AC 2008-1128: DEVELOPING AND ASSESSING ENGINEERING-BASED MODULES FOR A FRESHMAN ENGINEERING CLASS

Joe Guarino, Boise State University
Dr. Guarino is a Professor of Mechanical and Biomedical Engineering at the College of Engineering, Boise State University.

Janet Callahan, Boise State University
Dr. Callahan is Associate Dean for Academic Affairs and Professor of Materials Science Engineering at the College of Engineering, Boise State University.

Seung Youn Chyung, Boise State University
Dr. Chyung is an Associate Professor in the Department of Instructional & Performance Technology in the College of Engineering at Boise State University.

Randi Walters, Boise State University
Randi Walters is a Junior majoring in Geosciences at Boise State University. Ms. Walters is also a tutor and peer instructor for the Engineering with Precalculus class offered by the College of Engineering at Boise State University.

Bill Clement, Boise State University
Dr. Clement is an Associate Research Professor in the Center for the Geophysical Investigation of the Shallow Subsurface (CGISS), at Boise State University.

Developing and Assessing Engineering-Based Modules for a Freshman Engineering Class

Abstract

Most freshman engineering students at our University take precalculus (MATH 147) as their first math course. These students are strongly encouraged to take a companion course called Engineering with Precalculus (ENGR 110). ENGR 110 is intended to familiarize new students with the University, reinforce math concepts, and introduce diverse fields of engineering. For the Fall 2007 semester, interactive computer simulations were created using the modeling programs Working Model2D[TM] and MDSolids[TM 1,2], to introduce and reinforce topics and skills associated with of the four engineering specialties (Civil, Electrical, Materials Science, and Mechanical) offered at our University. A specific assessment strategy, including administration of the Gregorc Style Delineator[TM 3], was created to benchmark the effectiveness of the simulations and to facilitate their continuous improvement. Results indicate that students liked using the simulations and considered them to be enjoyable learning supplements. Students also felt that the simulations improved their confidence to take future engineering courses and were willing to use more simulations in their academic careers. There was no significant correlation between dominant learning styles of the students and their perceptions of the simulations. Therefore, adaptations based upon learning styles may not be needed for effective use of simulations in learning environments similar to ENGR 110.

Introduction

Most Freshman engineering students at our University take Precalculus (MATH 147) as a prerequisite for their first calculus course. In 2005, Engineering with Precalculus (ENGR 110) was developed as a companion course to MATH 147, with the goals of increasing student success in precalculus, and promoting interest in engineering. The primary activity in ENGR 110 is based upon a supplementary math tutorial program (ALEKS[TM])[4], which the students use while progressing through their precalculus course. In Fall 2006, interactive simulation modules in the Working Model2D[TM] environment were introduced to the students in ENGR 110 on an *ad hoc* basis[5]. At that time, a formal assessment of the effectiveness of the simulation modules was not conducted; however, student comments encouraged us to implement simulation modules on a structured basis for Fall 2007. The ENGR 110 course grades for Fall 2007 were portioned into three equal parts: progress in the ALEKS[TM] interactive math program, participation in University retention activities, and progress in the engineering part of the course. The engineering part of ENGR 110 included interactive computer simulations, build activities, and handouts. A test to assess engineering knowledge was administered at the beginning and at the end of the course. This approach facilitated a formal assessment of the simulation models in attaining the course goals of ENGR 110.

Background

Many authors provide helpful strategies for implementation, assessment, and continual improvement of computer simulations in basic University courses. Costanzo and Gray suggest

that exercises including interactive simulations must be structured with sustainability in mind to ensure permanent inclusion into the engineering curriculum[6]. Moreno presents an evaluation of the "guided feedback hypothesis," contrasting the effects of corrective feedback (cf) with explanatory feedback (ef), on novice learners using the same interactive botany "game" simulation[7]. The ef group produced higher game scores, rated the game more helpful, and indicated more interest than the cf group[7]. Hall *et al.* [8] compared the performance of two groups of students from a Mechanics of Materials course in computerized courseware modules. One group was provided with feedback and the other was not. The feedback group had a significantly higher score on the question related to metacognition, and were also "more positive about their perceived learning[8]." Both Hall *et al.* and Moreno point out that in the absence of feedback, a discovery learning process such as an unguided simulation can actually have a deleterious effect on learning, especially with novice learners. Research involving computer simulations used in higher-level courses provided additional results which the authors found useful in creating simulations. Davies conducted a comparative study of two sections of a Heat Transfer course: one section without computer simulations offered in 2000, and another section including simulations offered in 2001[9]. An overall positive effect was observed, and Davies suggested that important factors in the effectiveness of computer simulations were an easily-navigated user interface, the overall learning environment, and congruence between learner objectives and simulation objectives[9].

Methods – Implementing Simulations

With due regard to the importance of explanatory feedback, learning environment, and easily-managed user interfaces, five computer simulations were created for the engineering segment of ENGR 110. The simulations were created with Working Model2D™ and MDSolids™ programs. Working Model2D™ (rigid-body statics and dynamics simulator), and MDSolids™ (mechanics of materials and structures simulator), are very popular programs with convenient and intuitive user interfaces. Both programs have low purchase prices for educational entities. However, the cost in faculty time associated with creating interactive modules using Working Model2D™ is highly dependent upon proficiency and experience. Working Model2D™ is most suited to creating simulations in fields such as Mechanical and Civil Engineering; however, the convenient and powerful user interface enables the creative developer to make simulations in fields such as Electrical, Chemical, and Industrial Engineering. Examples of previous studies involving interactive Working Model2D™ simulations included in freshman-level engineering courses are provided by Guarino[10], and Gramoll[11]. The five Working Model2D™ simulations used in this project are illustrated in Figures 1 through 5. All of the simulations, with the exception of the Materials Science simulation, were interactive. The simulations were embedded into the engineering modules of Materials Science, Mechanical Engineering, Vectors, Civil Engineering, and Electrical Engineering. A sixth engineering module (Matrices) was included in the course, but had no simulation. Student use of the simulations took place in a computer lab in the constant presence of a professor. The professor interacted with each student, providing guided feedback on their use of the computer simulations and their overall progress in meeting the objectives of each engineering module.
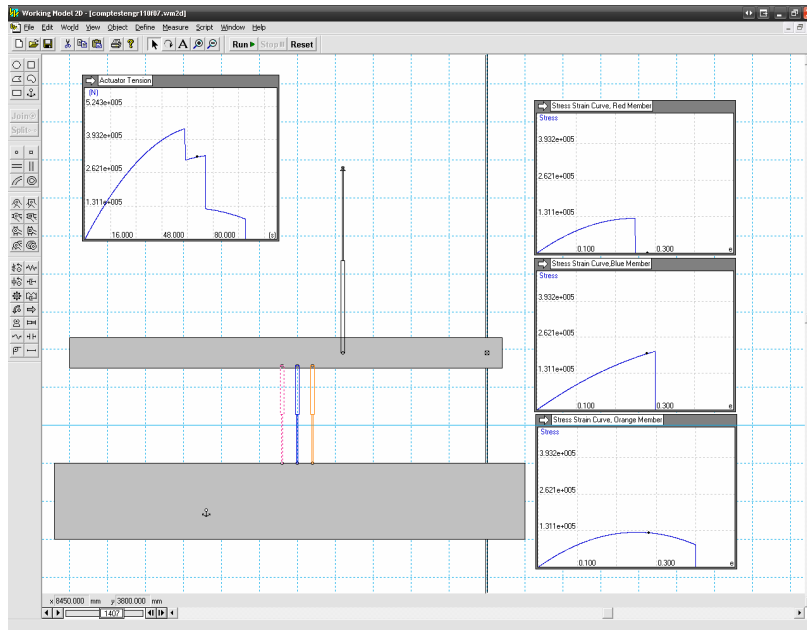
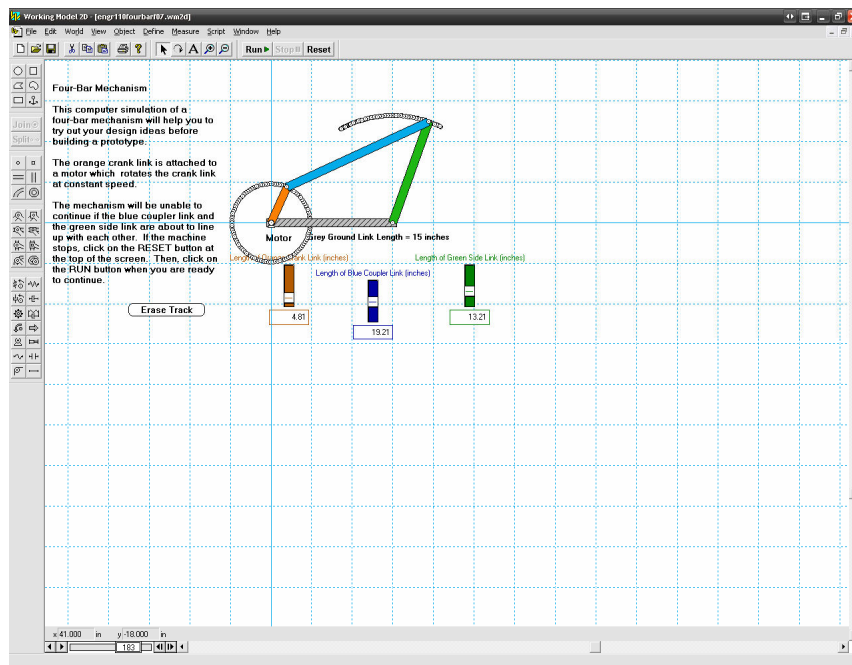Figure 1 – Uniaxial test of Composite Specimen (Materials Science)

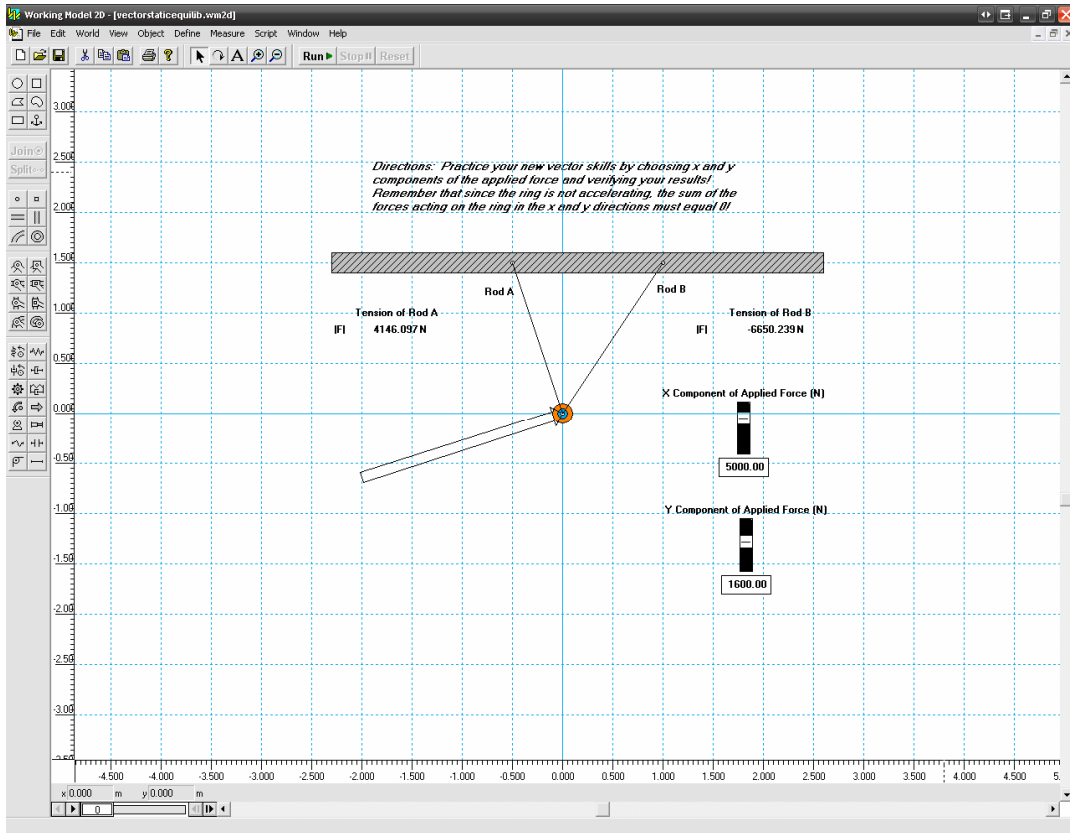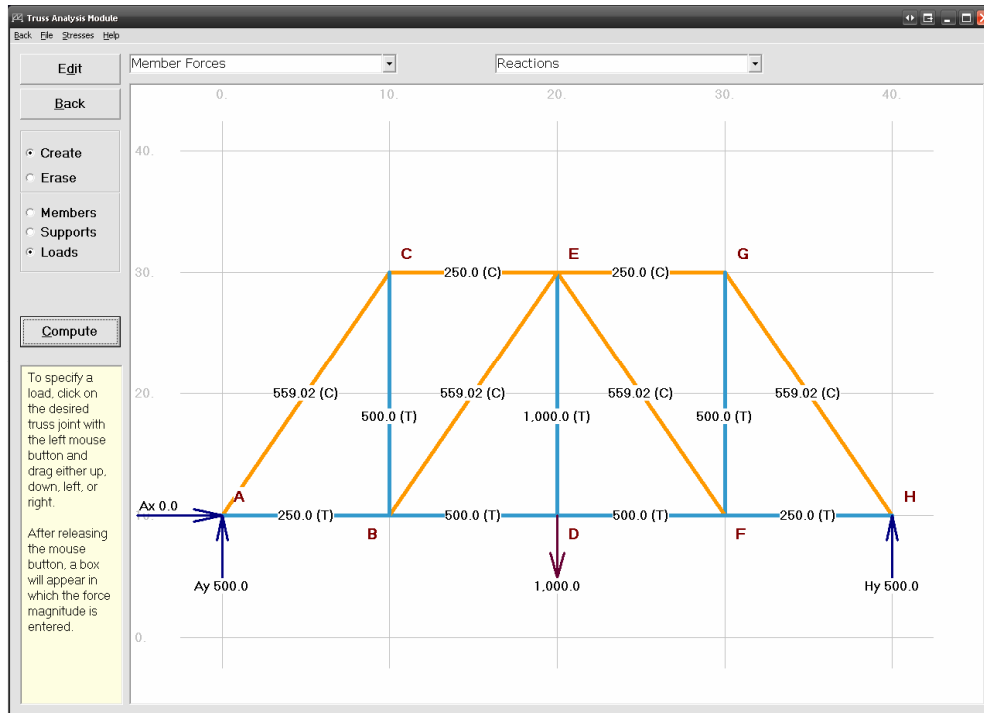Figure 2 – Four-Bar Linkage (Mechanical Engineering)

Figure 3 – Vectors

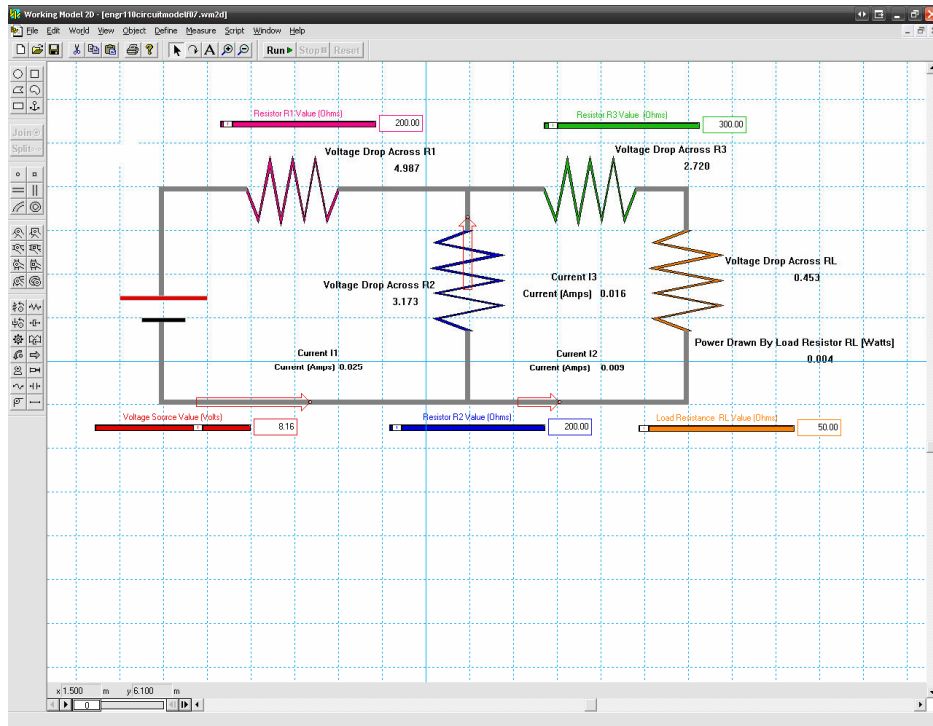Figure 4 – Planar Truss (Civil Engineering)

Figure 5 – DC Circuit (Electrical Engineering)

Methods - Assessment

Subjects

Fifty students enrolled in two sections of ENGR 110 Engineering with Pre-Calculus class, but 2 students withdrew from the course during the semester. Therefore, data obtained from 48 students were used in the study. Among them, 4 students were female and 44 students were male.

Instruments and Procedure

Pre- and Post-Knowledge Tests: A pre-test was administered in the beginning of the course, and a post-test at the end of the course. They measured students' pre- and post-knowledge of the learning content delivered in the engineering part of ENGR 110. Thirty identical questions were included in both tests. The Knowledge Test is attached in Appendix A. Please note that after each question, students were asked to indicate their confidence on a scale of 0 (not confident at all) to 7 (absolutely confident). These queries appeared after each question, and are omitted from Appendix A in the interest of brevity. Also, note that Question 7 was equivocal and was therefore omitted from the analysis.   Forty-three students completed both tests.

To assess students' dominant learning styles, the Gregorc Style Delineator[TM] was administered during the course. Forty-four students completed the instrument. The Style Delineator measures four qualities of concreteness, abstraction, sequence, and randomness in people's perception toward, and ordering of, their world[3]. Dominant learning styles are identified with one of four style types: concrete sequential (CS), abstract sequential (AS), concrete random (CR), and

abstract random (AR). Every individual is believed to have the ability to orient himself or herself toward all four styles; however, people tend to have strong orientation toward one or two, which is viewed as their dominant style(s).

Exit Survey: At the end of the course, an exit survey with 7 questions was administered, and 42 students completed the survey. The exit survey, shown in Figure 6, specifically addressed the students' experience with the simulation programs used in the course. Students were told that their data would not be reviewed until the final grades were submitted and were advised to provide honest responses to the questions.

Name: _____
Q1. The simulation modules helped improve my confidence level in learning engineering.
Strongly disagree 1 2 3 4 5 6 7 Strongly agree
Q2. I think the simulation modules are good learning supplements.
Strongly disagree 1 2 3 4 5 6 7 Strongly agree
Q3. I enjoyed using the simulation modules.
Strongly disagree 1 2 3 4 5 6 7 Strongly agree
Q4. I would recommend future ENGR 110 students to use these simulation modules.
Strongly disagree 1 2 3 4 5 6 7 Strongly agree
Q5. I would like to take more engineering courses.
Strongly disagree 1 2 3 4 5 6 7 Strongly agree
Q6. I would like to use more simulation modules like these in my future engineering courses.
Strongly disagree 1 2 3 4 5 6 7 Strongly agree
Q7. Write any comments or suggestions about the use of the simulation modules:

Figure 6 - Exit Survey for Engineering Simulation Modules

Data Analysis: Data were analyzed using SPSS 15.0 for Windows (2006)[12]. Statistical procedures used for inferential statistics include the paired-samples *t* test for comparing the means of two variables (pre-test and post-test scores) for a single group and Pearson correlation coefficients for measuring correlations among multiple variables[13].

Benchmarking Simulation Programs

Engineering simulation modules were not the only educational materials used in ENGR 110. Further, no process was applied to ensure equivalent difficulty of the questions in each subject category on the pre and post knowledge test, and the questions were not evenly distributed within each category. These issues preclude a feedback metric based upon statistics; however, scores from the pre and post knowledge tests, when grouped by category, might indicate which modules need improvement. We compared average improvement of scores on the pre and post knowledge tests for each of the five categories related to the simulation modules: Mechanical,

Materials, Electrical, and Civil engineering disciplines, and Vectors. Unfortunately, subject-specific data from one of the two sections were not retained.   Therefore, only 21 students were included in this analysis.

Results

Learning Outcomes

Both the pre-test and post-test contained 30 questions, each worth 1 point. The mean value of the pre-test scores was 12.21 ($SD = 3.02$), ranging from 8 to 18. The mean value of the post-test scores was 22.95 ($SD = 3.30$), ranging from 14 to 29 (see Table 1). The normality tests showed that the normality assumptions for both variables (pre-test scores and post-test scores) were not markedly violated. Therefore, a paired-samples t test was conducted to reveal whether the gap between the pre-test scores and the post-test scores was significant [14]. The t test revealed that the gap between the two scores was significant at a .01 level, $t (42) = -16.56$, $p < .00$, indicating that a significant amount of learning occurred during the course.

Table 1. Paired-Samples T Test Statistics.

	Mean	N	SD	t	Df	Sig. (2-tailed)
Pre-test	12.21	43	3.02	-16.56	42	.00
Post-test	22.95	43	3.30			

Understanding Students' Learning Styles

The most frequent dominant learning style among the students was concrete-sequential (CS); 25 students (56.8%) scored CS as their most dominant style. AS and AR were the least dominant styles among the students; 18 students (40.9%) and 17 students (38.6%) scored AS and AR as their least dominant styles, respectively.

The normality assumptions for the four sets of learning style scores and the learning scores (i.e., the gap between the pre-test and post-test scores) were not markedly violated. Therefore, Pearson correlation coefficients were computed. To minimize the chances of making a Type I error across the 10 correlations, the Bonferroni approach was used and a p value of less than .005 (.05/10 = .005) was considered for significance[15] . An interesting finding from the correlational analyses was that the scores of the two sequential types (CS and AS) and the scores of the two random types (CR and AR) among students were negatively correlated at the .005 significant level (see Table 2). It implies that when students have a strong *sequential* tendency or preference in a concrete or abstract manner (CS or AS), they tend to exhibit a weak *random* tendency or preference in those manners (CR or AR).

When using a p value of .05 as the significant level by taking a risk of making a Type I error, interesting results were found. The more CS tendency or preference they had, the more learning improvement they achieved (Pearson's $r = .31$, $p < .05$). On the other hand, the more CR tendency or preference students had, the less learning improvement they achieved during the course (Pearson's $r = -.33$, $p < .05$). AR scores also had a negative correlation with the degree of learning, although it was not significant at the .05 level. However, the possible Type I error

when using a *p* value of .05 across 10 correlations should be noted, and the results should be interpreted with caution. Also, it is important that these results indicate correlation, not causation; therefore, it should not be interpreted as if the characteristics of randomness *caused* the observed results.

Table 2. Correlations Matrix among Learning Styles and Learning Outcomes.

		CS	AS	CR	AR	Learning
Pearson Correlation	CS	-	.23	-.51[**]	-.57[**]	.31[*]
	AS	-	-	-.55[**]	-.62[**]	.27
	CR	-	-	-	.04	-.33[*]
	AR	-	-	-	-	-.21

** Correlation is significant at the 0.005 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Learning Styles and Perceptions toward the Use of Simulation Programs

The exit survey revealed that students liked using simulation programs during the course. On a 7-point scale where 1 is the lowest and 7 is the highest, students' responses to the first 6 questions about their experience with the simulation programs were 5.38 or higher (see Table 3). Students viewed the simulation programs to be enjoyable learning supplements, thought that the programs helped them improve their confidence level in learning engineering, and were willing to use more simulation programs in their future engineering courses. One particular positive result found in this survey, especially considering that ENGR 110 is an entry-level engineering preparation class taken by freshmen, was that students expressed a strong desire to take more engineering courses at the end of the course ($M = 6.26$, $SD = .98$). This likely indicates this course's success in promoting interest in engineering among students and potentially increasing retention.

When students' dominant learning styles were correlated to their perceptions toward the use of simulation programs, no significant positive or negative correlations were found. This might imply that no special attention to students' learning styles is needed when using simulation programs as learning supplements in an engineering course.

Table 3. Descriptive Statistics of Student Perceptions toward Simulation Programs.

	Mean	*SD*
Q1. The simulation modules helped improve my confidence level in learning engineering.	5.38	1.20
Q2. I think the simulation modules are good learning supplements.	5.83	1.16
Q3. I enjoyed using the simulation modules.	5.93	1.23
Q4. I would recommend future ENGR 110 students to use these simulation modules.	6.05	1.16
Q5. I would like to take more engineering courses.	6.26	.98
Q6. I would like to use more simulation modules like these in my future engineering courses.	5.95	1.03

Quality of Simulation Programs

Average improvement between scores on the pre and post knowledge tests for each of the four categories related to the simulation modules are shown in Table 4.

Table 4. Average Score Improvement between Pre and Post Knowledge Tests by Subject

Subject:	Vectors	Mechanical Engineering	Materials Science Engr.	Electrical Engineering	Civil Engineering
Mean Improvement:	5.2	10	6.5	5.2	2.7

Conclusions

Significant improvement between student scores on the pre and post knowledge assessments indicates that student learning was significant in the engineering portion of ENGR 110. However, engineering modules included model building and handouts; therefore, this learning cannot be solely attributed to computer simulations. A survey specific to the use of computer simulations showed that students liked the simulations and enjoyed using them. Students also felt that the simulations improved their confidence in learning engineering, and were willing to use more simulation programs in future engineering courses. There was no correlation between dominant learning styles of the students and their perceptions of the simulations. This result may indicate that there is no need for adapting simulations to specific learning styles in similar learning environments. With due regard to the limited significance of the results in Table 4, it appears that the Civil Engineering simulation might benefit from revision.

Acknowledgement

Bibliography

1. Working Model2D^{TM} Version 4.0.1, Knowledge Revolution, Inc., Copyright 1989-1996

2. MDSolids^{TM}, Version 3.2, T. A. Philpot, Copyright 2006

3. Gregorc, A. F. (1982). *An adult guide to style*. Columbia, CT: Gregorc Associates, Inc.

4. ALEKS^{TM} , University of California Regents and ALEKS Corporation, 2007

5. J.M. Hampikian, J. Guarino, Y. Chyung, A. Moll, P. Pyke, J. Gardner, C. Schrader, "*Assessing a Retention Program for Pre-Freshman Engineering Students*," CD-Proceedings of the 2007 American Society for Engineering Education Annual Conference & Expo, Honolulu HI.

6. F. Costanzo and G. L. Gray, "*On the implementation of Interactive Dynamics*," International Journal of Engineering Education, Vol. 16, No. 5, 2000, 385-393.

7. R. Moreno, "*Decreasing Cognitive Load for Novice Students: Effects of Explanatory versus Corrective Feedback in Discovery-Based Multimedia*," Instructional Science **32**: 99-113, 2004.

8. R. H. Hall, T. A. Philpot, D. B. Oglesby, R. E. Flori, N. Hubing, S. E. Watkins, and V. Yellamraju, "*A Model for the Evaluation of Innovative Engineering Courseware: Engineering an Assessment Program*," Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, 2002

9. C.H.J. Davies, "*Student engagement with simulations: a case study*," Computers & Education, Vol 39, Issue 3, November, 2002, Pages 271-282.

10. Guarino, Joe, "*Implementing Design-Based Engineering Education with Computer Simulations*," Proceedings of the ASEE 1998 Conference in Seattle, Washington, June 28 - July 1, 1998.

11. Gramoll, Kurt, "*Using 'Working Model2D to Introduce Design into a Freshman Engineering Course*," Proceedings of the ASEE 1994 Conference in Edmonton, Canada, June, 1994.

12. SPSS 15.0 for Windows (2006). SPSS Inc.

13. Ho, R. (2006). *Handbook of univariate and multivariate data analysis and interpretation with SPSS.* New York: Chapman & Hall/CRC.

14. Morgan, G. A., Leech, N. L., Gloeckner, G., W., & Barrett, K. C. (2007). *SPSS for introductory statistics* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

15. Green, S. B., & Salkind, N. J. (2008). *Using SPSS for Windows and Macintosh: Analyzing and understanding data* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Appendix A: Pre and Post Knowledge Test

<div align="center">

Engineering 110
Final Exam - Engineering
Fall, 2007

</div>

NAME:_____

Instructions: Choose the best answer from the four possible responses. Don't be discouraged if you don't know the answer, just write down your best guess at a solution. For each question, please indicate how confident you are of your answer by circling a number between 1 and 7, with 1 meaning "not confident at all" and 7 meaning "absolutely confident", for each question.

Vectors
1. Vectors have _____, while scalars have _____.
   A) energy and force, energy
   B) magnitude; magnitude and direction
   C) magnitude and direction; magnitude
   D) energy and magnitude; direction
2. Vectors and Scalars are part of a family called _____.
   A) tensors
   B) forces
   C) stresses
   D) magnitudes
3. Unit vectors have a magnitude of _____ and are used to indicate _____.
   A) 0; direction
   B) 1; direction
   C) 0; torque
   D) 1; torque
4. Which of these is *not* something the dot product can be used for:
   A) finding the force between two vectors
   B) finding a vector that is perpendicular to another vector
   C) finding the angle between two vectors
   D) finding the component of a vector in the direction of another
5. Engineers use the vector cross product to describe _____ and _____.
   A) volume and velocity
   B) energy and force
   C) volume and displacement
   D) rotation and torque

Four-bar Mechanisms
6. In a four-bar mechanism the side links are attached to the _____, and the _____ is always opposite to the ground link.
   A) coupler link; frame link
   B) ground link; frame link
   C) ground link; coupler link
   D) coupler link; side link
7. Omitted
8. Grashof's Criterion is _____ when S is the length of shortest link, L is the length of longest link, and P and Q are lengths of the intermediate links.
   A) (S + L) - (P + Q)
   B) $S + L \leq P + Q$
   C) (S +L)² - (P + Q)²
   D) $S^2 + L^2 \leq P^2 + Q^2$
9. Some four-bar linkages have *dead points* (or toggle points), which occur when two moveable links _____.
   A) create a 45˚ angle

B) create a 90˚ angle

C) line up

D) move continuously

Electrical Engineering

10. The current in a DC circuit _____ direction.

    A) does not change

    B) does change

    C) has no

    D) none of the above

11. If we had guessed the wrong direction for the current in each loop in a circuit, we'd have simply obtained a _____ value for the variable "i" in the equation for Ohm's Law.

    A) positive

    B) undefined

    C) irrational

    D) negative

12. Kirchoff's voltage law predicts that adding the voltage drops to the voltage source in a circuit gives an overall loop voltage change of _____.

    A) infinity

    B) ten

    C) one

    D) zero

13. In circuits, currents flowing through resistors from + to – give _____, while currents flowing through elements from – to + give _____.

    A) voltage gains; voltage drops

    B) voltage drops; voltage gains

    C) stable voltages; unstable voltages

    D) unstable voltages; stable voltages

14. At steady state, the magnetic field around an inductor is fully developed, and the inductor acts like a short circuit with _____.

    A) a finite resistance

    B) an infinite resistance

    C) no resistance

   D) an unstable resistance

Materials Science:

15. The Stress-Strain curve is a plot of _____ as a function of _____.

    A) strain; stress

    B) stress; strain

    C) elasticity; force

    D) force; elasticity

16. In many cases a uniaxial test, which pulls or pushes a sample along its vertical axis, would proceed until the sample _____.

    A) fails

    B) bends

    C) reaches a stopping point and returns to its original state

   D) none of the above

Civil Engineering:

17. Which of the following is an example of a planar truss?

    A) Arch dam

    B) Pile-supported bridge

    C) Suspension bridge

    D) Side of many railroad trestle bridges

Support
Element A
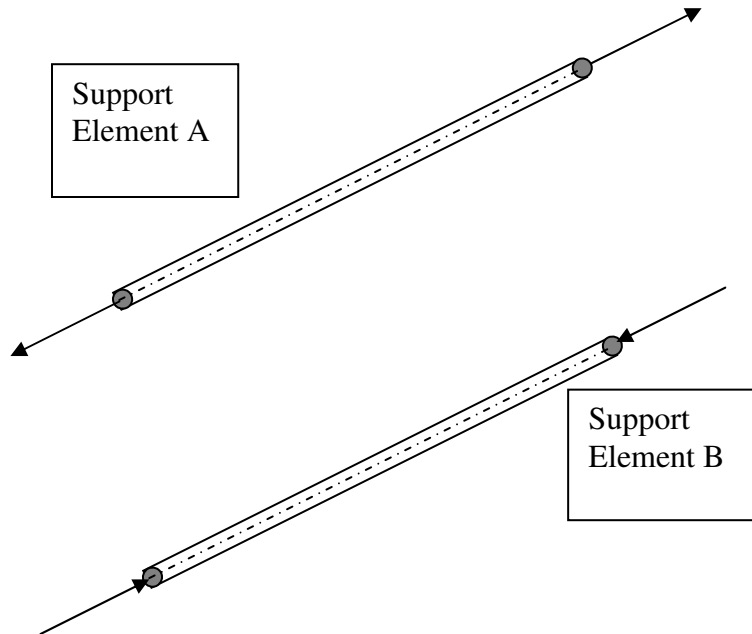
Support
Element B

18. In the figure above, Support Element A is a two-force member in _____, while Support Element B is a two-force member in _____.
    A) stress; strain
    B) strain; stress
    C) compression; tension
    D) tension; compression

19. In order to treat the elements of a truss as two-force members, we apply all of the following assumptions *except*:
    A) all members are connected by smooth pins at their ends
    B) the angles the members make should be considered
    C) all members are loaded on their ends by forces
    D) we can neglect the weight of each member, compared to the loads

20. The force vectors acting on any joint in a truss must combine to equal _____ in order to be in force equilibrium.
    A) infinity
    B) ten
    C) one
    D) zero

21. When finding the forces on the members of trusses, it is important to know that _____ forces will be positive, and _____ forces will be negative.
    A) tensile; compressive
    B) compressive; tensile
    C) weak; strong
    D) strong; weak

22. Referring to the figure below, use the force equilibrium equations at the joints to find the forces in each member. Write the force equilibrium equations in the x and y directions for the joint and solve the system of equations for the unknown forces:
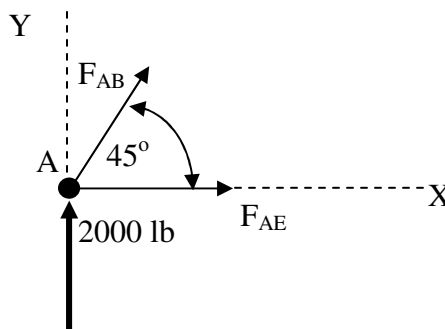
23. Member A in the truss joint shown below is a _____-force member.
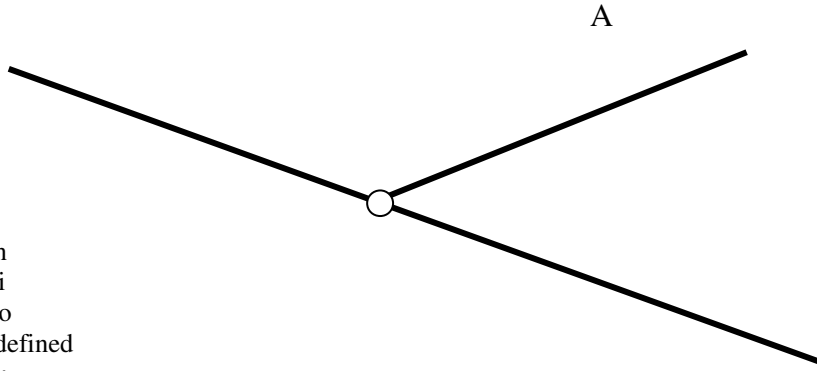
   A) non
   B) anti
   C) zero
   D) undefined

Matrices:

24. The elements in a matrix are arranged in horizontal _____ and vertical _____.
   A) perpendiculars; parallels
   B) parallels; perpendiculars
   C) rows; columns
   D) columns; rows

$$a= \begin{bmatrix} 2 & 4 & 6 \\ -9 & 1 & 0 \\ 3 & -6 & -4 \end{bmatrix} \quad b= \begin{bmatrix} 11 \\ -5 \\ 3 \end{bmatrix} \quad c= \begin{bmatrix} 7 & 3 & -12 \\ 4 & 9 & 1 \end{bmatrix} \quad d= \begin{bmatrix} 6 & 2 & -1 \\ 15 & -5 & 4 \\ 9 & 0 & 2 \end{bmatrix}$$

25. Considering the matrices above, specify the particular element c_{21}:
   A) 3
   B) 4
   C) 9
   D) -12

26. Matrices with the same number of _____ can be added and subtracted successfully.
   A) values
   B) rows
   C) columns
   D) rows and columns

27. To multiply two matrices together, multiply each _____ of the first matrix by each _____ of the second matrix.
   A) perpendicular; parallel
   B) parallel; perpendicular
   C) row; column
   D) column; row

Considering the matrices above, find the values for the following expressions:

28. a + d

29. 3b

30. a * b

31. Use Gauss Elimination to find the unknowns x, y, and z in the following set of linear equations:

$2x + y - z = 4$
$4x - 2y + 3z = 2$
$x + 4y - 6z = 0$