NOVEL WEB-BASED MODULES FOR A COURSE IN NUMERICAL METHODS

Web based resources are being developed, assessed and disseminated for a typical undergraduate course in Numerical Methods. These resources are holistic, that is, they include pre-requisite information, real-life applications, presentations and textbook notes, simulations, and self-assessment. The student interest and learning are maximized by providing customization of content based on a student's engineering major and computational system of choice. The effectiveness of the resources was measured via two mixed assessment instruments – student satisfaction survey and student performance. Statistical analysis of the assessment data indicates that web-based modules for instruction improved both student satisfaction and performance.

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Mission

We are committed to bringing numerical methods to the engineering undergraduate. Provided free of charge,

- the developers believe in "*having open dissemination of educational materials, philosophy, and modes of thought, that will help lead to fundamental changes in the way colleges and universities utilize the Web as a vehicle for education*" - MIT OCW [1].
- provide resources that are pedagogically neutral[1] but can be modified to suit an instructor's needs.

Below is one of the many conversations[2] the first author has had with undergraduates using numerical methods and computational systems [3-6] to solve problems in engineering courses.

Peter: "Dr. Kaw, I am taking a course in Manufacturing. We need to find an efficient and smooth path that a robot could traverse to inspect holes at 6 specific locations on a $12in \times 12in$ square plate. I am using Maple [4] to fit a 5^{th} order polynomial through the 6 points. But, when I plot the polynomial, it is oscillatory! It is a smooth path but by no means does it look efficient."

Kaw: "As I recall, you took my course in Numerical Methods. What was that – one year ago?"

Peter: "Yes, your memory is sharp but my retention from that course – can we not talk about that!"

Kaw: "Come into my office. I wrote this program using Maple [4]. See this function, $f(x)=1/(1+25\ x^2)$. I am choosing 9 points equidistantly between x = –1 and 1. Now look at the 8^{th} order interpolating polynomial and the original function (Figure 1). Do you see the oscillations in the interpolating polynomial? In 1901, Runge [7] used this example function to show that higher order interpolation is a bad idea. One of the solutions to your problem of the robot path is to use quadratic or cubic spline interpolation option in Maple. That will give you a smooth path with no oscillations."

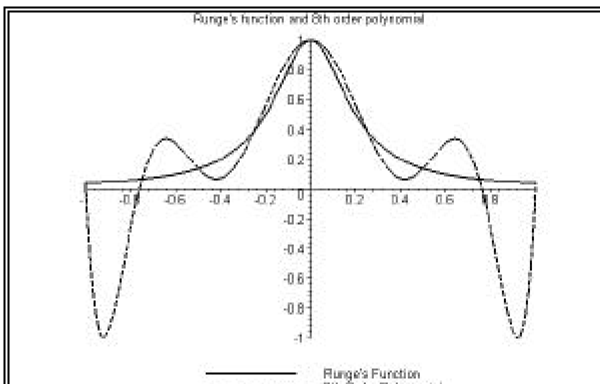

Figure 1: Runge's function used to show that higher order interpolation is a bad idea (The above plot was generated using Maple [4]).

[1] See an example [2] of how we took the resources from the website to make an interactive E-book on Newton-Raphson Method of solving nonlinear equations.

[2] The acts and the names of the characters are real! Resemblance to persons and incidents, past or present, are true and not coincidental.

Most experienced engineering faculty will attest having conversations similar to these with current and former students. In engineering courses, we want our students to gain a comprehensive and conceptual understanding of engineering principles and not have to struggle with the mathematical and numerical aspects of engineering problems. When it comes to applying numerical methods, why do our students in upper level engineering courses face problems like these [8]? The following are some of primary reasons.

- In many US public universities, under legislative pressure, graduation requirements for undergraduate engineering degrees have been reduced 8-10 credit hours to be comparable to liberal arts degrees. To accommodate these reductions, some have dropped the Numerical Methods course or reduced its credit hours. Others programs have bundled numerical methods in courses such as *Quantitative Methods* where students are also expected to learn linear algebra, programming language or computational system, and complex analysis.
- With increasing use and popularity of computational systems [3-6], some curriculums rely too heavily on them rather than on a healthy balance with traditional numerical methods. In such cases, most students lack ability to interpret the results of a computational system.
- Some curriculums introduce numerical methods as per need basis such as introducing simultaneous linear equations in *Statics*, eigenvalues/ eigenvectors in *Vibrations*, and ordinary differential equations in *Circuit Theory or Systems Modeling*. Unless regulated carefully, the course content/depth of numerical methods in such courses can vary substantially between instructors. In universities, such as those of the authors, such regulation is impossible. More than 50% of the upper-level engineering students at the University of South Florida (USF) transfer from various community colleges.
- In universities with large nontraditional students population, such as those of the authors, many students take longer to complete their degrees and retention of course content diminishes dramatically over time. In a recent survey[3] [9] conducted of all the students in the Numerical Methods course at USF, 42% took the pre-requisite course[4] four or more semester prior to enrolling in the Numerical Methods course, 49% work more than 20 hours/week, and 20% anticipate to take more than seven years to finish their undergraduate degree.

All the above reasons become all the more critical when 43% of the 5000 engineering professors surveyed [10] believe that students drop out of engineering school because they have not mastered difficult mathematical skills.

Pedagogy

We are developing web-based modules for faculty teaching and for students enrolled in a junior-level course in Numerical Methods. The unique features of the web-based modules are that they are both *holistic* and *customized*. *Holistically*, the web-based modules (see Figure 2) review essential course background information; present numerical methods through several options - textbook notes, presentations, simulations and assessments; show how course content covered is applied in real life; tell stories to illustrate special topics and pitfalls; and give historical perspectives to the material [11].

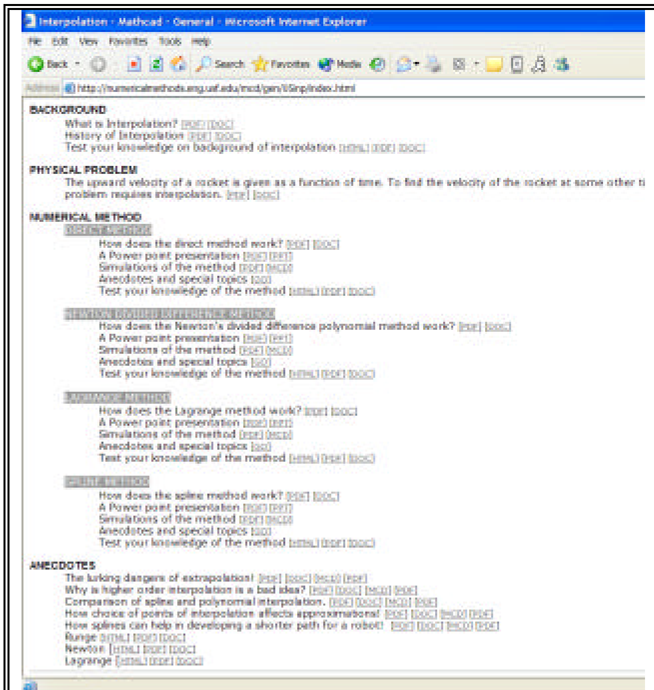

Figure 2: Holistic resources for interpolation for General Engineering and Mathcad [3] option.

[3] The survey included 116 students of the Summer 2001, Summer 2002 and Spring 2003 classes of Numerical Methods at University of South Florida. Other notable results of the survey include: 15% are over the age of 26, 17% are women and underrepresented minorities, 52% are transfer students from community colleges, and 21% are adults over thirty years old who are changing their career path.

[4] In the USF Mechanical Engineering semester-by-semester curriculum, Numerical Methods course is scheduled in the semester following the pre-requisite course - Differential Equations. Numerical Methods also requires retention of course content of Calculus I, II, and III sequence.

From a *customized* view (see Figure 3), faculty and students choose the web-based modules based on their preferred computational system – Mathcad [3], Maple [4], Mathematica [5], Matlab [6], and choice of engineering major - Chemical, Civil, Computer, Electrical, General, Industrial, and Mechanical.

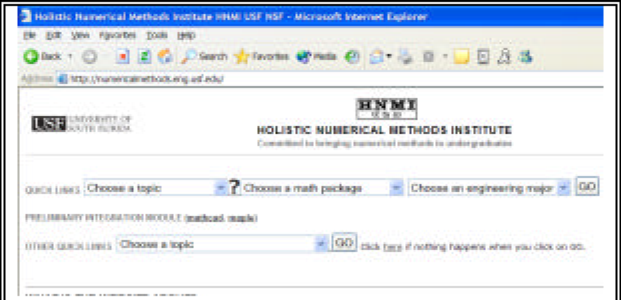

Figure 3. Menu on website to choose computational system and engineering major for a choice of topic.

There are four primary reasons for developing simulations using multiple computational systems.

1. For continuity, cost, and pedagogy, a college may select and employ only one of these packages across their curriculum.
2. There is no additional cost involved if a university already has a site license to just one of the four computational systems.
3. Given a choice, students are typically reluctant to learn a second computational system if they already know one.
4. Those motivated can use an alternate computational system to gain greater proficiency in it.

There are three main reasons for developing resources for several engineering majors.

1. Students are interested in acquiring knowledge and skills directly related to their major or career path. Typically, when Numerical Methods is taught, either instructors focus on the methods while paying little attention to showing applications in the engineering majors or they put most of the emphasis on solving engineering problems via computational systems while spending little time on the algorithms of numerical methods. The web-based modules allow the user to do both by choosing specific real-life examples to illustrate numerical methods applications and procedures from each of the engineering disciplines. For instance, a student majoring in civil engineering may choose an example pertaining to a structural engineering problem that needs to be solved numerically.
2. The examples from seven different engineering majors provide the critical cross-disciplinary opportunity for students and instructors to see how others use numerical methods.
3. It also gives a student access to seven different examples if he or she is facing difficulties in understanding a numerical method.

There is now considerable current research, much done with funding from the National Science Foundation (NSF), exploring how to enhance student learning in science, mathematics, engineering, and technology (SMET) courses. This literature greatly influenced and guided the work presented in this paper. Especially relevant to this paper, for example, is work summarized in the outstanding text *How People Learn* [12].

For example, we know that experts (that is, faculty) "*often forget what is easy and what is difficult for students* [12, p. 32]." This work offers both students and faculty a comprehensive instructional package for simplifying and enhancing the teaching of numerical methods across the engineering curriculum.

Further, research has demonstrated that it is beneficial to provide "*instruction that enables students to see models of how experts organize and solve problems*" and that "*the level of complexity of the models must be tailored to the learners' current levels of knowledge and skills* [12, p. 37]." The design and format of the web-based modules helps students see how experts apply fundamental numerical methods to solve real world engineering problems both within and across different engineering disciplines.

And finally, citing again from this same synthesis of research findings, we know that "*A major goal of schooling is to prepare students for flexible adaptation to new problems and settings* [12, p. 65]" and that "*knowledge that is taught in only a single context is less likely to support flexible knowledge transfer than is knowledge that is taught in multiple contexts* [12, p. 66]." Our effort was to provide instruction opportunity to suit different learning styles [9]. In a survey [9] conducted of 50 students at USF in Spring 2003, when asked about how they learned best, the results were as follows: apprenticeship (42%), incidental (24%), inductive (22%), deductive (8%), and discovery (4%). By enabling students to select both a preferred computational system as well as to select one or more illustrative examples drawn from seven popular engineering majors within each topic area, these interactive instructional modules maximize the likelihood of lasting and flexible learning transfer of essential numerical methods course content.

Content

Once the user selects a track based on one of the seven engineering majors and one of the four computational systems (Figure 3), a menu showing web-based modules (Figure 2) includes the following.

Background Review: In this section, the theory of the mathematical procedure is introduced and discussed based on the ideas introduced in the previously completed mathematics courses. Examples are provided and exact methods are discussed. This lays a foundation for the need for numerical methods, as most problems do not have exact solutions.

Modeling: Students introduced to numerical methods with generic functions and data without direct relation to physical applications easily lose interest in the course. For each mathematical procedure, models (Figure 3) of seven physical examples (corresponding to engineering major) are developed to show the need for finding solutions numerically. The example(s) chosen then become a common theme for developing and comparing different numerical methods.

Numerical Methods and Associated Concepts: The development of commonly used numerical methods is shown for each mathematical procedure. Each numerical method combines both text and interactive simulations. Using anecdotal conversations, such as illustrated in the background section, advantages and pitfalls are discussed, and round off and truncation errors, and convergence of each numerical technique are also simulated. For example, to show extrapolation is dangerous, we include the prediction of the stock market indexes; to show higher order interpolation is a bad idea, we use Runge's function (Figure 1); to show how spline and polynomial interpolation differ, we use calculating the length of the path of a robot as an example (Figure 4).

Self-Assessment: At the end of each section, the student answers a series of well-constructed multiple-choice questions. All multiple-choice options are chosen such that they address common mistakes and myths. The questions are distributed over all levels of objectives of Bloom's taxonomy [13].

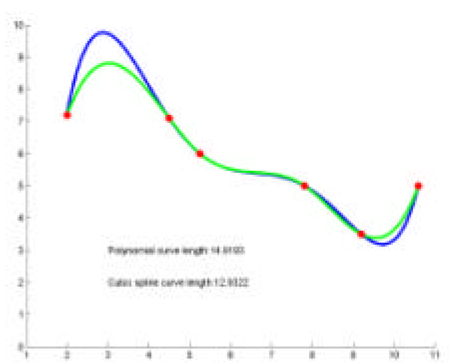

Figure 4. Anecdotal example of finding the length of the path traversed by a robot using polynomial and spline interpolation (The above plot was generated via Mathematica [5]).

Format of Content: All project contents are available in several formats. Text documents are available in three formats - HTML for general format, PDF for printer friendly version, and Word for customization. Simulations are offered in four computational systems - Mathcad, Maple, Mathematica, and Matlab. These simulations can be modified by students to run their own examples. Self-assessment tests are accessible in HTML format for immediate feedback.

Implementation & Assessment Instruments

Many universities currently have multimedia classrooms that are equipped with student computers and instructor stations, internet connections and multimedia projectors. Thus during class sessions, instructors will be able to go to the website and bring the workings of a numerical technique to life.

Questions commonly asked by students in a Numerical Methods course often require the instructor to conduct numerical experiments in class that are time prohibitive during the lecture and thus need to carry over to the next class period. The project contents not only support the spontaneity of answering many classroom questions but also the active engagement of students to run their own simulations in class or at home.

Of comparable importance, in engineering courses where the knowledge of numerical methods or application of a computational system needs to be reviewed or introduced, the website can be used as a reference. Since self-learning and self-assessment of the fundamentals of numerical methods are two of the main features of the project, the instructor can direct a majority of their instructional efforts to teaching engineering fundamentals.

In 2002, as a prototype, we started to develop the web-based modules for two topics in a typical undergraduate Numerical Methods course – Nonlinear Equations and Interpolation. These topics were selected for the prototype, as these are some of the first topics taught in a Numerical Methods course. In the summer semester of 2002, the web-based modules were still in the initial stages of development. This was an appropriate time to measure the student satisfaction and performance *without* the web-based modules.

To measure student satisfaction, a survey was developed that was divided into three distinct sections - reading assignments, class presentation, and problem sets. Each section consisted of the same eight questions [14, Appendix A]. Students answered the questions on the survey on the Likert [15] scale from 1 (truly inadequate) to 7 (truly outstanding).

To measure the student performance, we asked 12 multiple choice questions (6 questions each from Nonlinear Equations and Interpolation) as part of the final examination. The six questions of each topic were based on the corresponding six levels of Bloom's taxonomy - *Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation* [13]. A sample of the final examination questions is given in [14, Appendix B].

Having collected the assessment data from the above two instruments – student satisfaction and performance in the summer semester of 2002, we first implemented and tested the web-based modules tentatively in the spring semester of 2003. The modules were implemented fully in the summer semester of 2003 as follows:

1. *Reading Assignments*: For reading assignment and as a reference to class presentations, the students used the textbook notes from the web-based modules (Figure 2) rather than the assigned commercial textbook. Since the modules are developed for seven different engineering majors, they had access to seven different examples for each numerical method.

2. *Classroom Presentations*:
   a. Before discussing numerical methods for a mathematical procedure, we conducted an in-class and informal diagnostic test on the background information via several questions. This allowed us to review specific material that most students struggle with.
   b. We used PowerPoint presentations to present the Numerical Methods. These presentations were continually supplemented with discussions based on instructor and student questions. Several times during the presentation, students were also paired in class to work out an iteration or a small problem.
   c. Once a week, we met in a computer classroom where each student has access to a computer. Simulations for various numerical methods were conducted. Some of the anecdotal simulations such as
      - showing higher order interpolation is a bad idea,
      - that extrapolation is dangerous, and
      - finding a smooth path of a robot

      were programmed in Maple by students themselves. This active participation was critical in a deeper understanding and ownership of the course material.
3. *Problem Sets*: Modeled after Bloom's taxonomy [13], we developed multiple-choice problems for pre-requisite information and each numerical method. These problems are available on the course website and feedback is immediate. We also developed other problem sets where students needed to work problems through several steps.

To find the effectiveness of the web-based modules, in summer semester of 2003, we used the same assessment instruments of student satisfaction survey and final examination performance as used in summer semester of 2002.

Assessment Results

As mentioned in the previous section, two assessment instruments [11, 13, 16, 17]

1. student satisfaction survey, and
2. student performance,

were used to measure the effectiveness of the web-based modules for instruction.

Summer 2003 is referred as the semester where web-based modules were used while Summer 2002 is referred as the semester where web-based modules were not used.

A. Student Satisfaction Survey

Student satisfaction surveys were given in Summer 2002 (without web-based modules) and in Summer 2003 (with web-based modules). Surveys [14, Appendix A] were given on the individual topics of Nonlinear Equations and Interpolation.

Results of the student surveys (means and two-sample t-test) from Summer 2002 (without web-based modules) and Summer 2003 (with web-based modules) are given in Table 1. Since the sample size (that is, 42 students in Summer 2002 and 27 students in Summer 2003) was low, design of experiments techniques (that is, t-test) were used to validate the accuracy of the results.

Table 1 indicates that the web-based modules were very effective for interpolation and nonlinear equations with a greater than 99.9% level of confidence that the web-based modules increased overall student satisfaction including the individual areas of reading assignments, class presentations, and problem sets. Furthermore, as a result of using web-based modules, the overall student satisfaction increased by about three-quarters to over one-point on the seven-point Likert scale.

B. Student Performance

How well students performed in the course with and without web-based modules was found by asking twelve multiple-choice questions on the final examination [14, Appendix B]). The twelve questions are comprised of

1. Six questions on Nonlinear Equations: Three questions were at low level (*Knowledge, Comprehension, and Application)* of Bloom's taxonomy; the other three were at high level (*Analysis, Synthesis, and Evaluation)* of Bloom's taxonomy.
2. Six questions on Interpolation: Three questions were at low level of Bloom's taxonomy; the other three were at high level of Bloom's taxonomy.

Table 1 – Results of Surveys (number of samples, means, t-values, p-values, and percent confidence level) With and Without Web-Based Modules.

QUESTION	*NONLINEAR EQUATIONS*	*INTERPOLATION*
Without Web	4.57	4.02
With Web	5.27	5.16
Score Diff	+0.70	+1.14
t[5]	-11.22	-18.65
p[6]	<0.001	<0.001
Confidence Level[7]	>99.9%	>99.9%

Each correct answer was given a score of 1 and an incorrect answer was given a score of 0, for a total of 12 possible points. Table 2 shows that the final examination scores increased in each category in Summer 2002 and Summer 2003. Furthermore, in some instances, there was a high level of confidence (that is, greater than 90%) that the final examination scores increased because of web-based modules.

[5] The *t* value is the test statistic [18, chapter 2].
[6] The *p* value (or performance measure) is the value of the t distribution at the test statistic (or the left tail of the distribution) [18, chapter 2].
[7] The confidence level, in percent, is simply *100(1-p)*.

Table 2 – Results of Final Examination Scores (number of samples, means, t-values, p-values, and percent confidence level) With and Without Web-Based Modules for Instruction.

CATEGORY	*TOTAL*	*LOW BLOOM*	*HIGH BLOOM*
Without Web	6.45	3.12	3.33
With Web	7.44	3.67	3.78
Score Diff	+0.99	+0.55	+0.45
t	-2.50	-2.22	-1.54
p	0.008	0.016	0.085
Confidence Level	99.2%	98.4%	91.5%

However, we found that the mean GPA in the pre-requisite mathematics courses (that is, Calculus I, Calculus II, Calculus III, and Ordinary Differential Equations) of students in Summer 2003 was nearly 9% higher (2.81 on a scale of 4) than in Summer 2002 (2.59 on a scale of 4).

This leads to a question – Did the final exam scores improve in Summer 2003 because of the introduction of the web-based modules or was it the higher mean pre-requisite GPA (MPGPA) of the students?

To address this question, students' final examination scores in both semesters were separated, based on two criteria

1. pre-requisite GPA was above or below the MPGPA (2.68 on a scale of 4 for all students in both summer semesters of 2002 and 2003) of both semesters (42 students in Summer 2002 without web-based modules, and 27 students in Summer 2003 with web-based modules), and
2. web-based modules were used or not.

We found that regardless of pre-requisite GPA, students with web-based modules performed better on the final examination in all categories but that of the score in High Level Bloom category for students below MPGPA (details are given in [14]).

Hence, students' use of web-based modules shows improved scores; however, the effect of the web is not perfectly evident yet.

To determine further the effect of the web-based modules, a two-factor ANOVA design of experiments (that is, an Analysis of Variance) with two levels for each factor, was performed [18, chapter 3]. An Analysis of Variance is used to compare student performance based upon various factors, such as, web-based instruction and MPGPA. The rationale for performing a two-factor design of experiments is to determine the student performance of the well-prepared students (that is, pre-requisite GPA higher than MPGPA) and poorly prepared students (that is, pre-requisite GPA lower than MPGPA), with and without the use of web-based modules. This analysis summarily yielded (the details are given in [14]) that with 90% confidence level there is no significant interaction between factors, that is, the use of web-based modules increased the final examination scores, regardless of the pre-requisite GPA.

Conclusions

Web based resources are being developed for an undergraduate course in Numerical Methods (http://numericalmethods.eng.usf.edu). The web modules are holistic in nature. They provide a contextual background and history of numerical methods, and further motivate students to learn fundamentals through real life applications, presentations, textbook style notes, and simulations of methods including convergence and pitfalls, and self-assessment.

The student interest and learning are maximized by providing customization of content based on 28 tracks based on seven engineering majors (Chemical, Civil, Computer, General, Industrial, Electrical and Mechanical Engineering) and four computational systems (Maple, Mathcad, Mathematica and Matlab). The motivation for having 28 tracks is based on teaching students by what major they are enrolled or interested in, and what computational system is available or taught to them.

The resources are offered conveniently through anytime-anywhere web access throughout one's degree program and hence broadly impact students and faculty of a Numerical Methods course as well as of engineering courses where numerical methods and computational systems are used. It is free of charge to anyone in the world.

The effectiveness of web-based modules is measured and shown to be successful for a course in Numerical Methods. First, we see an increase (with greater than 99.9% confidence) in student satisfaction in three areas - classroom presentations, reading assignments, and problem sets. Secondly, we found an increase in student performance via a twelve question multiple choice question examination that was formulated using Bloom's taxonomy.

Current State of Project

Based on the positive findings in this paper, the feedback received from students and instructors, and with renewed funding from National Science Foundation of USA until March 2007, we are adding web-based modules for four more topics - Simultaneous Linear Equations, Regression, Integration, Differential Equations. In 2006, we plan to seek funding for two more modules - Differentiation and Fundamentals of Scientific Computing to complete the resources for a typical undergraduate course in Numerical Methods.

We are currently using the three assessment tools not only at University of South Florida, but also at Florida A&M University (FAMU) and Wright State University (WSU). This partnership among three universities is allowing us to measure the effectiveness of the web-based modules in a diverse student population -

- underrepresented minorities and women in engineering (FAMU),
- transfer and over traditional-age adult students (USF),
- diverse engineering majors – Mechanical, Electrical, Chemical, and Biomedical,
- class sizes – small (FAMU), medium (WSU), and large (USF),

- computational systems (Matlab at FAMU and WSU, and Maple at USF).

We anticipate formally presenting and publishing the assessment results for the full course in 2008.

Resources

The complete resources [11] of this paper are given at http://numericalmethods.eng.usf.edu.

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