AC 2011-1025: INTEGRATING COMPUTING INTO THERMODYNAMICS: LESSONS LEARNED

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Integrating Computing into Thermodynamics: Lessons Learned

Even though computing has become pervasive in today's workplace, many engineering curricula have lagged in creating engineers with computational aptitude. Computational-capable engineers are ones who can utilize computing effectively to solve engineering problems. Developing these computationally capable engineers means understanding that changes in the undergraduate engineering curriculum must recognize it's context in an educational continuum. Starting from the first computing course, the computing skills need to be reinforced at subsequent levels in the curriculum (i.e., in selected 200, 300 and 400 level courses) in order for students to continue to use and build on their skills. In this paper, we will illustrate the kinds of computing based on Excel/VBA that were utilized in an engineering thermodynamics course as part of a program to create a computational thinking thread in the curriculum. Assessment data over three years was used to modify the approaches and problems in each subsequent year. Finally, the lessons learned in introducing computing into engineering courses is addressed in terms of the amount of computing exercises to paper calculations, the types of assistance needed to help students in overcoming the time since taking the first computing course as well as a varied background in terms of computing. These lessons will be applicable to other types of engineering courses where computing is being introduced.

Introduction

Many engineering curricula around the country are re-evaluating their introductory computer programming requirements. Realizing that the standard introductory programming courses no longer appropriately complement the education of systems engineers (i.e., Textile Engineers (TE) and Industrial and Systems Engineers (ISE)), a new Computer-Based Modeling for Engineers course (TE/ISE 110) that integrates critical thinking and problem solving within a computational thinking framework has been developed[1–3] and taught for the past five years at our institution. This introductory course is intended to teach students how to model problems relevant to their specific engineering discipline through software platforms (i.e., Excel and VBA) commonly used in industry. A focus of the course is to encourage students to solve engineering problems and to analyze solutions through the development of decision support systems. Excel augmented with VBA has tremendous modeling capability.[1,2] Many engineering curricula (i.e., Chemical, Civil, Textile, and Industrial and Systems Engineering) at our university utilize Excel with VBA in their courses. However, some students do not recognize the modeling capability potential and thus utilize Excel mostly as a glorified calculator or simple graphing tool.

Based on the successful implementation of this course, the goal is to now create a computational thinking thread that spans from the freshman to senior years, where students can apply their

Table 1: Core Textile Engineering courses, illustrating the computational thread with shading. Courses in italics are electives and thus not all students take it.

	FALL	SPRING
Sophomore	TE 110: Computer-Based Modeling for Engineers	TE 201: Textile Engineering and Science
	TE 200: Introduction to Polymer Science and Engineering	TE 205: Analog and Digital Circuits
Junior	TE 301: Engineering Textiles Structures I: Linear Assemblies	TE 302: Textile Manufacturing Processes and Assemblies II
	TE 303: Thermodynamics for Textile Engineers	
Senior	TE 401: Textile Engineering Design I	TE 402: Textile Engineering Design II
	TE 440: Computer Information Systems	TE 404: Textile Engineering Quality Improvement
	TE 463: Polymer Engineering	

freshman year computing to take computing competency to the next level, where they are able to perform high-level computing tasks within the context of a discipline. The core classes in our Textile Engineering curriculum are listed in Table 1, where the courses that are shaded illustrate those that are currently utilizing computing. The program strategically chose courses where computing made sense in creating and implementing the computational thinking. There are courses in the curriculum that utilize computing, but not all students take these electives, and are indicated by the courses in italics. Note that not all of the core courses utilize computing because these courses are typically descriptive rather than quantitative engineering courses.

One of the first courses selected by our program for this computing integration is TE 303: Thermodynamics for Textile Engineers, which is an engineering thermodynamics course that is taught from both the molecular and macroscopic perspectives and is taken in the junior or senior year. This course was chosen since the current instructor is also an instructor for TE/ISE 110, thus creating a bridge in content. However, the gap between when the students take both courses posed some challenges that will be addressed in this report.

TE 303 is offered each fall to about 25-40 students, most of whom are textile engineering (TE) and polymer and color chemistry (PCC) majors. This course is required in TE but an option in the PCC curricula, and is a co-requisite for TE 463, Polymer Engineering. The implementation of computing into TE 303 was part of the fellows program of the NSF grant, Computing Across Curricula.[4,5] The fellows program was an effort to create a community of faculty engaged in using computing in their courses through workshops, seminars, and action research projects.
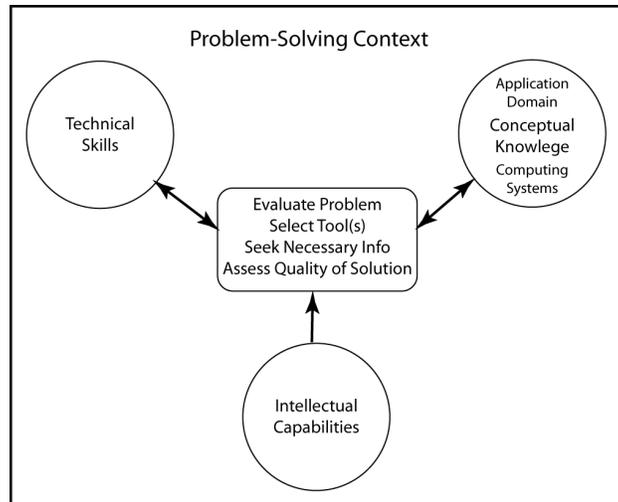
Figure 1: Computational Capabilities Model reproduced from Weibe and coworkers.[5]

Figure 1 illustrates the computational capabilities model developed by Weibe and coworkers[5] as part of the NSF grant that provides the framework. They recognized that certain innate *intellectual capabilities* are essential for problem solving, which include the general cognitive abilities necessary for learning and applying declarative and procedural knowledge. The *technical skills* refer to the abilities to manipulate and use a particular computing tool (i.e., Excel/VBA in this context). The last of the triangle needed to utilize computing in engineering problem solving is two types of specific knowledge. *Conceptual knowledge* is higher-level knowledge (i.e., understanding at a more abstract level) of computing technologies and their limitations and strengths. The application domain knowledge necessary is dependent upon the engineering discipline where the problem resides. The student must not only understand the domain where the problem resides (i.e., principles of thermodynamics) but also have the ability to evaluate which tool, if any, is needed to assist in solving the problem. If computing is appropriate, then the student must be able to effectively model the problem in that particular tool and analyze the results given in terms of accuracy and relevance. Based on the capabilities model, industry feedback, and literature searches, Weibe and coworkers defined three levels of computing efficiencies reproduced in Table 2 that we will use to describe later in this paper the difficulties that the students encountered. Creating computational capable engineers means that they are competent in the computing technologies in their domain area and moving into the infancy stages of proficiency by the time they graduate.

Computational Thinking in Thermodynamics

The objective of this action research project is to determine if homework assignments in TE 303 that utilize Excel with VBA will enhance the students' understanding of thermodynamics concepts and principles, improve their retention of computing skills that they learned in previous

Table 2: Three Levels of Computing Efficiency, reproduced from Weibe and coworkers.[5]

Competency	The individual has technical skill mastery of certain computational tools and/or programming languages. Limits in conceptual knowledge means that they are limited to solving well-defined tasks with specified tools. When faced with a more open-ended or complex problems, limits in conceptual knowledge will mean they will probably not be able to solve the problem.
Proficiency	The individual has some conceptual knowledge of both computing systems and their application domain. When presented with a problem, they are able select the appropriate tools(s), seek the necessary information, and present a solution. The regularly used technical skills are committed to memory and external information resources are not needed in these cases. More complex problems and problems with multiple possible solution paths for which they have to evaluate the quality of the different solution paths will create difficulties for the individual. Overall intellectual capability may be a limiting factor.
Fluency	The individual has extensive knowledge of the technical tools and conceptual aspects of both computer systems and the application domain of their profession. Within their professional area, they are able design and evaluate multiple solution paths to complex problems. They are well versed in general knowledge in the problem space and do not need to refer to external resources for common problems. New computing tools are readily evaluated and integrated into their existing tool set. Limits to problem-solving usually result from moving outside their professional application domain or the bounds of general intellectual capabilities.

courses, obtain experience in adapting these skills to a variety of new applications, and improve their confidence in utilizing computing for engineering problem solving. The current instructor for this thermodynamics course is also an instructor for TE/ISE 110 (Excel/VBA modeling), and thus can provide a bridge for the content in both courses.

TE 303 is a typical first engineering thermodynamics course except that it is taught from both the molecular and macroscopic perspectives. The course introduces students to the concept of energy and the laws governing the transfer and transformation of energy with emphasis on thermodynamic properties and the First and Second Laws of Thermodynamics. Although the fundamentals of thermodynamics are emphasized, applied examples and problems are heavily utilized, particularly for textile processes and sustainability issues. No formal textbook is used for the course, but the students are strongly encouraged to supplement their learning with an engineering thermodynamics textbook,[7,8] with a study guide,[9] and with online resources.[10,11] In addition, the course has a "homework blog" where the instructor and TA post hints and suggested

example problems to help students with the problem solving, and the students can post anonymous questions or comments. This blog is moderated regularly by the instructor and TA. In addition, the use of electronic resources for the thermodynamic data tables ("steam tables") are also required.[12,13] The following list outlines the typical topics covered in the course:

- Introduction: definitions and units (1 day)
- Phases and phase diagrams for pure substances, phase equilibrium and thermodynamic data tables, ideal gas, graphical and advanced equations of state (4 days)
- Internal energy and enthalpy, heat capacities, phase changes and hypothetical process paths (4 days)
- Work and heat, the first law of dynamics problem solving procedure, isobaric and isochoric processes, thermodynamic cycles (5 days)
- Introduction to mass balances, conservation of mass and energy, steady state processes, transient mass and energy balances (4 days)
- Second law of thermodynamics, internally reversible and irreversible processes, Carnot cycle, thermodynamic and ideal gas temperature scales and Carnot efficiency (4 days)
- The Clausius inequality and entropy, principle of increasing entropy, entropy generation, fundamental property relationships, polytropic and isentropic processes (3 days)
- Entropy balances on open and closed systems, isentropic efficiency, lost work or irreversibility (3 days)

Implementation

First, there were some significant challenges with the implementation of the computing thread into this course that had to be addressed. Since TE 303 has students in both engineering and science, it could not be presumed that all students had a laptop through the College of Engineering laptop initiative, and thus computing could not be used during class sessions or the practicum. In addition, TE/ISE 110 is not a prerequisite for TE 303, so proficiency in these skills cannot be presumed for all students; however, the majority of the students had taken TE/ISE 110 in a previous semester. Not all students who are required to take the course (or enrolled from other programs such as biomedical engineering) are required to take TE/ISE 110 as part of their degree program; only the TE majors are required to take TE/ISE 110. Therefore, there was a strong need for tutorials and instructional assistance outside of class to complement the computing modules.

This project was undertaken in phases over the past three years, so that the complexity of the thermodynamics problem solving that utilize Excel with VBA could be increased each year. This phased approach also allowed the development of tutorials for the computing tools learned in TE/ISE 110 that are useful for thermodynamics problem solving, such as Solver and VBA. These tutorials are intended to help students who are not proficient in these skills, particularly those who have not taken the TE/ISE 110 or similar courses.

The specific focus areas of interest in TE 303 span the basics of using Excel/VBA to solve

engineering thermodynamics problems, such as:

- Spreadsheet formatting, including name ranges and establishing "constant" variables;
- Utilizing built-in functions such as mathematical operations;
- Solving problems by breaking the problem into pieces and writing Excel formulas;
- Creating charts of data and relationships, and performing linear regression analysis and other curve fitting tools;
- Apply concepts to other solution strategies, such as numerical integration;
- Using optimization tools such as Solver;
- Performing a sensitivity analysis;
- Recording macros for automation, such as for looking up values in a plug-in for the thermodynamic data tables;
- Writing simple code in VBA to calculate a relevant relationship.

Research Objectives

Initially, the questions of the action research project was to determine if computing (i.e., Excel modeling with VBA) is utilized for homework assignments in TE 303, then the students will be able to:

- Enhance their understanding of thermodynamics concepts and principles;
- Improve the retention of computing skills that were learned in previous courses (TE/ISE 110);
- Adapt these computer skills to a variety of new applications (i.e., move towards proficiency); and
- Develop a greater confidence in utilizing computing for engineering problem solving.

To address the research questions, a mixed approached using the following instruments is being employed:

(1) Survey of students at the beginning and the end of the course on their confidence and competency on specific Excel/VBA skills. Compare these to similar questions given at the end of the first computing course if taken; and

(2) Perform a self-assessment on homework assignments throughout the semester, and to make changes to future assignments accordingly.

Task Descriptions

So far, four different types of Excel/VBA applications have been incorporated into the engineering thermodynamics course, which will be outlined below. While completing the

assignments, the students had the use of the course blog for hints and asking questions as well as example problems on the Internet [10,11] and in textbooks [7,8] and study guides. [9] They also had access to the tutoring center, which had tutors who were proficient in both TE 303 and the TE/ISE 110 courses. The instructor also worked with the students to set up some of the problems in the optional course practicum sessions. The course policies allowed the students to work together on the assignment, but students were required to turn in their own individual solutions. A few changes affected the consistency over the course of the three years. First, the Excel plug-in for the thermodynamic data tables [12] was not available in the 2010 semester. In addition, year 2008 was the only year that it was attempted to have the students complete their entire homework assignment using Excel/VBA (refer to "Lessons Learned" for the explanation why.) Finally, tutorials were developed on the Excel/VBA components and general computing problem solving, but they were only available in the 2010 semester.

Task 1: Use of Spreadsheets for Problem Solving

2008:
Students were required to complete all homework problems in an Excel spreadsheet, using xlThermalFluids [12] for thermodynamic property data. (This requirement was abandoned by mid-semester due to the excessive time it was taking students for minimal gain in knowledge.)

All Three Years: Only select problems were required to be done computationally. *Refer to problems from all other tasks.*

Task 2: Graphing

All Three Years: *Refer to Task 4 and Figure 2.*

HW 1 in 2009: *Adapted from Problems 1-133E and 1-134E in Cengel and Boles. [7]*
Given an equation for calculating the chilling effect of the wind, which takes into account the wind velocity and the ambient air temperature, perform the following:

a) Convert the equation into USCS units.

b) Plot the equivalent wind chill temperatures in ◦ F as a function of wind velocity in the given range for three different ambient temperatures.

c) Discuss the results from Part (b).

HW 2 in 2010: *Refer to Task 3 for details, specifically parts (a) and (b).*

HW 5 in 2010: *Adapted from Problem 3.23 in Schmidt. [14]*

A given mass of liquid water is put into a rigid tank of a known volume at standard temperature and pressure, and the water is heated until it exists in the saturated vapor state. For this system, the students were asked to generate the thermodynamic data table ("steam table") using an electronic resource such as xlThermalFluids[12] or NIST WebBook[13] and then do the following:

a) Graph the volume of liquid and vapor versus pressure (on same graph).

b) Graph the pressure and temperature versus quality (on same graph is preferred).

c) Graph the specific Cp and Cv versus temperature for both liquid and vapor (on same graph).

d) Discuss the trends in these graphs.

Task 3: Use of Solver for Numeric Optimization

HW 2 in 2010: *Adapted from Problem 1.48 in Moran and Shapiro.[8]*
Given a tank of a substance at known mass, temperature and pressure, and a nonlinear equation that describes the relationship between pressure, specific volume, and temperature, perform the following:

a) Plot the pressure versus specific volume for the three different temperatures and a given range of specific volume.

b) Estimate from your graph what the specific volume is for specified pressure and temperature values.

c) Numerically solve for the specific volume for specified pressures and temperatures. (HINT: The Newton numerical method or the use of Excel's Solver function would help with this step.)

d) Discuss the comparison between your results from Parts (b) and (c).

e) Annotate solution and label units throughout.

Task 4: Perform Numerical Integration

All Three Years: *Refer to Figure 2 for the task description.*

Figure 2: A computing problem that has been assigned in all three years. This problem was adapted from Problems 1.6 and 1.7 in Ref. 9. It involves graphing data, using linear regression to obtain the polytropic "n" exponent, evaluating the boundary work analytically using the appropriate equation from class, and then performing numeric integration of the data to estimate the boundary work.

Results

Based on Tasks

Task 1: Use of Spreadsheets for Problem Solving

Students used spreadsheets for problem solving on a variety of problems for each year. In Year 2008, all homework was initially expected to be completed in its entirety with the use of Excel and the plug-in for the thermodynamic data tables.[12] However, by the third assignment, it was apparent that this expectation was more tedious than it was helpful, and so it was abandoned. After that time, only select problems were selected for computing, such as the numerical

	2009 HW 1				2010 HW 2						2010 HW 5				
	a	b	c	TOT	a	b	c	d	e	TOT	a	b	c	d	TOT
Total points	10	15	5	30	8	2	8	5	2	25	3	4	5	4	16
Avg. points missed	1	3.2	1.1	5.4	1.6	0.7	2.3	1.1	0.2	5.9	1.2	1.9	2.0	2.1	7.2
Avg. grade percent	90	78	77	82	80	65	71	78	92	76	61	53	60	46	55
% students > 70%	83	62	76	79	68	61	63	78	90	76	54	44	51	46	55
% students = 0%	7	10	21	7	7	32	20	22	7	7	29	37	34	54	27

Figure 3: Student performance results for computing problems that were assigned in 2009 and 2010.

integration problem in Figure 2.

In general, although students were supplied with an example worksheet of what type of formatting and layout is expected, students were observed to not use appropriate layout or formatting with their spreadsheet solutions. For example, cells containing variables or equations were not labeled as such; units for values were also not indicated; there was a general lack of organization on the spreadsheet; and the use of formatting such as coloring was not done. In addition, students tended to not set up their spreadsheets as a general use model, where variables are set up in separate cells rather than hard-coded directly into equations. Other formatting, such as text explaining their results, or the engineering model items (problem statement, system diagram, assumptions, and analysis) were neglected; see for example, the results in Table 3 for 2010 Homework 5 Part (d), where over 50% of the students did not include the engineering model.

Task 2: Graphing

Creating a graph with Excel is a common task that is performed, and thus problems were given each year that required graphs to be made. For example, Homework 1 in 2009 contained an equation for calculating the chilling effect of the wind based on the ambient air temperature and wind velocity. Student performance on this problem is given in the leftmost columns of Figure 3. The average grade on creating the graph itself in part (b) was a 78%, with 62% of the students earning a grade of 70% or better. The biggest challenge that students seemed to have is how to

generate the data set for each of the three temperatures using the given equation.

In 2010, Homework 5 contained a problem where the students generated the data from an electronic source of thermodynamic data tables, and then used that data to create graphs that compare various thermodynamic quantities such as the heat capacities. As Figure 3 indicates, a significant proportion (27%) of the students did not do the problem at all, and those that did, a significant proportion of the students did not do well (receive at least a 70% on it). The class was asked about this situation, and they informed the instructor that they were struggling with how to use the electronic data table resources, and not the graphing itself, despite being shown how to use the NIST Webbook[13] in class and in practicum, and being given some hints on the blog on how to use it for this specific problem. In that same year, graphing was also done on Homework 2 Part (a) (Figure 3), and the students did much better on this graph (80% average) than they did on a related problem in Homework 1 in 2009.

In addition, the numeric integration problem in Figure 2 that was assigned all three semesters also contained a graph. In 2008, the graph was not formally assigned but instead is one of the ways that the students could solve the problem for parts (b) and (c). Unfortunately, it was not recorded in the grading analysis whether students used a graph in 2008 to solve the problem. For 2009 and 2010, the results for the graphing problem are given in the leftmost "Graph" columns in Figure 4. In 2009, the students successfully completed this portion of the assignment with an average grade of 88%. The same is not true in 2010, where the average is a 52%. By further observation, it is noted that 46% of the students did not do this portion of the problem in 2010, whereas they did the other aspects of the problem. The only difference between the two years is that in 2010, a video tutorial on performing this numeric integration was available for the students; this video walked them through the techniques for solving parts (b), (c), and (d) of this problem, which included the numerical integration. It can be inferred, therefore, that a significant percentage of the students did not create the graph in part (a) because that aspect of the problem was not covered in the tutorial video. The same effect can be observed in the "Engineering Model" aspect of this problem, which also was not part of the video, as 32% of the students did not do this part of the problem either in 2010, whereas the other years the numbers were much lower.

Task 3: Use of Solver for Numeric Optimization

This type of problem was only assigned in 2010 on Homework 2 Part (c), and the results are given in Figure 3. For this problem, students who did not take TE/ISE 110 required outside assistance on how to use Solver, which the instructor provided both in practicum and after a class period. A video on how to use Solver was also posted on the homework blog. The average grade on this portion of the assignment was a 71%, and 20% of the students did not even attempt this part of the problem (thus Part (d) could not be answered, either). By removing the amount of students who did not complete this portion of the assigment from the statistics, those who did attempt it, solved it sufficiently.

	Graph		Find 'n'			Analytical			Numeric			Eng. Model		
	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Total points	4	4	5	5	5	5	5	5	5	5	5	5	5	5
Avg. points missed	0.5	1.9	0.9	1.1	0.7	1	1.2	1.2	1	1.6	1.3	1.1	0.6	2.6
Avg. grade percent	88	52	82	79	86	80	75	77	81	68	75	79	88	48
% students > 70%	79	51	83	79	85	73	69	68	83	62	68	77	83	39
% students = 0%	3	46	17	10	12	13	17	12	17	28	17	13	7	32

Figure 4: Student performance results over three years for the homework problem given in Figure 2. Note that the graphing question was not included in 2008. The categories are the total number of points for that portion of the problem, the average number of points missed by the students, the average grade percentage, the percentage of students who scored at least a 70%, and the percentage of students who did not do the problem.

Task 4: Perform Numeric Integration

The numeric integration problem (Figure 2) is the only one that was assigned all three years. The student results are summarized in Figure 4. In all three years, the problem solution was set up with the students in practicum and a link to a description of the "trapezoidal rule" was provided which also included an example Excel spreadsheet (see problem definition in Figure 2). In 2010, they also had the video that walked them through the problem solving steps of (b), (c), and (d). In general, the students did really well on this problem in all three years, which can be attributed, in part, to the amount of help that the students were given to complete the problem. In 2009, the average grade for the integration portion (part (d)) was lower than in the other years, which may be due to the higher number of students (28%) who did not do this part of the problem. In 2010, as addressed previously, a significant portion of the students did not do the graph (part (a)) or the Engineering Model (part (e)) aspects of the problem, which could be because these aspects of the problem were not covered by the tutorial video provided to the class that year.

Table 3: Student Confidence Survey. To calculate an average, the questions were coded where a 4 indicated "Very Confident," 3 was "Confident," 2 was "Somewhat Confident" and 1 was "Not Confident", except for the last question where 4 was "Strongly Agree," 3 was "Agree," 2 was "Disagree" and 1 was "Strongly Disagree."

Survey Questions	None	Total	Total Without None	TE 110
Moving around the worksheet	3.25	3.67	3.82	3.86
Entering values and formulas	2.75	3.47	3.73	3.86
Applying built-in financial, statistical and math functions	1.75	2.80	3.18	3.53
Using solver	2.00	2.27	2.36	2.98
Constructing data tables	3.00	2.80	2.73	3.32
Constructing graphs	2.75	3.20	3.36	3.72 *
Using Named Ranges	2.75	3.53	3.82	3.93
Recording macros	1.75	3.00	3.45	3.86
Using 'ifs' and 'cases'	1.75	2.40	2.64	3.48
Using Excel objects, methods and properties	1.75	2.47	2.73	3.47
Writing functions and subroutines	1.75	2.47	2.73	3.22
Defining variables of various types	1.75	2.60	2.91	3.42
Making assignments	1.75	2.33	2.55	3.13
Creating loops	1.75	2.33	2.55	2.94
Creating your own forms and controls	1.75	2.47	2.73	3.36
Writing event handlers	1.75	2.13	2.27	2.84
Developing decision support systems	1.75	2.20	2.36	2.83
I'll need a firm mastery of Excel/VBA programming for my future work[1].	2.50	2.93	3.09	3.13

Student Satisfaction Survey (2008 only)

Since the inception of TE/ISE 110 computer based modeling course, a confidence rating survey has been given at the end of the semester in that course. In a previous report, it was discussed how confidence statistically dropped in upper level courses at the junior and senior years.[2] The same confidence survey was given in 2008 in TE 303 with an additional question on when they took the TE/ISE 110 course, and the results are given in Table 3, where the shaded questions at the top of the table are related to Excel only while the non-shaded refer to VBA. Recall that we have students in TE 303 who have not had TE 110 and their averages are given in the "None" column, while the "Total" has all students in the class, and the "Total Without None" column representing all of the students who had TE/ISE 110. Finally, the TE 110 column represents the average from the survey of the years when the students took TE 110 and should have the highest student confidence.

Using a p-value of 0.05, most of the VBA questions were statistically different when comparing the "TE 110" and "Total Without None" columns. Of the Excel questions, both Using Solver and constructing data tables had means that were statistically different with a p-value of 0.1. In comparison, almost every question was statistically different before the computational thinking was reinforced in additional classes (i.e., students were less confident since taking the course four semesters before). The VBA portion was not emphasized in TE 303 and is the one aspect that is currently lacking in our computational thread in many of our classes. Again, finding appropriate uses of the computing technology is important rather than just forcing the students to carry out an exercise. It is important as an instructor to help the student recognize when and what is the appropriate computing needed to solve a particular problem. From Table 3, it can be observed that the students who had taken TE 110 between two to four semesters prior to TE 303 were more confident than those who had not had the class. It should be noted that both TE 110 and TE 303 have changed since 2008 to reflect these findings. The videos were created in the summer of 2009 and then revamped in 2010 to help assist the students. More computing has been put in place in the TE 205 course, which many students take the semester before TE 303, thus helping to bridge the gap.

Self-Assessments

Self-assessments from 2008 indicated that the students' computer skills were "weaker" than expected. More tutorials and guidance are needed to help the students utilize the computing for problem solving. In addition, completing the entire HW assignment with Excel was too tedious and time-consuming with little benefit to learning the content in many cases, as the use of the computer was not necessary for some problems. The use of computing also seemed to be distracting from the learning of thermodynamics problem solving rather than improving it. Starting with Homework 3, only select problems were required to be done with a computer. However, it was observed that students would try to maximize their points without doing the computing aspects.

Self-assessments from 2009 indicated that graphing abilities improved on later assignments: 62% of the students were successful in graphing on Homework 1 versus 79% on the numeric integration problem. The students who struggled with the computing aspects appeared to be the biomedical engineering majorsand TE students who had not yet taken TE/ISE 110 or whose grade in TE/ISE 110 was below a "B"; PCC majors seemed to do fine, but they graph a lot in their laboratories. Students' confidence in computing abilities improved in 2009 (qualitative evaluation, since Studetn Satisfaction Survey not done that year) due to more directed focus on picking problems that could only be solved computationally, and giving more directed guidance on how to implement the computational solution.

Self-assessments from 2010 indicated two distinct differences from previous years. First, the video tutorials were helpful in improving the overall confidence and success of students in utilizing computing to solve a problem. However, as Figure 3 indicates, there seemed to be

significantly more percentage of students who would avoid doing the computing problems. The source of this resistance is not known, especially since there was a lot of assistance, including tutorial videos, available to help guide the students through the computing aspects of the problem, and all students have access to computing through College resources if they do not have their own computers (student-owned computing is required in the College of Engineering, thus all but the science majors should have their own laptop).

In general, the instructor recognizes that too much computing integration was attempted for the first iteration. Also, as Table 3 indicates, students did not feel confident of their skills from previous computing courses like ISE/TE 110 by the time that they take thermodynamics, which could be 2-4 semesters later with minimal "reminders" through use in other courses in between. Now that computing is being integrated into more courses in the curriculum (Table 1), student confidence is expected to improve by the time they reach the thermodynamics course. In addition, students need tutorials or other guides to assist them in remembering the content from ISE/TE 110, and on applying computing skills outside courses where they originally learned them.

Lessons Learned

As faculty want to introduce computing or technology into their course, the following lessons learned should assist in providing an easier transition.

1. Instructors should begin the introduction of computing slowly into the course. Start with one or two assignments, and assess the difficulties encountered by the faculty and the students. We have found there is often an underestimation of the time needed to develop and complete assignments as well as the abilities of the students. These assignments can be both in-class assignments if students have access to computers or assignments outside of class, like were done here. In-class computer assignments presents additional challenges that have to be addressed. [1,2] Then, improve the current ones and add additional assignments in coming years.

2. In 2008, a student was required to complete every part of every assignment using Excel and VBA for the first three assignments. The goal was to force them to really utilize computing skills they had learned through lots of reputation. However, two things were observed. The students complained about the simple calculations taking too long or they blindly followed an example without thinking. They had not yet acquired the domain knowledge as observed in Figure 1. It was difficult to ascertain if the students struggled with the material, the computing or both. More importantly, the students lost an appreciation of when computing could be beneficial (i.e., they were turned off). The students could not see the benefit of using computing. Therefore, in later assignments only portions of the assignment were required to use computing, where appropriate. For example, larger problem instances that hand calculations would be difficult (e.g., systems of equations or optimization of set

parameters) or when a "what if" analysis is needed to be performed in order to try several different values and a computer model would make the repetition easier (see, for example, the 2010 problems). The students were also required to reflect or analyze on the results from graphs and results (looking at sensitivity) as observed in the sample homework equations given. These assignments have to be carefully constructed to make sure computing is seen as a benefit so the students can move toward computer competency. A balance of hand calculations to gain the domain knowledge to the use of the computing to answer more elaborate problems.

3. With the varied background of students or the time between the first computing class in the curriculum, it is important to provide a set of computing resources. Even if the instructors take the time to demonstrate the application of using computing to solve an engineering tutorial during class, we have found the need for additional out-of-class resources extremely important. The students may not be very competent yet with the particular tool. These resources could be examples or written instructions or tutorials on solving engineering problems with the tool, or basic tutorials on using the particular computing tool (e.g., solver, data tables). For us, we have created a series of videos illustrating the basic computing modeling tools in Excel and VBA to assist both faculty and students using these tools after the first computing class. We have also created specific videos that utilize a set of tools in solving thermodynamics problems.

4. The resistance of some students to use computing for engineering problem solving is an issue that needs to be addressed by the engineering faculty.

5. Many assignments currently given in engineering courses can be augmented with computing. It is easy for one to ask them to vary several parameters while looking at the effect on several outputs, to increase the number of variables, to graph and reflect on the results, or to optimize a set of parameters to achieve a particular output value. When performing engineering calculations, we often make assumptions in order to model and solve the particular problem, using the power of the computing what if analsyis or monte carlo simulations can be used to explore these assumptions to determine if the have great effect on the output of interest.

Future Directions

In the future, we plan to incorporate one or two more sophisticated computing problems into the assignments, such as a simulation for entropy; giving "skeleton" spreadsheets as a starting point for some problems, especially early in the semester; and more tutorial videos.

In addition, a new research objective will be added to improve assessment. We will compare the performance on exam problems that are correlated with specific computing skills, such as a sensitivity analysis of thermodynamic properties. We will compare exam questions with similar aspects from years before and after computing was introduced to determine if there are any

significant changes. In the Fall 2011, the self confidence surveys will be used again to see how confident they are coming in and leaving the course.

Acknowledgements

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