▪ System Thinking	▪ Ethics and Professionalism
▪ Self-Learning	▪ Technology Skills

Although there are certain to be local variations, every engineering and engineering technology department and program in the United States that is accredited by ABET has a list of student learning outcomes similar to Table I. Generating such a list, while not without its challenges, is a small task compared to developing curricula that coherently address meeting student learning goals. An approach to achieving curricular coherency vis-a-vis student learning is to develop some form of integrated curricula that addresses connections between the various pieces of technical education while addressing student learning outcomes. This integration can come horizontally, by tying together courses that happen concurrently, or it can come vertically, by tying together sequences of courses with a common thread or theme. The horizontal integration approach has been tried successfully at several institutions, especially with first-year curricula. Some of these programs are described in the next section. Due to structural considerations that are discussed later in this paper, however, faculty in the ETec Department at WWU have elected to develop a vertical approach to curricular integration by linking courses through design projects. Both approaches have merits, and it is likely that they could be used simultaneously, but one approach may fit better in any given environment.

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HORIZONTAL INTEGRATION OF CURRICULA

Everett, Imbrie, and Morgan define curriculum integration “as the act of making individual courses become integral components of a whole, while at the same time requiring them to be interdependent upon one another and bound by a common thread of knowledge.” [3, p. 167] Their definition captures the essence of horizontal curriculum integration. In programs with horizontal curricular integration, and many are described in either summarized [4], or detailed forms [5]-[9], the common approach is to integrate the first-year experience through the careful coordination of math, science, and introductory engineering courses. Some programs include chemistry as well as physics, and some also include English. Most adopt a tightly coordinated just-in-time approach to teaching topics that are either used in other classes, such as calculus techniques used in physics, or are common to two or more classes.

Those who provide integrated first-year curricula point to many important, and well assessed benefits of horizontal curricular integration, including higher performance and better material retention, better understanding of the integration of different fields, earlier introduction to cross-disciplinary work and teamwork, and higher rates of retention. It is quite clear that there are also many challenges involved with creating and running such a system, including course and classroom scheduling, maintaining curricular alignment, uneven student preparation and performance, different preparation needs for different intended majors (e.g. extra chemistry for chemical engineering), and most of all convincing faculty to invest in the system. Even with all of these obstacles to overcome, results indicate that the structure leads to better student learning, and that is the bottom line.

The question then becomes: why is it that not everyone has adopted an integrated curriculum? Someday an integrated curriculum, either the first-year or all of it, may be the norm. At this point, however, it is worth noting that the overwhelming majority of programs that have instituted horizontally integrated curricula have both large technical programs, so that these students are the main ‘customers’ for many math and science classes, and external support, mostly from the NSF, to aid with the reform efforts. The latter issue is important, especially when trying to overcome faculty inertia to initiate a new curricula, but not absolutely necessary, as has been demonstrated in at least one case [8].

Size is the more crucial prerequisite for instituting a curricular change that requires the cooperation of so many distinct departments. Smaller programs do not always have the clout to convince other departments to engage in time consuming curricular changes, especially when their students do not make up a majority of enrollment in service teaching courses. In at least one case a supporting department has pulled out of the agreement after the first year of a horizontally integrated curricula [6]. For those in such a situation, horizontal integration of curricula across departments is not

imminently attainable, but there are still ways to achieve some of the same benefits through integration of departmental courses.

VERTICAL INTEGRATION OF CURRICULA

Intradepartmental integration of curricula is usually achieved vertically, by weaving a common thread throughout several classes. By integrating sequential rather than concurrent courses it is not possible to make classes interdependent upon those which follow, but it is possible to create a more coherent educational program. The thread that is most often used to achieve vertical course integration is design.

Design is the obvious choice as the connecting link in engineering and engineering technology courses, as it is such a good way to bridge between the sheltered environment of the classroom and the ‘real world’ in which students must eventually operate [10],[11]. Moreover, design projects have been used successfully to enliven student experiences and meet learning goals, and design projects can be meaningfully integrated into almost any traditional engineering course [12]. From the integration of design projects into individual classes, it is a relatively small step to the integration of design projects across classes.

The integration of classes by the use of design projects can start small, such as a case where two faculty members link two or three courses across two terms through the use of a project that bridges between them by having the students start the project in one term and complete it in another [13]. This in itself is very similar to the well established model for capstone design courses that bridge two or three terms used in many engineering and engineering technology programs. This integration can also take place by having students in different courses, at different points in the curriculum work together on the same projects [14]. In cases such as this students are put into roles that match the level of learning they have attained. Vertical integration can also occur throughout many classes by finding a common theme for all design projects, such as the development site for civil engineering projects, even if the project does not strictly continue from where it left off the previous term [15]. The ETec Department at WWU is in the process of developing a system of integrated courses that are linked by design projects. In upper level courses the approach has been to link courses by having students from different classes complete different portions of projects at the same time. In lower level courses the approach has been to link courses through design projects that continue. The long-term goal for lower level classes is to create design project threads that students can follow through their classes for one or two years.

STRUCTURE AND LEARNING GOALS AT WWU

The ETec Department at WWU has approximately 450 students between its six different majors. The six programs are

currently taught by thirteen full-time and seven part-time or limited term faculty with backgrounds ranging from Engineering to Art. WWU, on the other hand, has 38 departments, numerous academic programs, and almost 12,000 students. The ETec Department actually has one of the larger numbers of majors at WWU, but it obviously comprises a small fraction of the overall university.

Size is one issue that makes horizontal curricular integration difficult. ETec students comprise a small fraction of the service teaching load for the Math and Physics Departments at WWU, and so a program that requires those departments to teach special versions of their classes is not an easy sell, although a model does exist with the Math Department and the College of Business and Economics.

Another issue that makes an integrated first year curricula difficult, even more so than lack of size, is the high number of transfer students. On the order of half of the students in the ETec Department first complete an A.S. or A.A. degree at a community college. These students often enter WWU having met some or all of their math requirements, occasionally enter having met their physics and chemistry requirements, and rarely enter having met any of their engineering technology requirements. Given this situation, a large percentage of students would not take part in much of integrated first year curricula even if it did exist.

Small program size relative to the size of the university and a high percentage of transfer students are the primary reasons that the ETec Department has elected to develop vertically integrated curricula instead of horizontally integrated curricula. The goal over the next few years is to link the three courses that would normally be taken in the first year by students in all majors except EET with one project, and to link the sophomore level courses MET and PET students take either to the first year courses with a continuation of that project, or together with an additional project. The former project would begin in Engineering Design Graphics I (EDG I), and continue on through Engineering Design Graphics II (EDG II), and into Machine Metal Processes, Introduction to Engineering Materials, and ideally into Engineering Polymers as well. The latter project begins in Applied Engineering Statics and currently completes in Strength of Materials, but may eventually be used in other classes such as Manufacturing Economics or Computer Integrated Manufacturing (CIM).

Forms of these two projects already exist. The more developed of the two is the Applied Engineering Statics and Strength of Materials project, which has been used for three years. Currently EDG I and II are also linked together through a design project as well. This project is an individual project in EDG I, and then starts from scratch as a team project in EDG II. Both of these structures have been successful, although the EDG I and II courses and project are being revised for the 2001-02 academic year to improve the continuity between the two classes, and also to allow for a smoother transition into other classes. These two course sequences and their projects, both current and future, are

described in the next sections. In addition, a brief description of a different kind of project that links Numerical Control Operations (CNC) and Manufacturing Automation and Robotics is given as well. This project has been more logistically difficult, but it has also received fewer trials than the aforementioned cases.

Engineering Design Graphics I and II

The Engineering Design Graphics I and II classes [16] were revised to their current form for the 1998-99 academic year. The WWU approach to Engineering Design Graphics, which is based upon one developed by Barr and Juricic [17],[18], is that engineering graphics contributes to the design process in three levels: ideation drawings, communication drawings, and documentation drawings. The EDG I course is an introduction to conceptual design, including the design process and tools for design communication such as sketching and basic solid modeling. EDG II, which builds upon EDG I, is an introduction to the utilization of high-end parametric modeling applications within the design process. Prior to this revision, EDG I and II were courses on AutoCAD®.

The link between EDG I and EDG II is both the design process students learn and utilize in both classes, and the design project they undertake. As the foundation course for every program in the ETec Department, EDG I uses design to allow students to develop their visual communication, creative problem solving, and project management skills. This is accomplished through two formal design projects, each of which is completed by individual students, that utilize a five-step design process. The first design project is intended to introduce students to the design process, so it is fairly rigidly scheduled and lasts for virtually the entire academic term. The second project is shorter and less rigid. In this project students are expected to complete all of the steps in the design process, and are expected to manage the division of time spent on each task on their own.

The second project in EDG I then becomes the team project in EDG II. EDG II is primarily an introduction to parametric modeling and team-based design. In EDG II students use the same design process, but they are introduced to more sophisticated project management techniques and to teamwork. Reusing an individual project from EDG I as a team-based project in EDG II both provides continuity between the classes, as expectations for the conceptual portion of the project are similar, and allows every student to enter the project with roughly the same amount of relevant experience to bring to the team. The project over recent years has been the design of a flashlight. Students are given a truly open-ended flashlight design in EDG I, where they can state any problem to be solved, and then a more specific project in EDG II, such as the design of a flashlight for automobile maintenance.

Students completing EDG I and II have been asked to complete qualitative surveys regarding their experiences in the two classes. Students have expressed more satisfaction

with the team-based project of EDG II as a valuable, and realistic seeming, design experience. Students have, however, also consistently commented positively on the value of having the second class build so clearly off the first to reinforce what they gained in the first class. In addition, a quantitative pilot survey given to one section of EDG II during the winter 2001 academic term showed that students felt they gained understand and practice in the following areas in order: CAD and design documentation, creative problem solving, teamwork, sketching and ideation drawing, and project management, with scores ranging from 4.37 to 3.72 on a 5-point Likert scale.

Faculty satisfaction with these courses has also been high, but it has become clear that these courses need to evolve to both meet student learning goals more effectively and to link more easily to other classes. Revised versions of these classes will be offered during the 2001-02 academic year. The student learning goals for the revised EDG I and II are given in Tables II and III respectively.

TABLE II
STUDENT LEARNING GOALS FOR REVISED EDG I

<i>Specific Learning Goals</i>
Develop Visualization Skills
<ul style="list-style-type: none"> • Represent Concept or Idea from Brain As Visual Image • Explaining Other's Representations
Develop Drawing/Sketching Skills for Development of Design Ideas
Develop CAD Skills for Development of More Design Ideas
Apply Steps in the Design Process
Apply Visualization, Sketching and CAD In Support Of Design Process
Develop Understanding of Concurrent Engineering
<ul style="list-style-type: none"> • Develop Project Management Skills • Develop Teamwork Skills
Support Development/Improvement of Communication Skills
Understanding the Product Development Process
Introduction to Concepts of Ethics and Professionalism

TABLE III
STUDENT LEARNING GOALS FOR REVISED EDG II

<i>Specific Learning Goals</i>
Reinforce Visualization Skills
Develop/Rein force Teamwork
Reinforce Sketching and Design Development
Reinforce Understanding of Design Process
Reinforce/Develop/Extend Project Management
Develop Parametric Modeling Skills
Develop Assembly Modeling Skills
Reinforce/Develop Communication Skills
Develop Design Documentation Skills
<ul style="list-style-type: none"> • Production Drawings • Dimensioning Concepts • Tolerancing • Sections • Exploded Views
Increase Understanding of Product Development Process
Introduce Business Concepts

The new versions of EDG I and II will be very similar to the current versions of the classes, but with three significant shifts: students will be introduced to team-based design projects and concurrent engineering principles in EDG I,

students will be introduced to parametric modeling in EDG I, and projects will be chosen specifically so that they can be continued in other program classes students take either concurrently with or after EDG II. In the current form of these classes, the former two topics are not introduced until EDG II, and the flashlight project does not flow well into other classes. The goal, to be accomplished within the next three years, is to allow students to continue the team-based project from EDG I and II into courses such as Machine Metal Processes, Introduction to Engineering Materials, and Engineering Polymers by allowing them to build, analyze, and refine the material choices in their original designs based upon what they learn in these classes.

Applied Engineering Statics and Strength of Materials

The other model in the ETec Department for vertically integrating classes through a design project are the sophomore level Applied Engineering Statics and Strength of Materials classes [19]. As with EDG I and II, these two classes were first linked in this manner in the 1998-99 academic year. In the first incarnation, students completed individual projects that began in one class and finished in the other. Logistical difficulties and the need for more teamwork in the curricula quickly led to these become team-based projects instead.

The Applied Engineering Statics and Strength of Materials sequence is taught once a year and primarily serves students who are in the MET and PET programs. In addition, it is taken by students in the pre-engineering program who are headed to mechanical, civil, and similar engineering programs, and it sometimes serves as an elective for students in the IT-Vehicle Design major. With a smaller and more homogenous group of students than in EDG I and II, it has been easier to integrate the project through Applied Engineering Statics and Strength of Materials than through the two graphics classes. As a result, the student learning outcomes of this design project are more clearly articulated than the student learning goals of EDG I and II. Tables IV and V respectively give the student learning outcomes addressed by the design project for these two classes.

TABLE IV
STUDENT LEARNING OUTCOMES FOR APPLIED ENGINEERING STATICS

<i>Specific Learning Outcome</i>
Identify external forces on an object
Draw a clear free body diagram showing external forces
Write appropriate equations of equilibrium
Correctly solve equilibrium equations
Develop safe solution to an open-ended problem
Develop design specifications for an open-ended problem
Meet deadlines for project milestone
Keep minutes of team meetings
Write project interim reports
Write a technical report to document work
Create communication level computer graphics
Assign team roles
Listen effectively at meetings
Show for team meetings
Complete individual tasks

TABLE V
STUDENT LEARNING OUTCOMES FOR STRENGTH OF MATERIALS

<i>Specific Learning Outcome</i>
Determine internal force at any point in a structure
Determine stress at any point in a structure
Determine deflection at any point in a structure
Develop safe solution to an open-ended problem
Select appropriate materials to meet structural needs
Select appropriate materials to meet costs needs
Estimate cost of manufacturing
Select realistic tolerances for needs
Meet deadlines for project milestones
Keep minutes of team meetings
Write project interim reports
Write a technical report to document work
Create CAD documentation drawings
Assign team roles
Listen effectively at meetings
Show for team meetings
Complete individual tasks
Prepare and give a professional design presentation

The project is integrated across the two courses so that students complete the level of analysis that matches the main engineering content of the course. In Applied Engineering Statics students final product is a design proposal that includes a static force analysis of all of the components in their design, in several different orientations if applicable. In the process of developing their design, students follow the same design process they learned and practiced in EDG I and II, which in a sense links this project back to the ones from those classes. In Strength of Materials students take their preliminary designs from Applied Engineering Statics and complete the stress and deflection analyses. This allows them to determine the final size and material for each piece of their design. In addition to these, students develop complete part and assembly drawings, cost estimates, and any necessary instructions for the set up and use of their design. The second course culminates in a formal presentation and design report.

Assessment data collected during the first two years of the cross-course project, primarily exams, projects, and general student feedback, has clearly indicated that the project is meeting its primary goal of reinforcing the course material and helping students make the jump from textbook problems to open-ended problems with many possible solutions. The overarching questions that the first two years of data have not elucidated well are: How well is the project addressing the ETec Department learning goals (Table I)? What areas need more or different instruction or activities in order to meet these goals? In order to better answer these questions a student feedback questionnaire has been created for each class. Feedback from the Applied Engineering Statics class showed that students found the primary learning benefits of the project to be in the creativity, project management, and teamwork aspects of it. Students also responded that the project was beneficial for reinforcing course material, but not as much as with the aforementioned issues. Students also responded that the project had less value as a learning

tool for visual and written communication. This is consistent with expectations, as students were asked to utilize skills from previous classes, not develop new ones, and also because these tasks were distributed among team members rather than addressed by everyone on the team. These responses show that students are benefiting in the intended areas, but that additional analysis tasks would be beneficial. This will be addressed in the next version of the class.

Overall the integration of a design project across Applied Engineering Statics and Strength of Materials has been a very positive experience for both students and faculty. As such, there are no plans to make anything other than minor revisions to the project in these courses based upon student feedback. The next goal for this project structure is to find ways to link these courses to others such as Manufacturing Economics or Computer Integrated Manufacturing. The main obstacle to overcome for this to happen is to find a family of projects that can satisfy the needs and goals of each of the individual classes.

Numerical Control Operations and Manufacturing Automation and Robotics

Both of the projects discussed so far use the vertical integration across subsequent classes model. The ETec Department has also experimented with vertical integration of projects across concurrent classes. The classes involved in this project are Numerical Control Operations (CNC), which is a CNC machining class taken by MET, PET, and many IT students as juniors, and the Manufacturing Automation and Robotics (MAR) class taken by MET and some EET students as seniors. Both classes have had design projects for many years. The CNC class project is completed either by individual students or by small teams (2-3 students), and involves programming a project that is built on a five-axis mill. The MAR project is always some form of a team-based (3-7 students) assembly automation project.

As part of the MAR project student teams must design and build fixtures and robot fingers to complete their assembly tasks. Starting in the 1999-2000 academic year, the faculty involved in these classes began a policy of trying to get the students in MAR to subcontract their machined parts to students in the CNC class. The primary goal of this endeavor is to get students to understand the importance of complete and careful design documentation, by having them experience both sides of the communication process. So far this has met with limited success due mostly to the existing schedules of the two classes. Students in CNC are usually completing their final projects at the same time as students in MAR, which does not give the MAR students enough time to properly fine tune their solutions if they have to wait until a week before their final presentation to get all of their parts. This structure does, however, have great potential, as has been demonstrated by having students in MAR give their part designs to the ETec Department technician for fabrication. Students learn quickly that poorly designed and docu-

mented parts either do not do what is intended, or do not get built at all. Moreover, they have learned the value of clear communication and respect when working with others. Changes to the structure of both the CNC and MAR courses planned for the 2001-02 academic year should allow the desired system of integration of the two to work more smoothly in the future.

CONCLUSION

The experience with vertical integration of curricula in the ETec Department at WWU has been very positive overall. While the process of developing successful project structures, and class structures to support them is iterative, it is a good method for both building connections between topics and for addressing student learning objectives. The two course sequences that have been successfully integrated with design projects, EDG I and II, and Applied Engineering Statics and Strength of Materials, have shown that students benefit in terms of a better understanding of course material, a clearer view of how various topics in the curricula interact, and making progress in meeting overall student learning goals in areas such as project management and teamwork. With both of these course sequences having been used in this form for three years, the next step is to expand the number of courses that are integrated together through projects. In the case of EDG I and II this will require some structural changes to the courses starting during the 2001-02 academic year in order to both enhance student learning and lead more smoothly into the courses that follow. In the case of Applied Engineering Statics and Strength of Materials, few structural changes are needed to the courses, but a new family of projects must be found to link smoothly to subsequent classes.

Vertical integration of curricula is an option for all programs, but is an especially attractive option for smaller programs that may have more difficulty developing horizontally integrated curricula. These two types of integration are not mutually exclusive, and one should not be thought of as preferable to the other, merely potentially more feasible or appropriate for a given situation. Both address the same goals of helping students to learn more effectively and more broadly, and both have been shown to be effective.

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