

Vertical Integration of the Undergraduate Learning Experience

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Abstract

In progressing through an engineering curriculum, students acquire familiarity with the use of modern computational tools for modeling, analyzing, and designing physical systems. Instructors put a lot of effort into identifying and implementing appropriate software packages for augmenting classroom material. Students undergo steep learning curves, often encountering three or more disparate packages in the course of a semester. They gain a reasonable degree of comfort with these tools, only to have new ones introduced the following semester; and the cycle repeats. To significantly reduce the burden to students of repetitively learning new software packages, a consistent computing environment can be introduced throughout the curriculum. Such an environment must be sufficiently versatile, robust, and powerful as well as extensively used by practicing engineers. While certain highly specialized functionality might be lost by eschewing specialized software, the students profit by gaining fluency and depth in using a general-purpose package. Moreover, it becomes possible to provide a vertically integrated learning experience, where experienced students can demonstrate to less-experienced students how their use of the very same package has progressively grown more sophisticated. This experiment in vertical integration is still in its early stages. However, based on student feedback, this approach is yielding the benefits of developing in senior students a confidence in their ability to communicate, work in teams, and mentor their juniors. Lower-class students are realizing the relevance of the fundamental courses to their career goals and the importance of developing their skills in computing, modeling, and analysis.

Introduction

As undergraduate students progress through an engineering curriculum, they are expected to acquire competence in lower-level courses in order to succeed in upper-level courses. Unfortunately, students do not always recognize the importance of retaining skills learned in one course for application in subsequent courses. Faculty members contribute to this break in continuity by collaborating in only a limited way with instructors of lower-level and higher-level courses on specific topics and tools that if emphasized would provide students with a better integrated experience. This is particularly true of computational tools.

Instructors can expend considerable effort augmenting their courses with suitable computational software. Students undergo steep learning curves, often encountering three or more different software packages in a semester. They gain a degree of comfort with these tools only to have new ones introduced the following semester. It often happens that tools used in one course are not used in subsequent courses. The possibility that this expenditure of effort might be reduced raises the following question: what manner of cooperative effort can faculty implement over a sequence of courses to help students develop their cognitive and engineering skills in the most efficient manner? In response, the authors propose a form of vertical integration.

Vertical integration

The term “vertical integration” has been used by some authors to mean the driving of upstream course content by downstream course objectives. For example, Mahajan and McDonald (1997) report on their experience with a multipurpose laboratory environment where students use the same experimental set-ups in multiple courses, and build upon the work done in previous laboratories of the same course as well as those of previous courses. Borges et al. (1997) used a knowledge-based system to help reconfigure their school's electrical engineering curriculum such that there was vertical integration of the content throughout the learning modules.

In the educational experiment described herein, the authors have broadened the definition of vertical integration to include not only the use of a consistent computing environment, but also to encompass mentoring and cooperative learning by using more experienced students to help and guide less experienced students. Upper-level students become role models without a “generation gap.” Past research (Dale, 1969) has proven the efficacy of active learning and Felder (1992) and Felder and Brent (1996) provide insight into the structuring of team activities and student-centered teaching. This paper describes our approach to this type of vertical integration, its implementation involving seven courses in mechanical engineering at North Carolina A&T State University, and student feedback and perceptions of our early efforts.

Approach

The theme of our approach to vertical integration is to consider as customers both the students in a particular course and the faculty members teaching subsequent courses. Therefore, instructors of downstream courses must make known to instructors of upstream courses their expectations regarding the skills and tools students should retain from course to course. Students too must be made aware of the skills they are expected to carry into the next course.

We use upper-level students to show lower-level students by example how the concepts they are learning in one course are applied in subsequent courses. This interaction is enhanced by using a consistent computing environment. For the greatest benefit the computing environment must be versatile, robust, powerful and extensively used by practicing engineers. While certain highly specialized functionality might be lost by using a general-purpose package, the students profit by gaining fluency and depth in that package. Through the vertically integrated learning experience, students progressively grow more sophisticated in their computational skills.

We are implementing uniform usage of the MATLAB package, augmented with the WORKING MODEL package, in the Mechanical-Systems stem of the Mechanical Engineering curriculum at North Carolina A&T State University. The courses involved in this experiment are listed in Table 1, spanning the third through eighth semesters of the eight-semester (four-year) undergraduate program. Students from higher-level courses in this sequence present to students in lower-level courses specific examples of how the concepts learned in one course are used in a subsequent course and how the use of a consistent computing environment can enhance their analytical and design capabilities. For example, students in MEEN 581 make a presentation to students in MEEN 474; students in MEEN 474 make a presentation to students in MEEN 336; and so forth. The details of each module are described in the next section. Four of the modules use MATLAB as the computing environment and the fifth module uses WORKING MODEL. Demonstrations are made using MATLAB 5.0 and Working Model 2D 4.0 running on a 166 MHz laptop PC. In most cases, two students from the source class, with the assistance of their

instructor, make the presentation to the target class. Presenters conclude their presentation in about fifteen minutes and answer questions from the audience. The students in the audience fill out module assessment forms. After the presentation, some of the presenters are asked by their instructors to informally assess their participation in the module.

Table 1: Courses Involved in the Vertical Integration Experiment

Semester	Courses
3	MEEN 210 Numerical Methods
4	MEEN 335 Statics
5	MEEN 336 Mechanics of Materials MEEN 337 Dynamics
6	MEEN 440 Mechanism Design MEEN 474 Engineering Design
8	MEEN 581 Vibrations

Implementation

Vibrations Module

In this module, seniors from the Vibrations class (MEEN 581) present to rising juniors in the Engineering Design class (MEEN 474) a demonstration of using MATLAB for vibration analysis of a truss structure. The general truss configuration is shown in Figure 1. The specific configuration used in this and three other modules is shown in Figure 2.

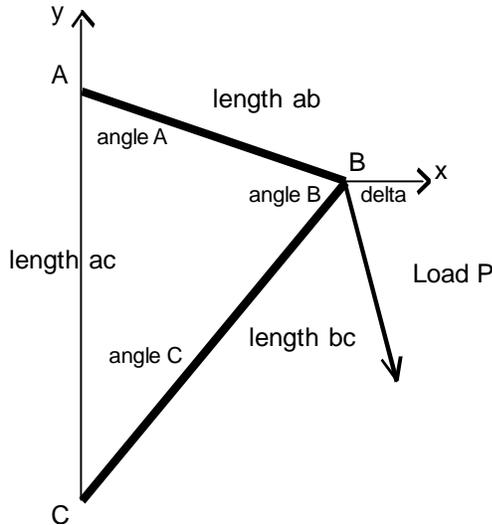


Figure 1 General truss configuration

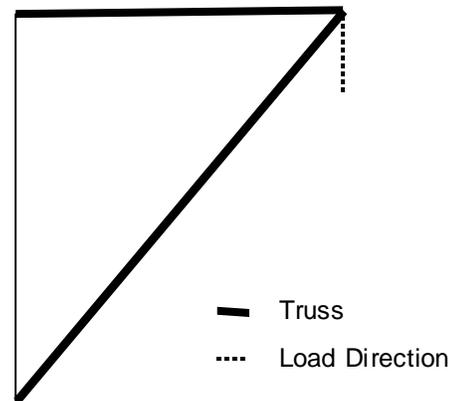


Figure 2 Truss configuration used in four modules

The Vibrations course instructor developed the code to compute steady-state vibration of a truss due to a rotating unbalance supported by the truss. Truss frequency response, static deflection, mode shapes, natural frequencies, and damping ratios are computed so that students can see how changes in truss parameters affect the vibration response. Results are plotted and tabular output generated by MATLAB.

During the presentation, students in 474 (the target audience) change the truss parameters and see the vibration analysis results in about 20 seconds. The students then change the cross-sectional area and damping of the truss members to reduce vibration. The concepts of natural frequencies and mode shapes and how they are computed in MATLAB are introduced. Students in 474 learn that for a structure operating near a resonant condition, small excitations can be amplified by a factor between 10 to 50 causing large forces and stresses in a structure. Thus static analysis as developed in previous courses may be inadequate when considering a structure subject to dynamic excitations. The software simplifies the computational burden of performing such analyses.

Design Module

In this module, rising juniors in the Engineering Design class (MEEN 474) present to juniors in the Strength of Materials class (MEEN 336) an example of truss design. A POWERPOINT presentation of truss design objectives and procedures is followed by a demonstration of design using MATLAB.

The Engineering Design class (MEEN 474) learns to design machine elements for static and fatigue loads. The major objectives of the course include (1) identification of the stress type(s) in mechanical elements, (2) selection of materials suitable for a given application, (3) selection and application of the appropriate theory of failure, and (4) iteration procedures to obtain safe designs. These objectives are highlighted in the module. The module illustrates the importance of understanding types of stresses, developing the appropriate stress analysis, selecting materials based on stress type, and selecting appropriate failure theory. The module uses concepts from statics, strength of materials, dynamics, materials engineering and manufacturing processes in one design procedure.

As an example, a truss is designed for various loading conditions using MATLAB. The sizes of the members are determined under a steady load and under a reversed fatigue load and compared. Emphasis is placed on the fact that truss members subject to variable loads are larger than truss members subject to steady loads. The module also emphasizes the importance to students entering 474 of retaining skills learned in prior courses, especially stress analysis skills learned in 336.

Mechanism Module

In this module, rising juniors in the Mechanism Design class (MEEN 440) present to juniors in the Dynamics class (MEEN 337) a preview of how the skills learned in 337 are applied in 440. WORKING MODEL software is used to illustrate how computers can be used to decrease the computational burden of analysis. In particular, the software automates the computation of position, velocity, acceleration, forces and moments over the full range of motion of a mechanism. Since students in 337 perform only instantaneous analysis, this module shows them how their nascent skills in analyzing dynamical systems can be broadened in the future.

To implement this module, a crank and piston (slider-crank) mechanism is animated in WORKING MODEL and the animation is shown to the students in 337 (the target audience) via a computer-screen projector. A snapshot of the animation is shown in Figure 3. To aid the Dynamics students in visualizing velocities, animated velocity vectors are shown at the pin

(denoted pin A) connecting the crank to the connecting rod and at the wrist pin (denoted pin B) connecting the piston to the connecting rod. These vectors show the magnitude and direction of the velocity vectors at each instant of motion while the animation is running.

In the study of rigid body motion, students in 337 learn to compute the instantaneous velocity of a points like a pin A and pin B. The software, however, computes these velocities at successive instants, demonstrating an extension of the concepts learned in 337 in an application in 440. To quantify the computation, piston velocity vs. time is graphed onscreen.

The students in 337 can solve for instantaneous forces in this mechanism. WORKING MODEL solves for such forces over the entire range of motion. To illustrate this capability, the force acting at the wrist pin is plotted onscreen. The audience is reminded that a primary purpose of performing a force analysis is to select a material, size, and shape for each component in a mechanism such that stress levels due to applied loads do not cause failure. Thus a connection is made between mechanism design, dynamics, strength of materials and statics. The utility of using software to automate tedious computations is clearly illustrated.

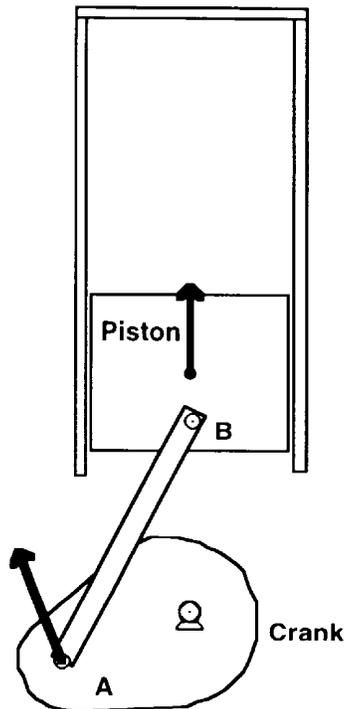


Figure 3 Slider-crank mechanism

Strength of Materials Module

In this module, juniors from the Strength of Materials class (MEEN 336) present to rising sophomores in the Statics class (MEEN 335) a stress analysis using MATLAB of a two-truss member subject to static loading (adapted from Turcotte and Wilson, 1998). The problem was readily extended to include determination of cross sectional areas for each truss member, factors of safety, and material strength.

The interactive environment for technical computing and remarkably simple graphics commands in MATLAB facilitate the presentation of two dimensional truss member data representation. Students in 335 (the target audience) could witness the application of skills learned in their course to a design problem in a subsequent course. Emphasis is placed on progressively developing a simple problem from a lower-level course to a more complex problem in a subsequent course and on the use of a consistent computing environment (in this case, MATLAB) to ease the burden on students of learning new software packages. Also emphasized is the utility of graphs in interpreting analytical results.

Statics Module

The sophomore students of the Numerical Methods class (MEEN 210) are introduced to MATLAB for the first time prior to the presentation of the statics module. In addition to learning MATLAB syntax, they are introduced to the basic mathematical analysis involved in a statics

problem using the two-dimensional example of the equilibrium of a weight suspended by two cables. It is shown that the scalar equations of equilibrium can be written in matrix form as $Ax = b$. The class then learns to program the linear algebra problem in MATLAB and solve for the vector of unknown forces x .

In the statics module, rising sophomores in the Statics class (MEEN 335) present to the Numerical Methods class an example of truss analysis. Statics students analyze a two-member truss (the same configuration described in preceding modules) with hand-calculations, use MATLAB TO verify their results, and thus convey to the MEEN 210 students the value of using numerical methods and computer tools like MATLAB in future classes.

Student Response

Students in the target audiences commented anonymously on the benefits and the limitations of interaction with the students from the upper-level classes. Sample responses are listed below:

Benefits

- Allows us to see how the present class relates to the future class.
- Acquired an idea of the quality of work required in advanced classes.
- Good introduction to design.
- See how courses relate, not just to hear about them.
- You learn to take courses seriously.
- Advice from senior students.
- Provides valuable information on what to concentrate on.
- Puts things in perspective. We learn from experiences of upper-level students.
- Course topics became clearer upon seeing applications
- Got a better understanding of what not to do.
- Better understanding of computing applications.
- Allowed for greater understanding of the big picture.

Limitations

- Time constraints - should allow more time for module presentation.
- Ran through demonstration only once.
- Students seem to know less than professors.
- Modules should have been in the beginning of the semester.
- This should have been done starting freshman year.

Student Presenters

- Honesty of presenters was especially good.
- Advice offered by presenters was appreciated.
- Presenters went straight to the heart of the matter.
- It is easier to communicate with fellow students than with faculty.
- Presenters gave good responses to questions.
- Presenters showed teamwork and good participation.
- Presentation was well thought out.
- Presenters were very familiar with material.
- Appreciated the advice on learning to work with people.

Comment

In an informal conversation between some of the presenters and faculty, the students commented on their enjoyment in getting a chance to share their experiences with lower-level students. In particular, they emphasized the importance of learning to work in teams. Cooperative learning is not an explicit topic of the various modules, but some of the presenters on their own initiative added a short exhortation to the lower-level students to learn how to cooperate in order to get the most out of their coursework. Their honesty in discussing the problems associated with teamwork elicited several positive comments from members of the target audiences.

Results and Conclusions

The following four survey questions listed below were asked of the target audiences at the conclusion of each module. Possible answers ranged on a five-point scale from “Strongly agree” to “Strongly disagree.” The overall survey results are shown in Figures 4 – 7.

Survey Questions

1. “From today’s presentation by upper class students, the information I am receiving in my current course is relevant to my training as an engineer.”
2. “Interaction with upper class students as in today’s presentation is a valuable supplement to my current course.”
3. “An engineering computing environment such as MATLAB (or WORKING MODEL) would be useful in my current course.”
4. “I would like to participate in more of these learning modules.”

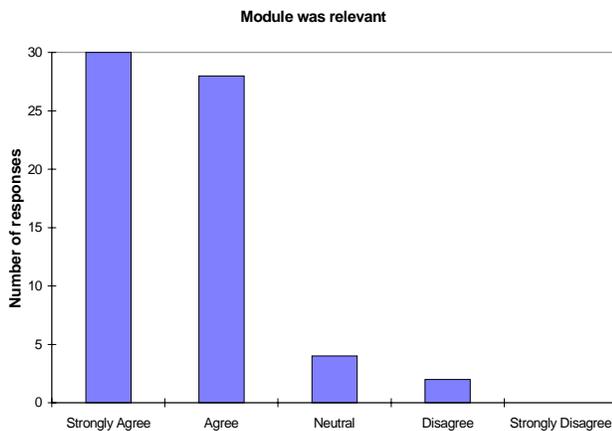


Figure 4: Relevance of module to engineering training

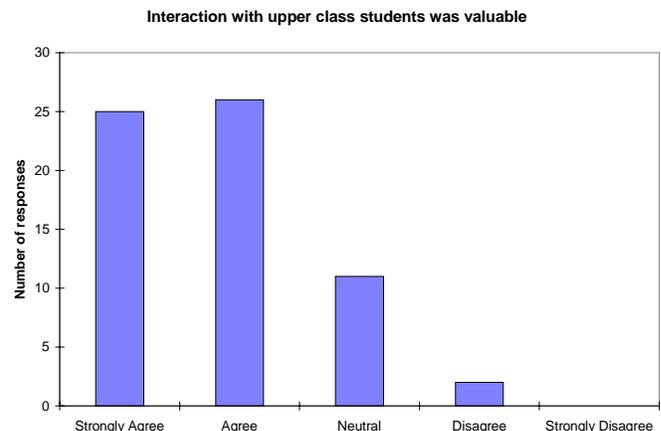


Figure 5: Value of interaction with upper-level students

The data show that most students validate the premise of active learning through teaching, doing, and querying others of their own generation. The concept of vertical integration has thus been expanded beyond curricular integration, to include mentoring and cooperative learning.

Students are afforded the opportunity to assimilate key concepts for solving increasingly sophisticated models of the same fundamental engineering system. The consistent use of MATLAB presented in this paper, augmented by WORKING MODEL, enables students to focus their

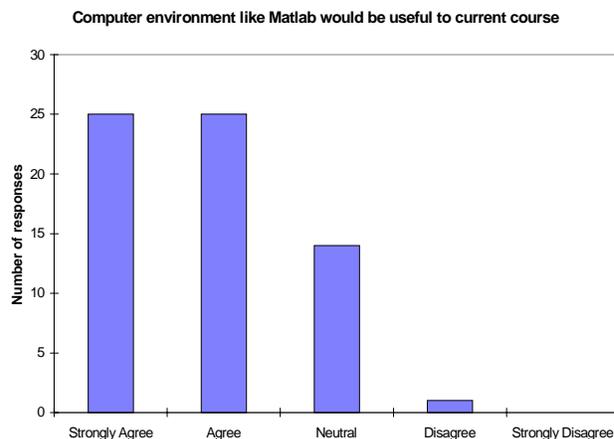


Figure 6: Utility of consistent computing environment

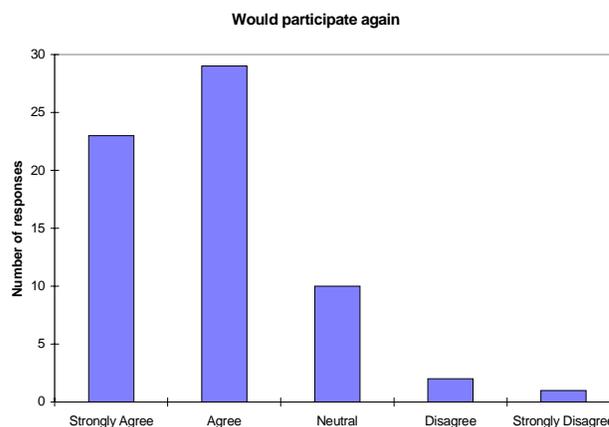


Figure 7: Desire to participate in future learning modules

energies on engineering principles. This reduces unproductive time spent combating the vagaries of computer packages that differ primarily in operational detail. Students grasp the usefulness of graphics in the interpretation of results, and gain fluency in decomposing and structuring problems for numerical solution.

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References

1. Borges, M. N., F. H. Vasconcelos, and M. Lewis, 1997, "New Paradigms in the Design of Engineering Curricula," *Proceedings of the 1997 ASEE Annual Conference*, Session 1532, # 3.
2. Dale, E., 1969, *Audio-Visual Methods in Teaching*, 3rd. Edition, Holt, Rinehart & Winston.
3. Felder, R., 1992, "How about a Quick One?" *Chemical Engineering Education*, Vol. 26, No. 1, pp. 18-19.
4. Felder, R., and R. Brent, 1996, "Navigating the Bumpy Road to Student-Centered Instruction," *College Teaching*, Vol. 44, No. 2, pp. 43-47.
5. Hamann, J. C., 1997, "A Brief Introduction to MATLAB[®]," Notes of a workshop presented at the ASEE 1997 Annual Conference, Milwaukee, WI.
6. Mahajan, A. and D. McDonald, 1997, "An Innovative Integrated Learning Laboratory Environment," *Proceedings of the ASEE 1997 Annual Conference*, Session 1559, Paper 6.
7. Turcotte, L., and H. Wilson, 1998, *Computer Applications in Mechanics of Materials Using MATLAB[®]*, Prentice Hall, Upper Saddle River, NJ, pp. 12 - 23.

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