Simulation-Visualization and Self-Assessment Modules' Capabilities in Structural Analysis Course Including Survey Analysis Results

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Abstract

In this paper, we describe an approach to analyze 2D truss, frame, and beam structures in a Flash-based environment. The Stiffness Matrix Method (SMM) module was developed as part of an ongoing project under the broad topic "Students' Learning Improvements in Science, Technology, Engineering and Mathematics (STEM) Related Areas" at Old Dominion University (ODU), and funded by the National Science Foundation (NSF). In this web-based simulation, 2D Civil Engineering models for truss, frame, and beam structures can be created and analyzed with appropriately specified material properties, boundary conditions, and loads. The entire process for creating and analyzing structural models can be done online with user-friendly web-based tools. The module can be viewed at http://www.lions.odu.edu/~amoha006. Tutorials and demonstrated movies of the actual implementation of the models are provided to help learners/users become more comfortable using the module. A theoretical description provides a detailed explanation of the theories behind the developed module. After the analysis is completed, the deflected shape of the structure and its member stress intensities are plotted. A self-assessment test module was developed which automatically grades the student's answers by comparing them with the computer-generated solutions. The student's graded test score and the corresponding correct answers are automatically sent back to both the instructor and student through their email addresses. A survey was conducted between two classes in Spring '07 (without students being exposed to the developed SMM module) and Spring '08 (with SMM module) in a Structural Analysis I course at ODU. Preliminary results from the surveys have indicated that significant improvements in students' performance have been realized through the developed on-line SMM module.

Keywords: Structural Analysis Course, Numerical Simulation & Visualization, Self-graded/Self-Assessment Tests, Stiffness Matrix Method, Improved STEM education.

Introduction

The Stiffness Matrix Method (SMM) is a very general and powerful method that employs matrix linear algebra operations to find joint displacements and/or member stresses of Civil Engineering structures (such as buildings, bridges, nuclear power plants) subjected to applied mechanical, wind, or earthquake loads. SMM module has been developed and evolved for CEE (Civil and Environmental Engineering) - 310 Structural Analysis[11, 3, 4,] a junior-level course required for the Bachelor of Science in Civil Engineering program at Old Dominion University (ODU). The module was recently implemented and assessed during the Spring 2008 semester. The module development and implementation is part of an ongoing transformation of undergraduate education at ODU which seeks to integrate technology-based student learning tools into a number of undergraduate engineering courses. Twelve faculty members from three engineering departments are participating in a National Science Foundation (NSF) supported project that uses simulation and visualization to enhance the quality of engineering education. The motivation for this transformation comes from the fact that general undergraduate students (especially engineering students) have much greater familiarity with and inclination to use computers, internet, and videogames as compared to their counterparts a generation ago. In order to accommodate these computer–savvy visual learners, it is important to develop web-based tools for undergraduate engineering education that are based in simulation and visualization, and that can be used at "any time, any place." Since the students only need internet access to use the tools, the students can learn from these teaching tools and materials at their convenience.

The SMM module (http://www.lions.odu.edu/~amoha006) includes brief reading sections on various components of the SMM process and the theoretical backgrounds behind the developed formulas adopted for calculations. The reading sections are followed by an interactive application unit, which includes the computation of the structural responses (such as nodal displacements, member-end-actions and support reactions), visualization and animation (such as plots of un-deformed and de-

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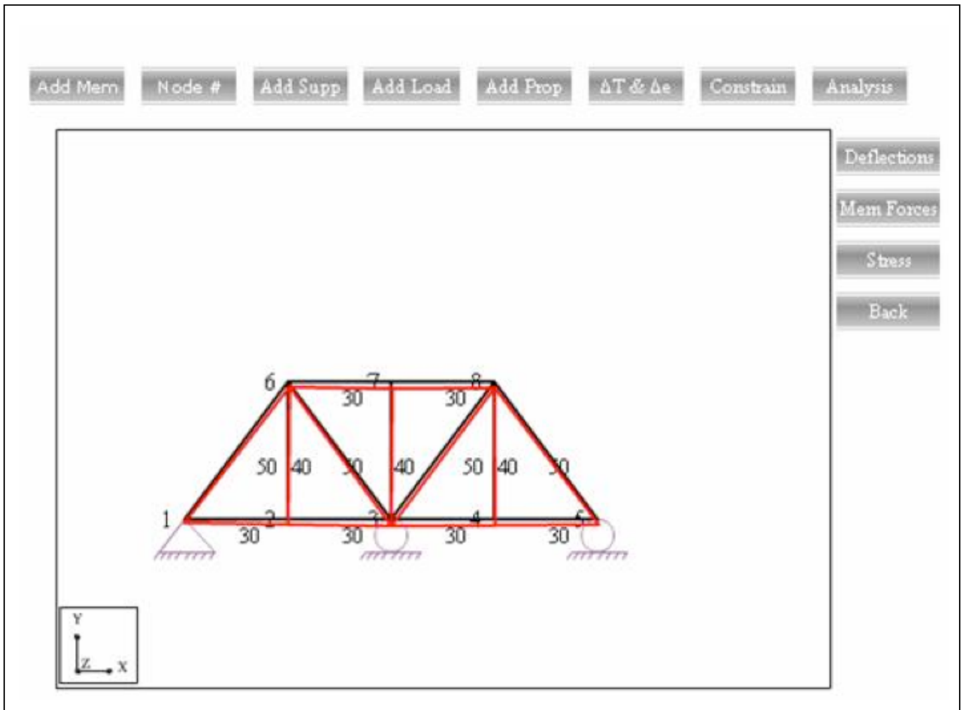


Figure 1: Deflected Shape for Support "Settlements" Bridge (Truss) Example.

formed structures)$_5$, with highlighted observations to enhance student learning. Students are then assigned exercises, which require both hand calculations and the use of the interactive unit. Figure 1 shows an example of the interactive (and visual) application unit for the "pre-processing" phase (to create the structural "bridge" model using the developed SMM module). This pre-processing phase is followed by the structural "analysis/computation" (to calculate the structural responses) and "post-processing" (to display the structural responses in the "graphical" forms) phases (see Figure 1).

The objectives and the outcomes of the module and their mapping are shown in Table 1. The table also includes the level of achievement for each outcome targets in relation to Bloom's taxonomy$_2$. In Table 1, corresponding to each outcome, a cross symbol (x) means this outcome can be used (and measured) to evaluate if Objective 1 and/or Objective 2 is met.

Figure 2 displays the layout of the module's structure. It also shows how the various components of the module contribute to the outcomes as well as the practicality, hierarchical, connectivity and the viscompana (VISualization, COMPutation, ANAlysis) characteristics.

A few definitions associated with Figure 2 are given below:

Viscompana: It is an abbreviation for visualization, computation and analysis

Objectives and Outcomes	Bloom's Level of Achievement	Objective 1: Students are able to compute/verify the structural responses (using either SMM and/or other methods learned from CEE 310 course)	Objective 2: Students can conduct "what if" studies, and are familiar with modern computer software/hardware technology
Outcome 1: Students can create the structural model/problem (in a user-friendly, interactive, visual environment)	Knowledge	X	X
Outcome 2: Students can compute "element" stiffness matrices, in both local & global references	Comprehension (level 1)	X	
Outcome 3: Students can "assemble" the "global" stiffness matrix, load vector and impose proper "boundary conditions"	Comprehension (level 2)	X	
Outcome 4: Students can compute and visualize the structural responses	Application/Analysis	X	X
Outcome 5: Students can conduct "what if" studies, interpreting the results and identify/fix potential errors made in earlier phase (such as creating an unstable/improper structural model)	Analysis/Synthesis	X	X

Table 1: Objectives and Outcomes of the Developed SMM Module

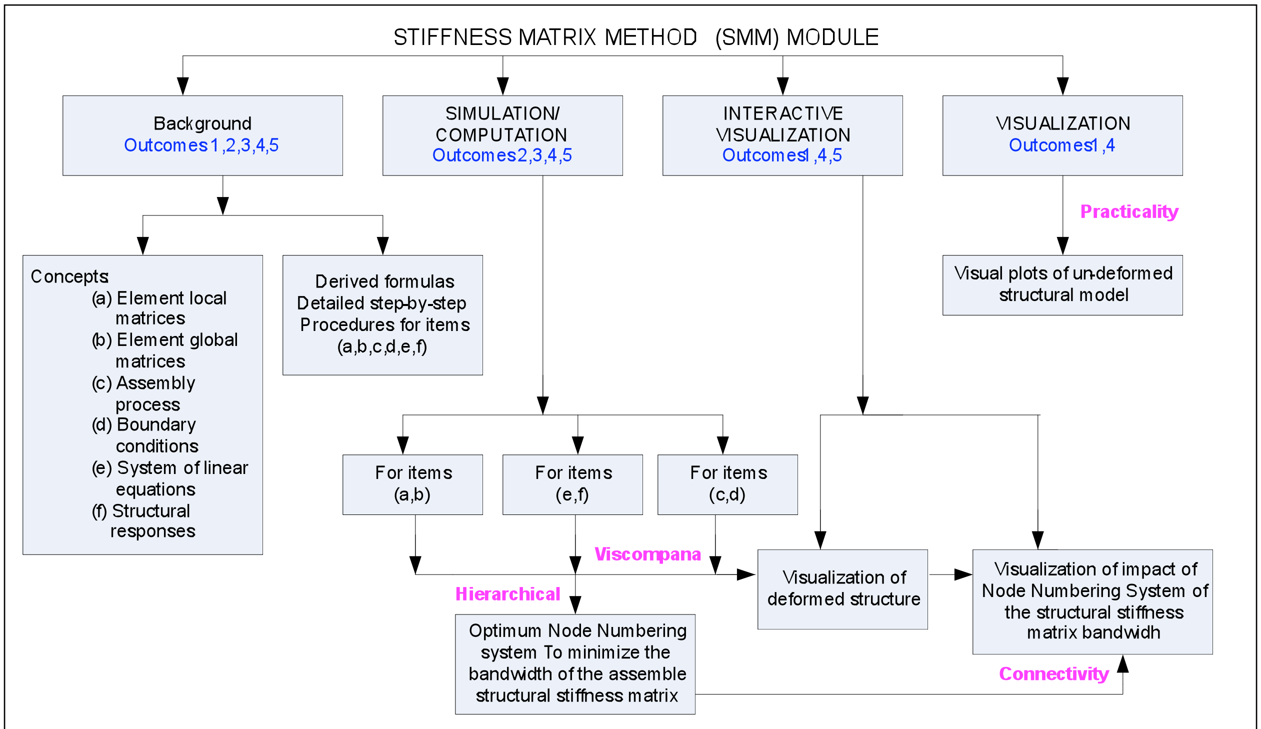


Figure 2: Layout of Stiffness Matrix Method (SMM) Module.

In this component, the Civil Engineering (CE) structures (such as bridges, buildings, or dams) can be graphically plotted and visualized. The analysis of CE structures can be done with the computation of joint displacements and element stresses by the SMM module.

Hierarchical: It refers to a module characteristics that signifies hierarchy, from simple to more complex levels of analysis, or arrangement of subject matter in the module.

As an example, in order to efficiently find/solve for joint displacements (or structural responses, see item "f" in Figure 2) of the Civil Engineering (CE) structures, one also needs to learn/know how to optimally assign the node numbering system.

Connectivity: Or interconnectivity, refers to a module characteristics that relates or connects a subject matter presented before or after the module with subject matter presented in the module.

As an example, before solving the SLE (Simultaneous Linear Equations) in order to obtain the structural joint displacements, as mentioned in items "e" and "f", one needs to incorporate the boundary (or support) conditions into the assembly process and the SLE.

Practicality: Refers to practical applications of the module in a real-life context.

As an example, a (2-dimensional) slice of a real-life (3-dimensional) bridge structure can be analyzed and visually seen by the authors' developed program.

The web-based module has been assessed by comparing two sets of students, one who had access to the module and used it during the Spring '08 semester. This group is designated as the experimental group. The control group did not have access to the module, and the group's learning was based only on conventional classroom teaching (in the Spring '07 semester). Both groups were evaluated using tests administered during the course. A comparison and a simple analysis of these two groups' performance are used to determine the efficiency of the module for student learning enhancement. These results are reported in this paper.

The comparison of pre-module and post-module test results will demonstrate how successful the module is. The assessment rubric shown in Table 2 will be used to prepare and grade these tests.

Theoretical Background for the Stiffness Matrix Method:

The entire Stiffness Matrix Method (SMM) will involve the following major components (also refer to Figure 2):

Outcome	Attempted	Marginal	Acceptable	Excellent
1	Little/no knowledge of what data is required to create a structural model/problem.	Can identify some data required to create a structural model.	Can identify most data required, but have difficulty to follow interactive instructions to (visually) create a structural model.	Can identify all data required and to visually/interactively create a structural model.
2	Inadequate ability to identify the degree-of-freedom (dof), size and rotational matrices associated with a particular truss/beam/frame element	Knows to identify the dof and size of element matrices, but can't compute numerical values of element stiffness matrix in local references	Can compute the element stiffness matrix in local references.	Knows to transform element stiffness matrix from local to global references.
3	Inadequate ability to determine the locations of element stiffness within the "structural" stiffness matrix. Also does NOT know how to impose "boundary conditions"	Knows to place the locations of element stiffness matrices in a structural stiffness matrix. However, still confuse to handle "over-lap" terms.	Knows how to "assemble" the structural stiffness matrix. Still have some difficulty to impose "boundary conditions".	Completely understand the assembly process, including properly imposed "boundary conditions".
4	Can't recognize the roles of linear equation solver (to solve for nodal displacements). Have no ideas to compute member-end-actions, support reactions. Have no abilities to interpret the obtained results.	Knows to compute the nodal displacements, and member-end-actions.	Knows to compute all structural responses. However, still has some difficulty to interpret the computed results.	Knows to compute all structural responses, and have abilities to interpret the computed results.
5	Can't identify important parameters that have impacts on the structural responses. No abilities to apply the SMM software to conduct "what if" studies. Can't identify/fix errors made in preparing the structural model.	Can identify some important parameters for conducting "what if" studies.	Can identify most (or all) important parameters for "what if" studies.	Can conduct all "what if" studies, interpreting the computed results and be able to identify/fix potential errors made in earlier phase (such as preparing the input structural model).

Table 2. Assessment Rubric for the Stiffness Matrix Method (SMM) Module

(a) Element local matrices: In this step, the individual "element" equations are established in its own "local" coordinate references.

(b) Element global matrices: In this step, each set of the above "element" equations are transformed into the "system", or global," coordinate references.

(c) Assembly process: In this step, all the elements' (global) matrices are assembled (or added) in order to form the "system, (or global,)" equations.

(d) Boundary conditions: In this step, the appropriated boundary conditions (or structural supports) need be incorporated into the above assembled (global) equations.

(e) Solution of system of linear equations: In this step, a set of SLE has to be solved in order to obtain the structural joint displacements.

(f) Structural responses: In this step, each structural element's stresses can be solved, by utilizing the joint displacements found (or computed) in the above step.

Details of the above key components has been explained and presented in the ODU website http://www.lions.odu.edu/~amoha006 (Then click on the theoretical development module). More advanced treatments of the above item (e) can be found in references 6, 7. and 10.

An Example:

Indeterminate Truss with Support Settlements (see Figure 1)

This example has been extracted from Example 7 in the theoretical development module at http://www.lions.odu.edu/~amoha006.

Several other examples and theoretical developments presented on the above ODU website have also been discussed in references [1, 3, 4, 8, 9, and 11].

Compute the bar forces in this 2-D truss (or bridge) structure, due to the following support (earthquake) settlements.

$E=30x\ 10^3$ kips/in^2.

Support (at joint 1) vertical displacement = 0.24 in. down.

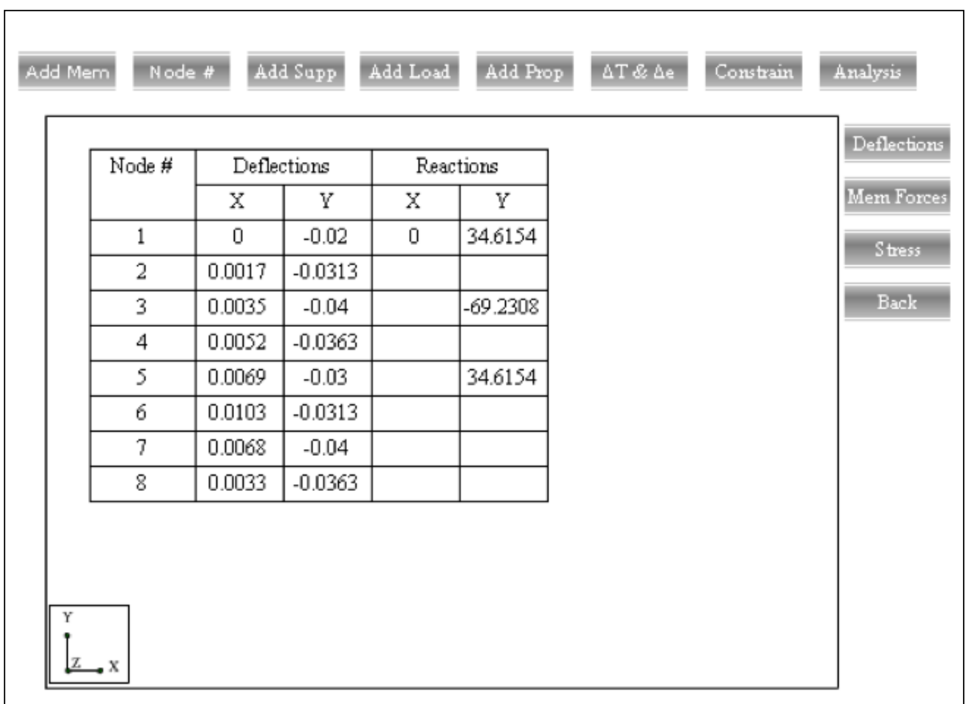
Support (at joint 3) vertical displacement = 0.48 in. down.

Support (at joint 5) vertical displacement = 0.36 in. down.

All members have the same cross-sectional area (= 10in^2). The output results (nodal joint deflections and support reaction forces) are plotted/shown in Figure1, and Figure 3, respectively.

Student Self-Assessment Test (in none_multiple choice style):

The self-assessment module is a friendly (and critically important) module where students can assess their own performance. In this module, a separate set of (randomly generated) questions were designed for 2-D truss, beam and/or frame problems. Students choose whether they want to be tested on truss, beam, or frame problems. The results of the test are automatically graded and sent to the instructor and student by email. The main advantage of this module is that the student has to compute some "detail, intermediate" variables before



Node #	Deflections		Reactions	
	X	Y	X	Y
1	0	-0.02	0	34.6154
2	0.0017	-0.0313		
3	0.0035	-0.04		-69.2308
4	0.0052	-0.0363		
5	0.0069	-0.03		34.6154
6	0.0103	-0.0313		
7	0.0068	-0.04		
8	0.0033	-0.0363		

Figure 3: Deflections and reactions for support "settlements" example.

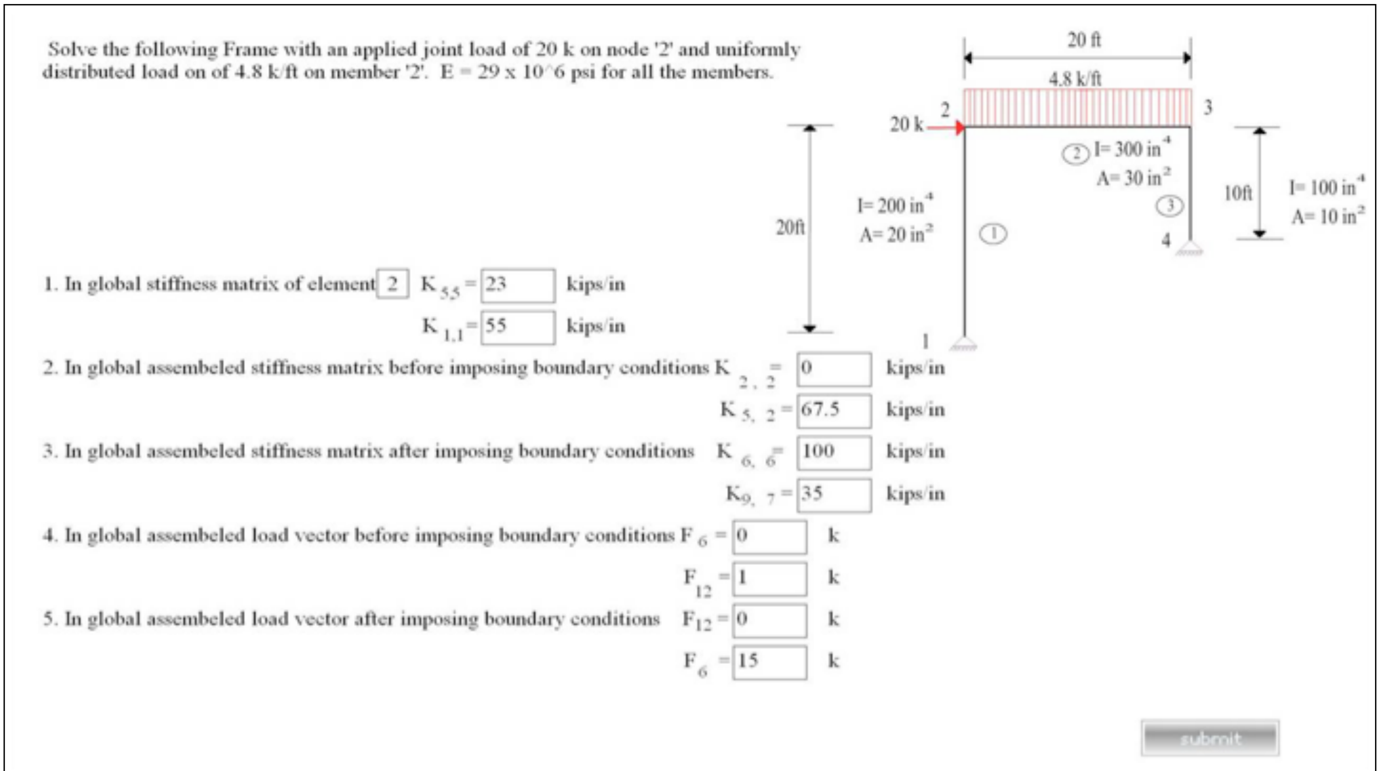


Figure 4: Self-Assessment Test: Frame problem (Students will enter his/her answers in the textbox provided).

Self Test CEE 310 Inbox

Ahmed Ali Mohammed <ahmedali484@gmail.com> show details 2:43 pm (4 r

Name:subhash

UIN:-1234567

Test Type:frame

Student Answers

1:23

2:55

3:0

4:67.5

5:100

6:35

7:0

8:1

9:0

10:15

Actual Answers

1:7.55208333333333

2:3625

3:2416.66666666667

4:1.47664990112384e-13

5:241666.666666667

6:1208.33333333333

7:-1920

8:0

9:0

10:-1920

Score

1:35

2:35

3:35

4:35

5:35

6:35

7:35

8:35

9:100

10:35

Average Scored:41.5

Figure 5: Self-Assessment results and graded score are included in each student's email.

getting their "final" answers. While the final answers can be obtained by the student through the developed "Interactive Simulation & Visualization Module" (See http://www.lions.odu.edu/~amoha006), the intermediate answers are intentionally unrevealed, for the student's self-assessment purpose! The grading policy adopted in this module is as follows: students receive 100% for each correct answer and 35% for partial credit for a wrong answer. At the end, the student's average test score is calculated and sent via email, along with the student's answers and the correct answers (automatically generated/printed by the computer). The grading policy of this module can be changed according to the instructor's choice. This is also a very helpful module for instructors, since they do not have to "painfully grade" students' tests (especially for those classes with high student enrollments!).

Educational and Research Values of the Developed Software Package:

The developed user-friendly, interactive, visualized software package VIS_SA (VISualized Structural Analysis) is based on the Stiffness Matrix Method (SMM) and took full advantage of the highly visualized and menu-driven capabilities of Macromedia FLASH computer environments[5]. Both the educational and research values offered from this work are summarized in the following paragraphs.

Educational values

(a) Special efforts have been made to explain the theoretical (and all equations derived) in a simple/complete manner, so that the students can read and understand the materials without (or with minimum) help from the instructor.

(b) By exploiting the graphical and menu-driven capabilities, provided by the FLASH environment, students can easily learn how to use the developed, powerful VIS_SA software in just few minutes.

(c) For the specific SMM topic, not only can students get the final results (such as nodal displacement, support reactions, member-end-actions, etc.) to compare with their own (hand-calculated) results, but they can also compare the intermediate results in order to understand where they have made errors. For other topics in the Structural Analysis I course (such as Virtual Work, Moment Area Theorems, Super-position methods for Indeterminate structures, Slope Deflection, Moment Distribution methods, etc.), the developed VIS_SA code (for SMM topic) is still useful for verifying students' final solutions (with VIS_SA's solutions)

(d) Students can quickly create "extra" homework problems, with known solutions (through VIS_SA) to further enhance their understanding on SMM (and other) topics. Different "what-if" scenarios (for analysis and optimal design) can be easily conducted. The students' learning enhancement can be made more fun through extensive usage of the colorful, graphical and menu-driven capabilities provided by VIS_SA.

(e) The instructor (using the software VIS_SA) can create new homework assignments, regular tests, and final examinations in just few minutes. Hence, the problems of giving the same homeworks or tests every year (to save the instructor's preparation time!) and students' passing old homework or tests to other students in subsequent years can be eliminated.

(f) Through our developed "Self-Assessment Module", we have basically created endless self-assessment tests for students' practices that do not have to be graded by the instructor!

Through this work, both the instructor and students are also given a set of clear lecture notes, presented in an attractive PowerPoint presentation and also made available on the website. Students can freely download these instructional materials from the site and learn these topics at their own convenience.

Research values

The developed software package, VIS_SA, is not only user-friendly, interactive and highly visual, but it also has many advanced capabilities. Example #9 (see http://www.lions.odu.edu/~amoha006, theoretical development module) has clearly demonstrated VIS_SA's capacity to handle quite general and complicated truss structures. More advanced graduate courses (such as Finite Element Analysis or Sparse High Performance Computing), and newly created research algorithms can be quickly validated by the VIS_SA software on small to medium-scale tested examples, before conducting more testing on larger-scale problems.

Comparisons of Students' Performance Test Scores In Spring '2007 and Spring '2008 Semesters – Surveys and Results:

In Figure 6, we have compared the effect of implementing the module in two semesters. A total of 34 students participated in Spring'

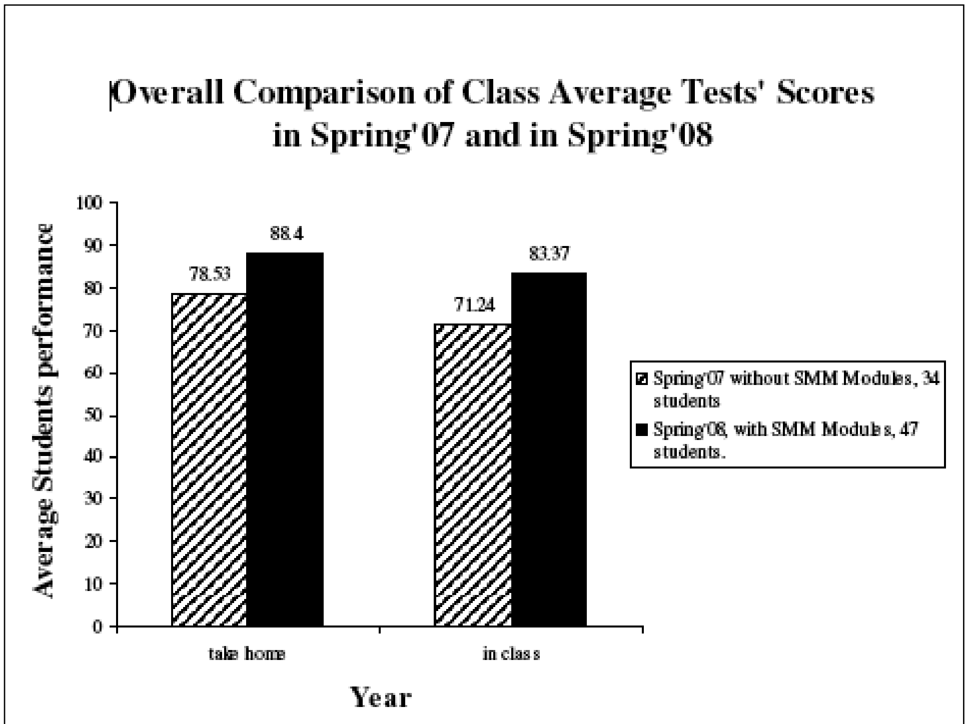


Figure 6: Overall comparison of Class Average Tests' Scores in Spring'07 and in Spring'08.

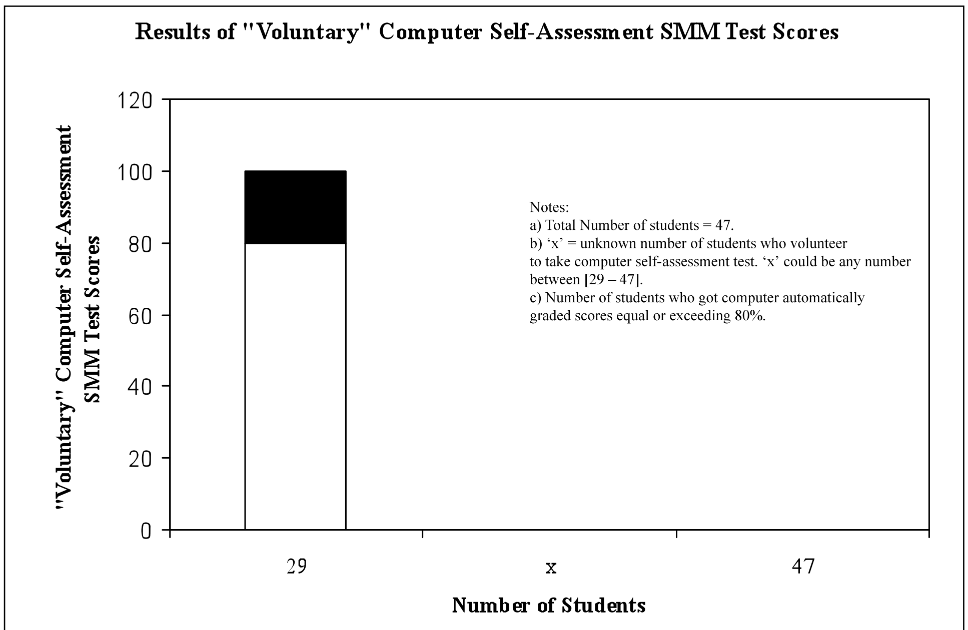


Figure 7: Results of "Voluntary" Computer Self-Assessment SMM test scores.

07, and 47 students participated in Spring '08 survey, respectively. We have compared the performance of Structural Analysis class in Spring '07 (without using the SMM module) and Spring'08 (using developed module). Two tests, a take home exam and an in-class exam, were conducted in this study. In both tests (during Spring'07 and Spring'08 semesters), the questions are framed in such a way that the question style and level of difficulty are essentially identical; only the numerical values are different. The results for both tests (in class and take home) have clearly indicated that the developed SMM module does help students' performance. Students in the experimental group exhibited

a 12.57% $= \frac{88.4 - 78.53}{78.53}$

improvement in the take home exam

and a 17.03% $= \frac{83.37 - 71.24}{71.24}$

improvement in the in-class exam.

In order to evaluate the effectiveness of the developed Computer Self Assessment Structural Analysis module, students in the Spring'08 semester Structural Analysis class were asked to voluntarily assess their understanding about the SMM module through the computer self-generated assessment tests.

As indicated in Figure 7, 29 of the 47 students in the Spring '08 class scored higher than 80% on the performance test (as automatically reported to the instructor) The system has been designed such that only students with performance scores of at least 80% were reported to the instructor by emails. Thus, the designed system will allow students to keep practicing their assessment tests until a certain level of mastering the subject matters (indicated by a test score say, 80% or better) can be achieved. Since the student's test score and the collected solutions are sent back to them by email, the student can review their mistakes at their convenient time, and as many times as needed.

In Figure 7, 'x' represents the actual number of students who participated in the self -assessment tests ('x' could be any number between 29 and 47 students). For example, there could be 32 voluntarily participated students, however, only 29 students had scores above 80%. The result in Figure 7 does seem to indicate that the developed simulation and assessment modules help students' performance in Structural Analysis course.

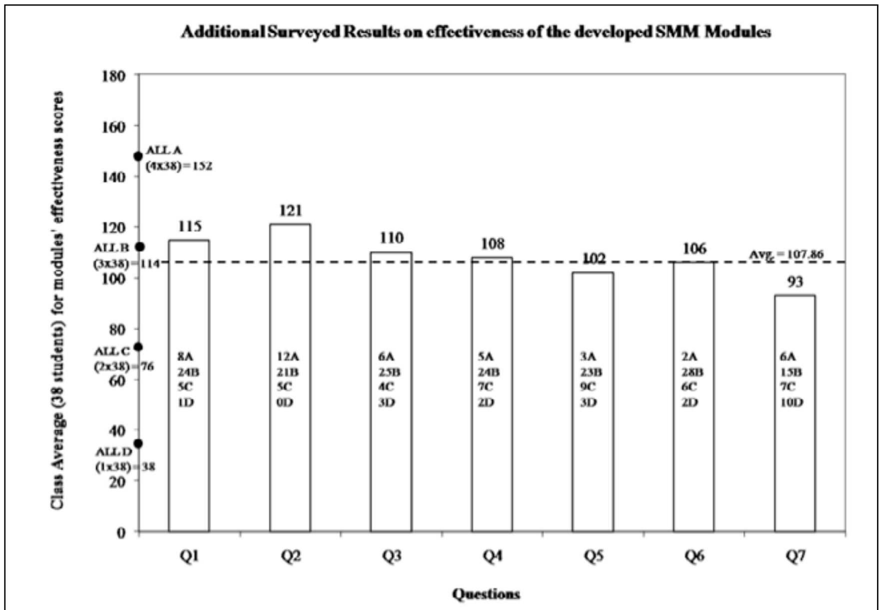


Figure 8: Surveyed results of effectiveness of the developed SMM modules.

Remarks on Figure 6 and Figure 7:

The take-home and in-class exams have been carefully designed to reflect the objective and outcome as mentioned in Table 1 and Table 2.

In order to understand more about the impact of the developed simulation and assessment

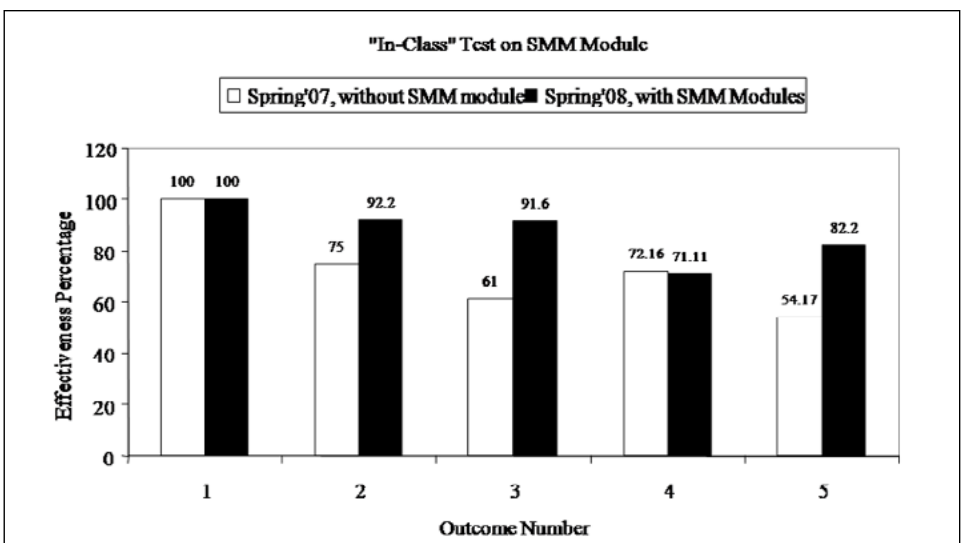


Figure 9: Results of "In-class" test on SMM module.

modules on students' performance, a seven-question survey was developed:

The ratings (for the following questionnaire) can be quantified as:

A = 4 points (Definitely Agree), B = 3 points (Agree), C = 2 points (Not Sure), D = 1 point (Not Agree)

Questions	**Selected Rating**			
The developed web-based Stiffness Matrix Method (SMM) modules will:				
1. Improve students' ability to solve SMM homeworks' problems.	A	B	C	D
2. Improve students' performance scores in SMM (take-home) exam.	A	B	C	D
3. Improve students' performance scores in SMM (in-class) exam.	A	B	C	D
4. Improve students' ability for better understanding of SMM lecture materials.	A	B	C	D
5. Help students to have more interests (through graphical displayed inputs and colorful output plots) in learning/practicing SMM materials.	A	B	C	D
6. Help students to accurately assessed (through automated, self-grading assessment tests) his/her understandings about the SMM module.	A	B	C	D
7. Help students to identify his/her errors in calculating some "intermediate" steps of the entire solution process.	A	B	C	D

As indicated in Figure 8, 38 students were participated in Spring'08 Structural Analysis class (for this particular survey date).

For question 1, the class average score voted by the students was $\frac{115}{38} = 3.03$ which is slightly between B and A range. Noting that

$$115 = 8 * (A = 4) + 24 * (B = 3) + 5 * (C = 2) + 1 * (D = 1)$$

For question 2, the average score voted by the students was $\frac{121}{38} = 3.18$ which is slightly between B and A range.

For question 3, the average score voted by the students was $\frac{110}{38} = 2.89$ which is very close to B range.

For question 4, the average score voted by the students was $\frac{108}{38} = 2.84$ which is close to B range.

For question 5, the average score voted by the students was $\frac{102}{38} = 2.68$ which is close to B range.

For question 6, the average score voted by the students was $\frac{106}{38} = 2.79$ which is close to B range.

For question 7, the average score voted by the students was $\frac{93}{38} = 2.45$ which is near the middle of C and B range.

The overall student voted score for all seven questions were shown in Figure 8 as

$$Avg = \frac{115 + 121 + 110 + 108 + 102 + 106 + 93}{38 \times 7} = \frac{755}{266} = 2.84$$ which is very close to B range.

Also noting that $\frac{755}{7} = 107.86,$ as shown in Figure 8.

Thus it could be concluded from Figure 8 that the students' voted score for each of the seven questions, and the average of all seven questions are both at (or near) the B range.

Since the in-class test might offer better indication of the true students' performance as compared to the take home exam, the five outcomes mentioned in Table 1 were used as a guide to design the in-class test for both the Spring '07 and Spring '08 semesters of the Structural Analysis class.

Note:

The results shown in Figure 9 seem to indicate that students' performance in Spring'08 class (using the developed SMM module) was much better than the ones in Spring'07 (without using SMM module) with regard to outcome numbers 2, 3 and 5, and without significant changes with respect to outcome numbers 1 and 4.

Conclusions and Future Work:

In this paper, we have presented a general/unified framework for developing simple, user-friendly interactive and highly visualized software VIS_SA for enhancing students' learning capabilities for the SMM module, which is one of the topics covered in the required Structural Analysis I course. The developed software leverages menu-driven and graphical capabilities offered by Macromedia FLASH computer environments to make the learning process more interesting. Numerous examples have been used to test different capabilities of the VIS_SA software. The VIS_SA software has significant potential for educational and research applications. Preliminary analysis of survey data (see Figure 6) conducted in the Spring 2007 (without using the developed SMM module), and in Spring '2008 (students were allowed to have access to the SMM module) have shown a 71.24% to 83.27% improvements (for in-class exam) and 78.53% to 88.4% (for take-home exam) improvement in students' performance test scores. We plan to continue to monitor/survey the performance of the students who have access to the developed SMM modules in the next few years. These additional results will also be reported in the near future. Current efforts include the expansion of VIS_SA for 3D truss, beam and frame for more extensive structural engineering applications. A built-in "intelligent" learning process is being developed (such as printing some intermediate warning messages when potential errors are made by students) to help students to detect and correct the errors made, hence improving the learning process.

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Prof. Nguyen has been a Civil Engineering faculty member at ODU since 1985. His teaching (including his 3 textbooks, published in 1999, 2002 & 2006, respectively) & research activities (nearly $3.3 million funded projects) in Numerical Methods, Large-scale Parallel Algorithms & Software Developments have led to several international, national and regional awards. As a senior investigator of the (already completed) NSF Educational Grant (August 2004 – August 2007) and 2 ongoing STEM Educational Grants (June 2008 – December 2011), Dr. Nguyen's team has developed the Stiffness Matrix Method (SMM) modules on the Internet for teaching purposes, which include theoretical, computer simulation & a computer self-assessment test (with automated grading test scores, delivered to students by emails). More details can be found at http://www.lions.odu.edu/~amoha006.
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