An Example of Vertical Integration in an Engineering Curriculum

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Abstract - In many traditional engineering programs, the first two years of study focus on core concepts and principles. At East Carolina University (ECU), our general engineering curriculum seeks to reinforce core concepts throughout the four years of study using vertical integration of key components. In this paper, we present details on the type of activities and assignments necessary to provide vertical integration of modern engineering tools. Although the details are based on how our curriculum integrates modern engineering tools, the types of assignments and their role in the integration process can be generalized and applied to other concepts in the curriculum.

Keywords:
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BACKGROUND

The *2007-2008 Criteria for Accrediting Engineering Programs* [1] lists eleven program outcomes that engineering graduates are expected to be able to demonstrate by the time they complete their degree. This list of outcomes is commonly identified as ABET's (a) through (k). Specifically, outcome (k) requires students to attain "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice." The faculty of the Department of Engineering at East Carolina University (ECU) believe that exposure to and utilization of these techniques and tools in several courses across the curriculum will increase students' understanding and comfort level, making them highly skilled and confident users of several modern engineering tools.

Although the specific software packages employed as modern engineering tools are ever-changing, the basic types of tools our students need to use remain fixed. As general engineers, our graduates will create engineering solid models, manipulate engineering formulas, and manage project schedules and finances. The tools currently employed to teach these topics are SolidWorks, MATLAB, Microsoft Excel, and Microsoft Project. These tools were selected by faculty to be used in our curriculum based on the recommendations of our Engineering Advisory Board and due to the tools' prevalence in companies throughout the state of North Carolina.

To describe how these tools are utilized in our curriculum, we use the term "vertical integration". This term is used to convey the idea that students are introduced to each tool in one or more courses at the freshman or sophomore level, and the capabilities and applications of the tool are further explored in higher level courses. This type of integration allows faculty members to go into greater depth with specific applications of the tool in the higher level courses because their students have the necessary background and know the basics of the tool. Such depth enables students to develop high proficiency use of each software package to which they are exposed. Our faculty believes this approach will provide a better prepared engineer than an approach that simply introduces numerous similar software packages.

The best learning occurs when the need for new knowledge is anticipated. As new skills and concepts are introduced, their mastery is instantly rewarded with a sense of self-esteem inherent in the discovery of an ability to address problems with a clear relationship to students' goals, both in the classroom and the workplace. Our vertical integration approach aims to introduce highly motivating and relevant concepts of modern engineering tools early in the curriculum, and to demonstrate the applicability of advanced concepts with these tools at later stages.

The sections that follow provide details on the vertical integration of four modern engineering tools currently taught in the Department of Engineering at ECU. It should be noted that courses with an ICEE (Integrated Collaborative Engineering Environment) prefix are part of the general engineering core curriculum and all students must take them. Courses with an SYSE (Systems Engineering) prefix are part of the systems engineering concentration, and not all students are required to take these courses. Only SYSE concentration courses are included in our current vertical integration of modern engineering tools because SYSE was the first concentration developed and it is the only concentration for which all courses have already been taught at least once. As each of our other concentrations are rolled out, faculty in those areas (engineering management, bioprocess engineering, biomedical engineering) will determine the appropriate concentration courses and/or labs in which to integrate these tools.

INTEGRATION OF MICROSOFT EXCEL

In most high schools, students are introduced to a variety of software packages, and this set usually includes the Microsoft Office suite (Word, PowerPoint, Excel). However, many students' exposure to these tools is limited and the features that make the tools powerful are not utilized. It is vital that our students become not only comfortable with but also proficient in using Excel, as the may rely on it regularly once they become practicing engineers. For this reason, our freshmen are formally introduced to engineering applications of Excel in the course ICEE 2050, Computer Applications in Engineering.

The purpose of ICEE 2050 is to develop student competencies with Excel and MATLAB. As the course name Computer Applications in Engineering implies, the course uses engineering applications as a basis to teach computer usage and programming skills. Faculty experience has shown that student proficiency with Excel is lower than previously expected, so the first half of this course provides instruction with Excel fundamentals such as entering data, manipulating data using formulas, changing the properties of a worksheet, and basic graphing. These fundamentals are reiterated and strengthened by the activities included in ICEE 1014, Introduction to Engineering Later in the course, advanced applications of Excel are considered. In one such exercise, students build upon an ICEE 1012 (Engineering Graphics) solid modeling activity where they modeled a four bar mechanism. In ICEE 2050, the students develop a mathematical model for the four bar mechanism and use Excel to animate the motion of the mechanism by utilizing Excel's VBA (Visual Basic for Applications) programming capability. Students gain insight into both tools, Excel and SolidWorks, by comparing this spreadsheet solution to the problem's SolidWorks solution from the previous semester. This exercise also enables the students to begin to learn engineering theory, as the four bar mechanism provides a basis to introduce kinematic concepts such as relative motion, rotational motion and Grashof's criterion.

Every activity in ICEE 2050 (beyond the basic introduction to the software) is designed to increase both the students' practical knowledge of using the software and their knowledge of engineering theory. As an example, a damped spring mass system is used as a basis for entering exponential and trigonometric equations in Excel. Discussions of the system introduce the students to the concept of the damping factor. In a subsequent exercise, the concept of the damping factor is further emphasized when the students graph the response for three different damping factors. The visual display of the oscillatory decay of the spring mass damper system provides very powerful reinforcement of the engineering concept. Through this integrated approach, students learn the tool and realize its potential value in solving real engineering problems.

Students enrolled in ICEE 2050 will simultaneously be enrolled in ICEE 1014, Introduction to Engineering. This course is built around a robot project. The robot used in this course is a wheeled robot controlled by a programmable microcontroller. The robot has the capability to utilize sensors and employ actuators. Basic engineering principles are taught using the robot as motivation. For example, students are required to program their robots to follow a course, reaching check points at designated times. To complete this task, the students must master the concepts of position, velocity, and acceleration. Since not all students have a sufficient calculus background to master the analytical solutions, Excel is an excellent tool to apply for the numerical approximations needed complete this task. Excel is also used in several more exercises that provide the students with insight on how various aspects of their robot can be mathematically modeled and analyzed.

As sophomores, students find that Excel skills introduced and developed in ICEE 2050 and ICEE 1014 are reinforced in the course ICEE 3300, Introduction to Engineering Project Management. In this course, students learn the roles and responsibilities associated with project management by working on a service learning project. Project teams are assigned to community organizations that have a problem which needs to be solved. Numerous modern engineering tools may be employed by the team to solve the problem or present findings. Specifically, Excel is used to perform calculations for budgets and/or engineering calculations. As an example, one project team from Fall 2007 utilized Excel and its graphics capabilities to analyze a heating and cooling problem at the local Ronald McDonald House. Using remote sensors placed in each room under study, the students collected data to determine the difference between the temperature in those rooms and the temperature displayed on the thermostat. Analysis of these temperatures showed a high degree of variation. This analysis was presented to the client using Excel's graphing capabilities.

A more advanced use of Excel is explored in laboratory portion of the junior-level course ICEE 3012, Thermal and Fluid Systems. Tasks for which Excel is used in this course include, but are not limited to: (1) presenting experimental results in tabular format, (2) presenting experimental results in graphical format, (3) calculating the equation of a least-squares line based on the data, and (4) calculating the standard deviation of the experimental data using the least-squares line. In one particular application, students learn to calibrate a measuring device and to decompose the total error of a measurement into the systematic error (bias) and the random error (imprecision). Students are encouraged to verify the normality of the data with which they are working prior to applying any analytical techniques that assume a normal distribution. This can be done using the Chi-squared statistical test. Though students can perform this test using the functionality of Excel, they must understand and be able to interpret the results to determine if it is proper to assume their data are normally distributed.

Also in the junior year, students work with Excel in the lab portion of the course ICEE 3050, Introduction to Dynamic Systems and Controls. Specifically, five laboratory activities are employed, and Excel is used in two of them for curve fitting. In one activity, a linearized thermistor circuit is characterized and calibrated using Excel. Resistance of the thermistor is graphed as a function of temperature and then fitted to a polynomial using Excel's built-in curve fitting functionality. The coefficients of the polynomial are then utilized in a LabVIEW [4] program to calibrate the circuit.

Systems Engineering (SYSE) was the first concentration in the engineering program with an established curriculum. For this reason, all SYSE courses have already been taught at least one time. We have been able to incorporate Excel's use at the concentration level by adding it to SYSE 3060, System Optimization. In this course, the Solver add-on to Excel is utilized for solving linear programming (LP) problems. As an example, the following problem was assigned for homework [6] :

> "U.S. Labs manufactures mechanical heart valves from the heart valves of pigs. Different heart operations require valves of different sizes. U.S. Labs purchases pig valves from three different suppliers. The cost and size mix of the valves purchased from each supplier are given. Each month, U.S. Labs places one order with each supplier. At least 500 large, 300 medium, and 300 small valves must be purchased each month. Because of limited availability of pig valves, at most 700 valves per month can be purchased from each supplier. Formulate an LP that can be used to minimize the cost of acquiring the needed valves." (p. 71)

Students had to formulate the given problem correctly, load the formulation into Excel, and run Solver to obtain a solution. As part of the assignment, students used their Solver solution and accompanying sensitivity analysis to answer questions designed to verify their ability to interpret the results they obtained. In general, students were required to identify the optimal values for all decision variables as well as the optimal objective function value. They had to interpret the values given for shadow prices of specified decision variables, reduced costs of specified constraints, and allowable increases/decreases for objective function coefficients.

Table 1 illustrates the six courses in which Excel is integrated. For each course, the application of the engineering tool is listed along with how the students' knowledge of the usage of the tool is reinforced or advanced.

Table 1: Excel Integration in a General Engineering Curriculum

Course	Course Title	Application	Reinforcement/Advancement
ICEE 2050	Computer Applications in Engineering	Fundamental Usage	
ICEE 1014	Introduction to Engineering	Robot Position, Velocity and Acceleration	Numerical Analysis, Problem Solving, Graphing
ICEE 3300	Introduction to Engineering Project Management	Project Management	Data Analysis, Graphing, Presentation
ICEE 3012	Thermal and Fluid Systems	Thermal System Analysis	Data Analysis, Error Analysis, Curve Fitting
ICEE 3050	Sensors, Measurements, and Controls	Control System Design and Analysis	Curve Fitting, Simi-log Graphs
SYSE 3060	System Optimization	Linear Programming	Solver, Constraints, Sensitivity Analysis

INTEGRATION OF MATLAB

According to the product description on its manufacturer's Web page [2], MATLAB is "a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation." MATLAB can be used for a variety of applications, including signal processing, image analysis, and control design, test and measurement. The goal of our program is to provide the students with a solid foundation in using this tool, and then build upon this foundation by providing advanced experiences that require the students to practice and develop their programming expertise.

As previously described, students take ICEE 2050 (Computer Applications in Engineering) during their freshman year, and the purpose of the course is to develop student competencies with MATLAB and Excel. During the first half of the course, students learn to use MATLAB interactively and as a programming language. During the second half of the course, applications such as matrix mathematics, plotting, root finding, numerical integration, simultaneous equations, and optimization are covered. It is important to note that when presenting these modern engineering tools to students, faculty teach not only how each program can be used, but also the relative advantages and disadvantages of each tool. Faculty want students to have a level of proficiency with each tool and to be capable of choosing the appropriate tool for a given problem. Students' ability to choose their engineering tools appropriately becomes particularly important as they enter their senior year and begin working on their capstone design project.

As sophomores, engineering students are required to take MATH 3100, Mathematical Methods for Engineers and Scientists. The major topics of this course are linear algebra and differential equations. The use of MATLAB in this course is new, and the faculty in the mathematics department are currently developing activities to include in this course. In Fall 2007, students enrolled in MATH 3100 fell under our previous curriculum, which did not include ICEE 2050. For this reason, introductory activities were needed to introduce the students to MATLAB. For example, these students used MATLAB to perform basic operations such as entering two matrices, **A** and **B**, adding the two matrices, and multiplying the two matrices. Building on this background, the students also learned how to do the following: (1) compute the transpose $\mathbf{A}^T$, (2) compute the inverse $\mathbf{A}^{-1}$, (3) convert a matrix to reduced row echelon form, *rref*(**A**), (4) solve a system of equations using the *rref* command on the augmented matrix, (5) place a *m*x*n* matrix **A** in reduced row echelon form via matrix multiplication by an invertible *m*x*m* submatrix **C** of **A**. In the future, incoming students will have been previously exposed to MATLAB in ICEE 2050, thus affording the math faculty the opportunity to provide greater depth in MATLAB programming experiences for our engineering students.

More work with MATLAB is accomplished during the junior year in the lab portion of the course ICEE 3050, Introduction to Dynamic Systems and Controls. As an example, the following two activities are conducted using MATLAB. First, using the previously described thermistor circuit activity, the student selects the appropriate resisters of a Wheatstone bridge that anchors the circuit’s voltage response to three temperatures (0°C, 50°C, and 100°C). MATLAB is then utilized to simulate the circuit’s response across the range of temperatures. In this exercise, the students utilize conditional statements and loops to complete the simulation. In a second lab activity, the students analyze and design a control system. MATLAB and the Controls Toolbox add-in are utilized extensively throughout the five-week activity. Ultimately, the students design a control system and then determine and program the system's transfer function into MATLAB to ascertain the system's response to a step input. This activity exposes the students to advanced MATLAB features available through the Controls Toolbox.

Table 2 illustrates the three courses in which MATLAB is integrated. For each course, the application of the engineering tool is listed along with how the students' knowledge of the tool's usage is reinforced or advanced.

Table 2: MATLAB Integration in a General Engineering Curriculum

Course	**Course Title**	**Application**	**Reinforcement/Advancement**
ICEE 2050	Computer Applications in Engineering	Fundamental Usage	
MATH 3100	Mathematical Methods for Engineers and Scientists	Linear Algebra	Matrices
ICEE 3050	Sensors, Measurements, and Controls	Control System Design	Controls Toolbox, Loops and Logic

INTEGRATION OF SOLIDWORKS

SolidWorks software is widely accepted as a standard in three dimensional design. According to the company's Web site [5], its "specific 3D CAD functionality includes advanced part, assembly and drawing development functionality including physical dynamics, surfacing, large assembly performance enhancing modes, routing and powerful drawing creation capabilities." With the Cosmos finite element analysis program add-on, SolidWorks is a very powerful engineering tool, providing engineers the capability to perform advanced motion, structural, and thermal analysis on their designs. The goal of our program is to provide the students with a solid foundation in using this tool, and then build upon this foundation by providing more in-depth exercises that require the students to further develop their design expertise.

ECU Engineering students are first exposed to SolidWorks in ICEE 1012, Engineering Graphics. This course covers the fundamentals of engineering graphics such as projection theory, orthographic projections, pictorial projections, and dimensioning and tolerancing. Concurrent with these topics, the students learn solid modeling using the software program SolidWorks. The SolidWorks topics are sequenced to dovetail with and reinforce the engineering graphics topics. As an example, after studying multiview drawings and completing multiview drawings by hand, students use SolidWorks to solid model the same objects and then create multiview drawings with the tool. Students are also assigned an open-ended project that challenges them to design an object made up of at least four separate parts. They are required to solid model all of the parts, create an assembly of the parts, and then create fully annotated part drawings and an assembly drawing. This is a challenging assignment for many students because it is the first time they are exposed to a solid modeling problem where they are not essentially following step-by-step instructions. Instead, this assignment requires them to determine on their own the best way to create the part.

Again in the freshman year, students are exposed to SolidWorks in ICEE 1014, Introduction to Engineering. As noted above, design of a robot is the focus of this course. As a requirement in their robot design, students must use SolidWorks to design and then build (using rapid prototyping technology) some functional aspect of their robot. To further advance their skills in SolidWorks, students then must solid model and animate their entire robot to demonstrate the robot's functionality.

Many students again work with SolidWorks when they take ICEE 3300, Project Management. Students' use of the tool in this class depends upon the type of project their team is assigned. In Fall 2007, one team was asked to design and create a device that would enable children in wheelchairs to participate in soccer matches without the soccer ball getting trapped under their chairs. This team used SolidWorks to design a device and built a prototype to share with their community partner. Another team used SolidWorks to design a wheelchair ramp to ADA (Americans with Disabilities Act) specifications, optimizing its layout, bill of material, and cost.

In Systems Engineering, we have been able to incorporate an application of SolidWorks into the concentration by adding it to the junior level course SYSE 3010, Principles and Methods of Systems Engineering. Early in this course, students are given a homework assignment in which they must design a jungle gym to meet the fictional (but realistic) specifications provided by a local YWCA. One portion of the assignment is a SolidWorks drawing of the completed jungle gym.

Table 3 illustrates the four courses in which SolidWorks is integrated. For each course, the application of the engineering tool is listed along with how the students' knowledge of the usage of the tool is reinforced or advanced.

Table 3: SolidWorks Integration in a General Engineering Curriculum

Course	Course Title	Application	Reinforcement/Advancement
ICEE 1012	Engineering Graphics	Fundamental Usage	
ICEE 1014	Introduction to Engineering	Robot Design	Design, Motion Simulation
ICEE 3300	Introduction to Engineering Project Management	Project Management	Design, Bill of Materials, Costing
SYSE 3010	Principles and Methods of Systems Engineering	Systems Analysis	Design, Applying Design Constraints

INTEGRATION OF MICROSOFT PROJECT

Microsoft Project (MSProject) is a project management tool. According to the product's Web site [3], this software has "the right blend of usability, power, and flexibility, so you can manage projects more efficiently and effectively." Users can perform numerous project management tasks such as controlling project work, creating and monitoring schedules, tracking finances, and keeping their project team up-to-date on the status of each project component. General engineers often find themselves, by necessity, acting as project managers for their company. For this reason, our graduates need to be experienced using project management software and the tools it encompasses.

Our students are introduced to MSProject in the course ICEE 3300, Introduction to Engineering Project Management. In this course, students are assigned a community service project. Each project team works to analyze the problems encountered by the community organization and develop a work breakdown structure (WBS) to address the project goals. Using the WBS, they develop a semester project schedule in MSProject. One member of each team is assigned responsibility for developing and maintaining the schedule in MSProject. Another project team member develops a master schedule for his/her project team that tracks important course milestones.

As seniors, all students take both ICEE 4010 and ICEE 4020, Senior Capstone Design Project I & II. In these courses, students work on a team to solve an engineering problem for a client. To keep their project team on-task and their work plan up-to-date, students may choose to utilize MSProject. The conceptual design report students submit for their capstone project may include a Gantt chart or WBS to enable the client to see students' progress on the project. Students may also track issues and risks using MSProject, so that all factors impacting the project are documented. ICEE 4020 will be offered for the first time in the Spring of 2008. It is our expectation that students will continue to utilize MSProject in the same manner they utilized it in ICEE 4010.

Table 4 illustrates the four courses in which MS Project is integrated. For each course, the application of the engineering tool is listed along with how the students' knowledge of the tool's usage is reinforced or advanced.

Table 4: MS Project Integration in a General Engineering Curriculum

Course	Course Title	Application	Reinforcement/Advancement
ICEE 3300	Introduction to Engineering Project Management	Fundamental Usage	
ICEE 4010	Senior Capstone Design Project (I)	Capstone Project	Gantt charts, WBS, tracking issues and risks
ICEE 4020	Senior Capstone Design Project (II)	Capstone Project	Gantt charts, WBS, tracking issues and risks

SUMMARY

Based on the ABET requirements, engineering programs are responsible for making sure their students attain "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice." [1] Our engineering department at East Carolina University believes that the best way to meet this outcome is to introduce students to these tools early in their academic career with fundamental usage activities and assignments, followed by reinforcement and advancement of each tool's usage in higher level courses. As our curriculum has undergone a recent change, there are currently no data available to assess how well our approach is working; however, the rubrics we develop and the survey questions we ask in the near future will provide us with both direct and indirect measures by which to assess this approach. We plan to report these findings at a future ASEE meeting.

REFERENCES

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BIOGRAPHICAL INFORMATION

Evelyn Brown

Evelyn Brown is an Associate Professor in the Department of Engineering at East Carolina University. She received a BS in Mathematics from Furman University, a MS in Operations Research from North Carolina State University, and a PhD in Systems Engineering from University of Virginia. Dr. Brown serves ad the coordinator of the Systems Engineering concentration at East Carolina University. Her research interests include manufacturing problems and applications of genetic algorithms.

Rick Williams

Rick Williams is an Assistant Professor of Engineering at East Carolina University. Prior to joining ECU, he was a faculty member and Associate Research Professor at Auburn University. Williams has sixteen years of industrial experience in design and project engineering functions. He received BS and MS degrees from Georgia Tech, and his PhD degree from Auburn University. Williams is a registered Professional Engineer in Virginia.

Purvis Bedenbaugh

Purvis Bedenbaugh received a BSE in Biomedical Engineering from Duke University, a MS in Bioengineering from Clemson University, and a PhD in Bioengineering from the University of Pennsylvania. After a postdoctoral fellowship at the Keck Center for Integrative Neurosciences at the University of California, San Francisco, he joined the faculty of the Department of Neuroscience at the University of Florida College of Medicine. He is currently on the faculty of the East Carolina University General Engineering Department, and serves as the coordinator of the Biomedical Engineering concentration. He also serves as Chief Technical Officer for Cranial Medical Systems.