Classroom Testing of Virtual Biomechanics Laboratory (VBL) Learning Modules

Ronald E. Barr[1], Marcus G. Pandy[2], Anthony Petrosino[3], Lawrence D. Abraham[3,4], Tejas Karande[2], and Bijal Patel[4]

Departments of Mechanical Engineering[1], Biomedical Engineering[2],
Curriculum and Instruction[3], and Kinesiology[4]
The University of Texas at Austin
Austin, Texas 78712

Abstract

This paper discusses the development and classroom testing of Virtual Biomechanics Laboratory (VBL) learning modules that offer students an opportunity for web-enhanced learning in a traditional biomechanics course. The pedagogical framework for the modules is based on the widely publicized book "How People Learn" (HPL). The HPL teaching framework presents the learning material as a series of challenges that are posed through a "Legacy Cycle." The first two challenges for the Virtual Biomechanics Laboratory deal with the kinematics and kinetics of walking. Students are challenged to solve specific conceptual problems. For theses challenges, actual laboratory data from a human gait lab is presented to the students at the website in the form of excel spreadsheets. Using formulae pasted into the appropriate spreadsheet cells, the students can calculate and plot the trajectory of the whole body center of mass (COM) and determine the ground reaction forces (GRF). Included in the modules are video clips of experts presenting their opinions on the problem, and video shots of the equipment used in the data collection process in the actual biomechanics laboratory. Several appropriate reference papers are also supplied for background reading. This paper concludes with some results of testing this approach to learning in a traditional biomechanics class taught at the University of Texas at Austin in the Fall 2002 semester. This research study included pre- and post-tests, module components' effectiveness rankings, a survey of learning outcomes, and a personal preference affect questionnaire.

Introduction to the Course

The course ME 354M, "Biomechanics of Human Movement," is an undergraduate technical block elective in Mechanical Engineering (ME) for students who want to specialize in the Biomechanical Area of ME. In the Fall 2002 semester, twenty-eight students were enrolled in the course. Twenty-five of the students were ME undergraduates, two were natural science undergraduates, and one student was an ME graduate student. The course is taught in a traditional format with chalkboard lectures, some use of overhead transparencies, and a few handouts are distributed as needed. There is no required textbook for the course and the primary lecture content has been prepared over the years by the first author. The major lecture topics covered in the course include:

1. Musculoskeletal Physiology and Anthropometrics;
2. Analysis and Simulation of Human Movement;
3. Biomechanical Systems and Control;
4. Computer Graphics Modeling in Biomechanics; and
5. Experimental Techniques in Biomechanics.

In the Fall 2002 semester, the course was involved in testing educational materials as part of a much larger educational research consortium, the NSF-sponsored VaNTH Engineering Research Center for Bioengineering Education.[1] The objective of the consortium is to develop a new generation of teaching materials and novel approaches for the education of bioengineering students. The pedagogical motivation for the consortium is based on the widely publicized book "How People Learn" (HPL) by Bransford, et al.[2] The HPL teaching framework presents the learning material as a series of challenges that are posed through a Legacy Cycle.[3] The Legacy Cycle (Figure 1) methodically marches the students through the challenged-based material. Key stages in the Legacy Cycle are: 1. posing the challenge, 2. asking students to generate ideas, 3. providing students with multiple perspectives, 4. making students research and revise, 5. testing students mettle, and 6. having them go public. Concepts learned during each cycle are used as 'legacies' for subsequent cycles. This approach was used in the development and testing of the two Virtual Biomechanics Laboratory (VBL) modules discussed in this paper.

A request to use students as human research subjects for the course was approved by the University of Texas Institutional Review Board (IRB) under protocol #2002-02-0139. Students were asked to sign a human subject consent form and all 28 students graciously obliged. Before the first VaNTH challenge was assigned, the class randomly drew a slip of paper from a hat with either the letter A or B written on the slip. Based on this random draw, the students were assigned to either Group A (control) or Group B (trial). This group assignment was maintained for both challenges. The course instructor recorded the students' names in Group A and Group B, but also assigned a random two-digit ID number to each student with no correlation between the ID number and the group assignment (see later Table 1 for code numbers used). This ID number was subsequently used for all data processing and grading, and only the course instructor had the code matching the ID number to the student name.

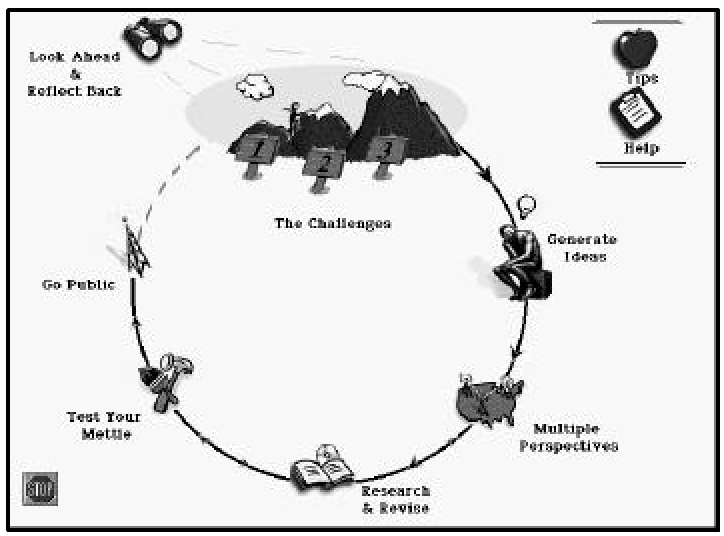

Figure 1: The Legacy Cycle Framework.[3]

The Virtual Biomechanics Laboratory (VBL)

The goal of the "Virtual Biomechanics Laboratory" (VBL) is for engineering students to learn about experimental biomechanics without the need of actual experimental equipment or hands-on data gathering. The goal is achieved through a series of challenged-based learning modules that are made accessible on the internet. For this project, a human gait laboratory was chosen as the learning environment. Two challenges have been developed to date. The first challenge focuses on recording human kinematics data and the calculations that can be performed with the data, such as joint angles and centers of gravity. The second challenge deals with kinetic data during human walking measured using a ground-reaction force plate.

VBL Challenge I

The VBL Challenge I is "How does your whole body center of mass (COM) move when you walk?" The VBL Challenge I was presented to Group A and Group B in different manners. Group A (control) received a traditional packet of homework assignment. The packet included some papers for reading, a floppy diskette with some Excel spreadsheets, and five written exercises. This was essentially the same work that Group B was given.

The VBL Challenge I was presented to Group B (trial) using a Prometheus internet website at http://pro.engr.utexas.edu/ with simple user name and password protection. Once they accessed the site, students were confronted with the HPL Legacy Cycle framework for the instruction. The content of the website had the following Legacy Cycle features.

Look Ahead & Reflect Back

In this initial stage, the learning objectives for the challenge are presented to the students. They are encouraged to look back at previous educational experiences and extrapolate how these will aid them in learning the specific challenge for this module.

Generate Ideas

The students start their exploration by generating ideas on how the whole body COM moves when walking. Video clips of a human stick figure walking at normal and slow speeds are made available for viewing at the website (Figure 2). Shown on the video clip is a "red dot" that traces the COM trajectory, leading the observer to generate ideas for the problem.

Multiple Perspectives

The multiple perspectives stage gives the students opinions on the challenges from various experts involved in experimental biomechanics. Three different professors were interviewed on videotape and asked to explain their perspective on how the whole body COM moves during human gait. These video interviews are made available to the students at the website, as shown in Figure 3. They offer both general agreements on the problem, as well as some contrasting opinions, thus forcing the students to develop their own critical thinking about the problem.

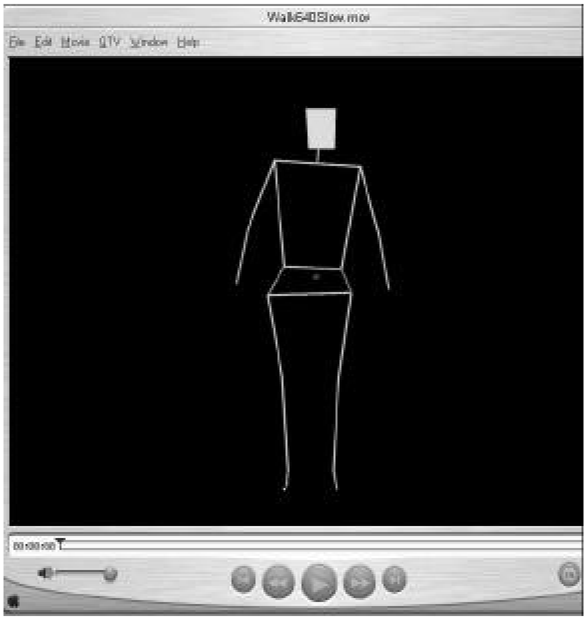

Figure 2: Human Stick Figure Walking Video Clip.

Figure 3: Multiple Perspective Video Clip from Professor One.

Research and Revise

The research and revise phase of the Legacy Cycle compels the students to do some research on their own. References to common textbooks[4,5] and journal papers[6,7] are given. Two review articles on center of mass calculation and on kinematics, written by our group, are available on-line at the website. In addition, several more video clips on kinematics data acquisition and apparatus are made available (Figure 4).

Figure 4: Kinematics Data Acquisition Video Clip.

Test Your Mettle

This stage of the Legacy Cycle presents the students with some challenging exercises that require them to apply and transfer the knowledge they have learned in the earlier multiple perspectives and research phases. There are five specific homework exercises that are assigned to the group:

1. “Static Center of Mass (COM) Calculation” is an assignment to find the whole body center of mass of a human stick figure (see Figure 5) when given data about the individual segments. The students use an anthropometric data table and a formula provided in the paper to perform this static calculation.

2. “Spreadsheet Calculation of Whole Body COM” is an exercise to find the COM using a formula pasted into an Excel spreadsheet cell that links the various segment data in the columns. This is done at each time sample point, and then the students plot out the result of this Excel COM calculation across the entire gait cycle (see Figure 6).

3. “Comparison of ASIS Markers to Whole Body COM” is similar to exercise 2 in which the whole body COM is estimated by the average value of the right and left ASIS (pelvic girdle) markers.

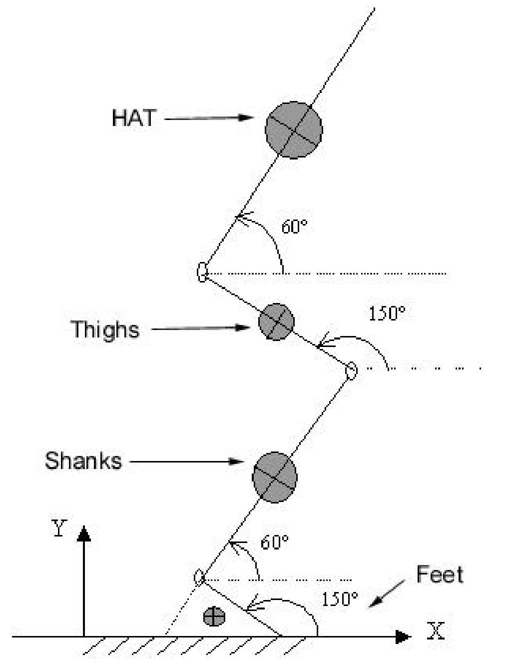

Figure 5: Static COM Calculation.

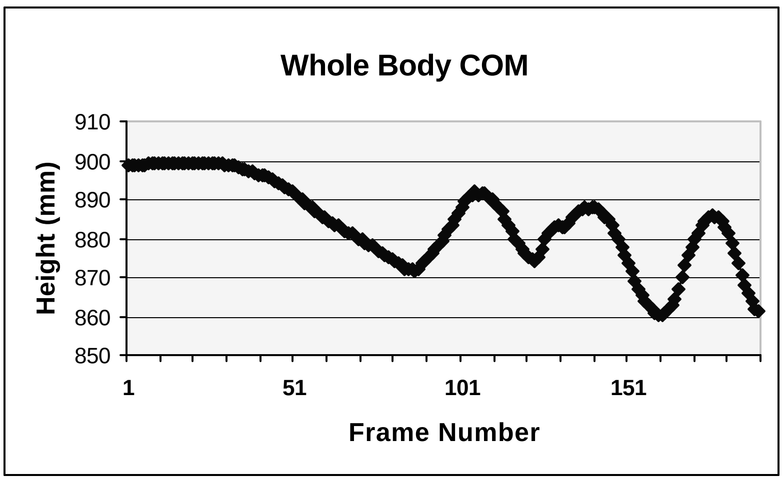

Figure 6: Solution to the Whole Body COM Spreadsheet Exercise.

4. “Head Tip Trajectory” exercise poses an interesting question: “Can you walk under a door of exactly your height without hitting your head?” The students must find out by plotting the trajectory of the tip of the head using the data given in the same spreadsheet as Exercise 2. They can then plot out the head tip trajectory, compare it to the head tip when the subject is standing erect (frame 1), and then answer the question.

5. “Description of Kinematics Data Acquisition” exercise asks the students to write a one-page essay on how kinematics data are gathered in a biomechanics laboratory, based on the information provided in the module.

Go Public

This final phase of the Legacy Cycle is when the students assemble all their assigned work and submit it for grading. They also completed a VBL Challenge I survey questionnaire.

Both Groups A (control) and B (trial) had essentially the same assignment content, but it was just framed in a different educational pedagogy. Both groups were allowed two weeks to complete the assignment. Students in Group A and Group B worked as individuals, and there was no teamwork involved.

VBL Challenge II

The VBL Challenge II is "What forces do you exert on the ground when you walk?" The VBL II challenge was presented to Group A and Group B in different manners. Since Group A was the control, it received a traditional in-class lecture and paper assignment handout. The assignment packet for Group A consisted of papers on kinetics, the gait cycle, and the ground reaction force (GRF) curve. They also received a floppy diskette with the GRF kinetic data and an assignment sheet with five exercises.

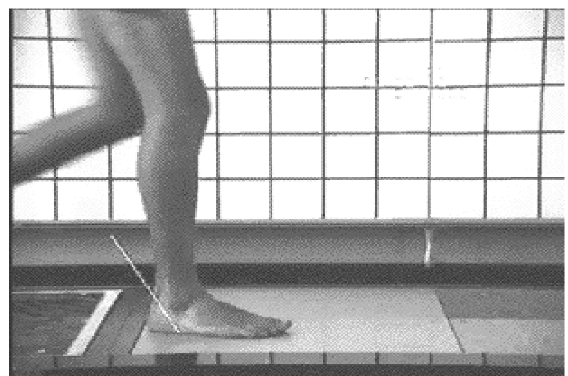

Figure 7: Striking the Force Plate.[8]

For Group B, the VBL Challenge II was presented using the same Prometheus internet website at http://pro.engr.utexas.edu/ with simple user name and password protection. Once they accessed the site, they were confronted with the HPL Legacy Cycle framework for the instruction. The content of the website had the following features.

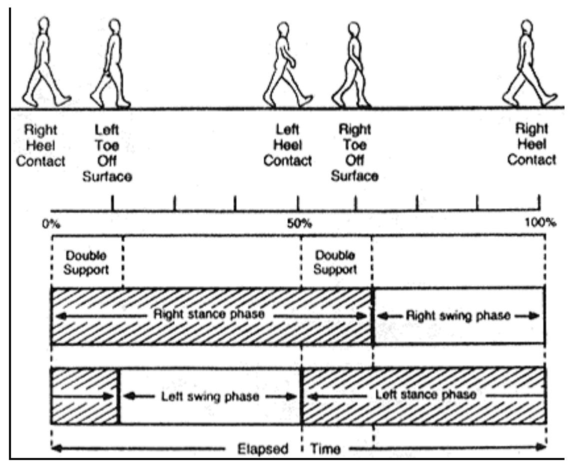

Figure 8: Gait Cycle Depiction.[9]

Look Ahead & Reflect Back

In this initial stage, the learning objectives for the challenge are presented to the students. They are encouraged to look back at previous educational experiences and determine how these will aid them in learning the specific challenge for this module.

Generate Ideas

In this activity, students can view a video of a person walking across a force plate (Figure 7) and generate ideas on their own about what the ground reaction forces might look like.

Multiple Perspectives

In multiple perspectives, the students can view video clips of an expert talking about ground reaction force measurements, and about moments and torques in general.

Research and Revise

In this stage of the Legacy Cycle, the students are presented a number of resources from which they can gain factual knowledge. There is a paper on the human gait cycle explaining and labeling the various gait cycle phases (Figure 8). There is a paper on kinetics that shows the typical shape of the GRF curve (Figure 9) and several references[4,10,11] that the students can research. There are also several video clips that show how kinetics data are obtainede laboratory.

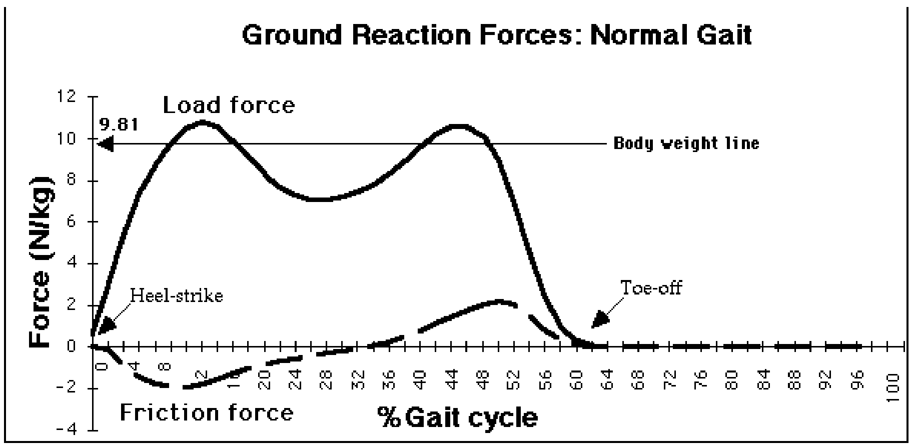

Figure 9: The Typical Ground Reaction Force (GRF) Curve.[8] The Vertical Axis is Normalized.

Test Your Mettle

The test your mettle phase is when the students solve the assignment. Again, five homework exercises are given.

1. "Identifying the Phases of the Gait Cycle" is a multiple choice exercise in which the students match the leg position, gait cycle stage name, and the set of events that occur at that stage.

2. "Interpreting the GRF Curve" is an exercise in which the students label certain parts of the GRF curve (Figure 9). In particular, they study and report on the physical nature of the double hump in the curve.

3. "Spreadsheet Calculation of Acceleration Curves" is a computational assignment in Excel to plot the acceleration of the whole body COM using both the GRF curve as well as a direct finite-difference calculation of the COM position found in VBL I. They then are asked to compare the two plots and explain any discrepancies.

4. “Question on Body Weight and GRF Curve” poses an interesting question “When you walk, do you ever exert a force on the ground that is less than your body weight?” They ponder this question, referring to previous research and revise material, and then submit a one-page written answer.

5. “Description of Kinetics Data Acquisition” is an exercise that asks the students to write a one-page essay on how kinetics data are gathered in a biomechanics lab.

Go Public

This final phase of the Legacy Cycle is when the students assemble all their assigned work and submit it for grading. They also completed a VBL Challenge II survey questionnaire.

Both Groups A (control) and B (trial) had essentially the same assignment content, but it was just framed in a different educational pedagogy. Both groups were allowed two weeks to complete the assignment. Students in Group A and Group B worked as individuals, and there was no teamwork involved.

Testing the VBL Challenges

Before the two VBL challenges were assigned, Pre-Tests were given to the whole class. The Pre-Tests consisted of questions related to simple biomechanics calculations that could be done with pencil and paper. A short affect questionnaire on learning factors was also included at the end of each Pre-Test. After the VBL I and II assignments were completed, the same respective tests were given again as Post-Tests (some small numerical changes were made to differentiate the Pre- and Post-test questions) to both groups A and B in class. The Post-Test also included the same affect questionnaire again. At the end of all the VBL challenges, a student outcomes survey was also administered.

The homework assignments for Groups A and B were submitted to the instructor and then numerically coded by the instructor for grading. This submission included a diskette with Excel files on them. The coded assignments were graded by a TA, who used a common grading rubric for both Group A and B. The assignments were then returned to the instructor, decoded, and the grades were recorded. The assignments were then returned to the students for their review. At the end of the semester, all of the work was re-submitted to the instructor for archiving.

Results of Testing VBL Challenge I

The assignment scores for Group A (control) and Group B (trial) are shown in Table 1. It can be seen that the Group A average score was 42.1 and the Group B average score was 39.1. A maximum achievable score was 50. The standard deviation for Group A was 7.6 and for Group was 9.4. It should also be noted that the lowest performing student (low score of 18) was in Group B. It is possible that the Group B (trial) students expected the technology of the website to do more of the homework for them, and that the traditional Group A results were more in line with the expectations of the homework grading rubric.

Table 1: VBL I Assignment Scores				
Group A (code)	Score		Group B (code)	Score
39	25.0		26	35.0
64	28.0		99	46.0
12	43.0		81	47.0
49	50.0		37	39.0
86	45.0		55	42.0
41	48.0		42	18.0
95	39.0		71	48.0
17	45.0		23	32.0
91	45.0		89	43.0
33	44.0		52	26.0
56	47.0		14	31.0
67	36.0		35	48.0
77	48.0		74	46.0
21	47.0		19	46.0
Group A Average	**42.1**		Group B Average	**39.1**
Std. Deviation	7.6		Std. Deviation	9.4

The Pre-Tests and Post-Tests for VBL I were scored by the TA using a common grading rubric with a maximum score of 15 points. The results are shown below in Figure 10. It can be seen that both Group A and Group B Post-Tests scores were higher (12.04 and 12.50 respectively) than the Pre-Test (10.54 and 10.71, respectively). This shows some learning of the material based on completion of the assignment. When measuring the differential gain between the Pre-Test and Post-Test, Group A had a differential gain of 1.50 and Group B had a differential gain of 1.79. Thus, both Group B's Post-Test score and differential gain were higher than Group A's.

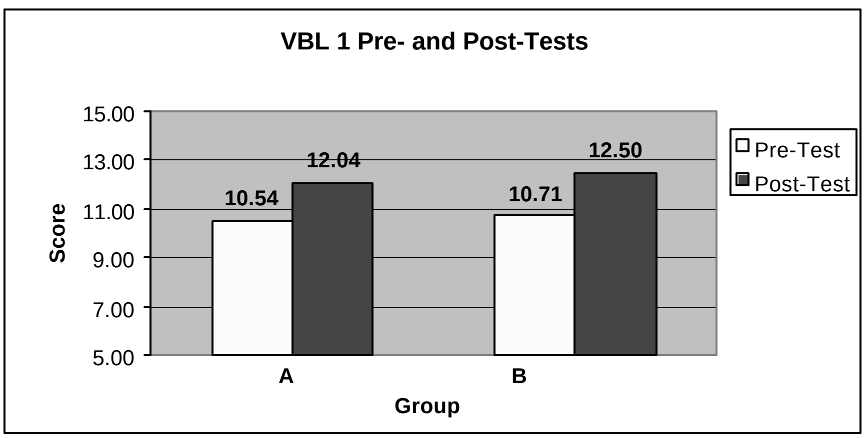

Figure 10: VBL I Pre- and Post-Test Results

The affect questionnaire is shown in Table 2. It includes seven learning factors that may or may not enhance the quality of a student's learning experiences in the course. The students used a scale of 1 (none) to 5 (exceptional) to rate the factors that contributed to their current learning.

Table 2: The Affect Questionnaire					
	Quality of Learning				
Learning Factor	**None**	**Below Average**	**Average**	**Good**	**Exceptional**
1. I gain factual knowledge (terminology, classifications, methods, trends).	1	2	3	4	5
2. I learn conceptual principles, generalizations, and/or theories.	1	2	3	4	5
3. I get a chance to talk to other students and explain my ideas to them.	1	2	3	4	5
4. I am encouraged to frequently evaluate and assess my own work.	1	2	3	4	5
5. I learn to apply course materials to improve my own thinking, problem solving, and decision-making skills.	1	2	3	4	5
6. I develop specific skills, competencies, and points of view needed by professionals in the field.	1	2	3	4	5
7. I acquire interpersonal skills in working with others in the class.	1	2	3	4	5

The results of this affect questionnaire are shown in two different ways. First, the Pre-Test and Post-Test results for the affect questions are plotted for each question for both Group A and B combined. As can be seen in Figure 11, 5 of 7 questions had a higher score at the Post-Test stage when compared to the Pre-Test. This could indicate that the students felt better about their general learning environment after doing the VBL I assignment, regardless of whether it was Group A or Group B.

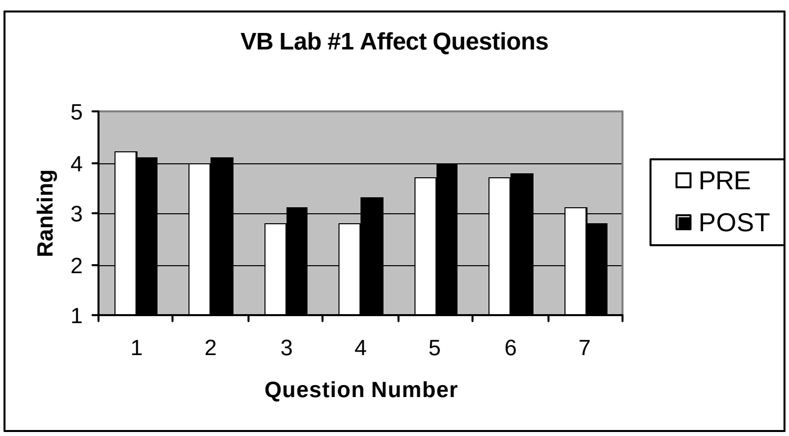

Figure 11: Pre- and Post-Test Affect Scores for VBL Lab I.

A second comparison is shown in Figure 12, in which the Post-Test affect results are compared between Group A and Group B. As shown in the figure, 5 of 7 questions had a higher Post-Test score for Group B versus Group A. This could indicate that the treatment received by Group B (trial) resulted in a higher affect than the treatment received by Group A (control).

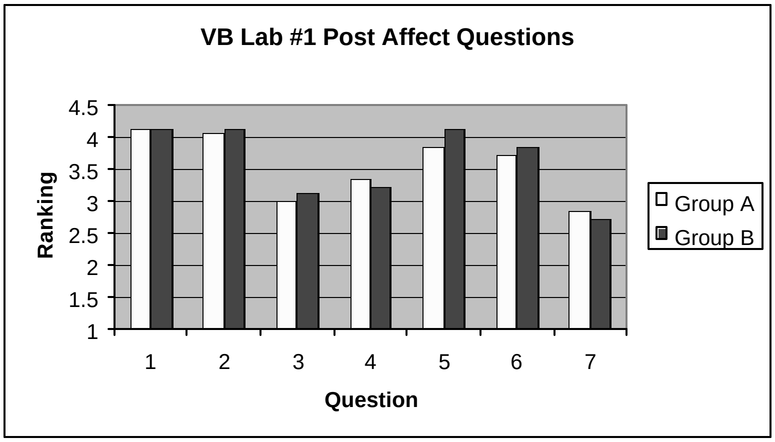

Figure 12: Post-Test Affect Scores for VBL Lab I for Group A versus Group B.

Student Evaluation of VBL I Effectiveness

An exit survey was conducted to determine the students' opinions on the effectiveness of different aspects of the VBL I module. The results are shown in Table 3 for Group B (website trial group). The ranking scale was 1 (not effective) to 5 (extremely effective). The students liked the availability of the Excel spreadsheet and most of the homework exercises, except the description of kinematics acquisition, which was an essay question. They also found the background papers less useful, although the video clips were somewhat effective. In general, one could conclude that engineering students do not like to read nor do they like to write, when doing quantitative exercises.

Table 3: Learning Effectiveness of VBL I for Group B

Module Aspect	**Rank**
Look Ahead & Reflect Back	**3.29**
Generate Ideas: Video of Walking Motion	**4.36**
Multiple Perspectives: Video of Student	**3.57**
Multiple Perspectives: Video of Professor 1	**3.86**
Multiple Perspectives: Video of Professor 2	**3.86**
Multiple Perspectives: Video of Professor 3	**4.00**
Research and Revise: Paper on Center of Mass	**3.00**
Research and Revise: Paper on Kinematics	**2.64**
Research and Revise: Kinematics Data Collection Video Clip	**4.29**
Test Your Mettle 1: Static Center of Mass (COM) Calculation	**3.64**
Test Your Mettle 2: Spreadsheet Calculation of Whole Body COM	**4.07**
Test Your Mettle 3: Comparison of ASIS Markers to Whole Body COM	**4.14**
Test Your Mettle 4: Head Tip Trajectory	**4.21**
Test Your Mettle 5: Description of Kinematics Acquisition	**3.36**
Go Public: Assemble and Submit Work	**3.00**

Results of Testing VBL Challenge II

The same testing and grading procedure was repeated for the VBL II challenge. The assignment scores for Group A and Group B are shown in Table 4. It can be seen that the Group A average score was 46.8 and the Group B average score was 45.9. A maximum achievable score was 50. The standard deviation for Group A was 2.3 and for Group B was 4.9. It should also be noted that the lowest performing student (low score of 30) was in Group B. When compared to the scores achieved in the first VBL I assignment (Table 1), the VBL II assignment scores for the whole class improved by about 5 points. This is true even though the subject matter for VBL II was deemed harder to learn. However, it was also noted that VBL II was computationally less intense, with fewer spreadsheet calculations than VBL I.

As before in VBL I, Group A (control) had a slightly higher average homework score than Group B (trial). It is possible that the Group B (trial) students expected the technology of the website to do more of the homework for them, and that the traditional Group A results were more in line with the expectations of the homework grading rubric.

Table 4: VBL II Assignment Scores

Group A (code)	Score		Group B (code)	Score
39	44		26	45
64	49		99	47
12	50		81	47
49	50		37	46
86	47		55	43
41	46		42	30
95	47		71	48
17	43		23	49
91	45		89	47
33	45		52	43
56	49		14	49
67	48		35	46
77	48		74	49
21	44		19	42
Group A Average	**46.8**		Group B Average	**45.1**
Std Deviation	2.3		Std. Deviation	4.9

The Pre-Test and Post-Tests for VBL II were scored by the TA using a common grading rubric with a maximum score of 15 points. The results are shown in Figure 13. It can be seen that both Group A and Group B Post-Tests scores were higher (8.86 and 10.00 respectively) than the Pre-Test (7.11 and 6.89, respectively). This shows some learning of the material based on completion of the assignment. When measuring the differential gain between the Pre- and Post-Tests, Group A had a differential gain of 1.75 and Group B had a differential gain of 3.11. Thus, both Group B's Post-Test score and differential gain are higher than Group A's. This might suggest that the treatment received by Group B (trial) created better knowledge-based learning.

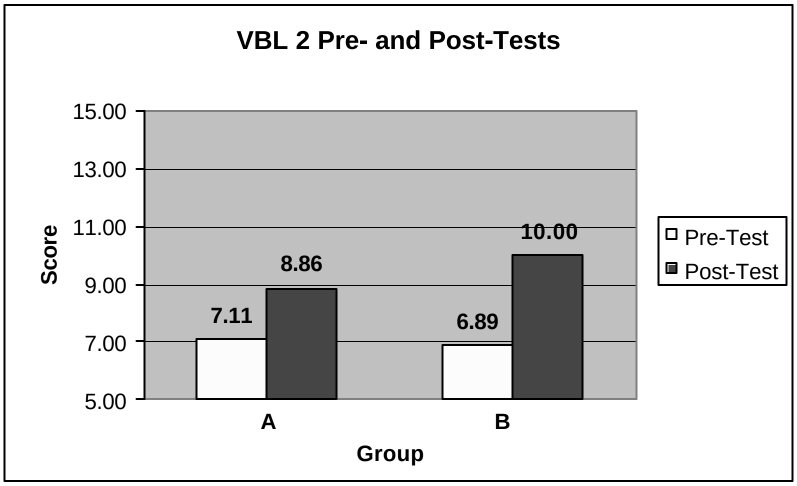

Figure 13: VBL II Pre- and Post-Test Results.

The same affect questionnaire used in testing VBL I (Table 2) was administered for VBL II. The results of this affect questionnaire are shown in two different ways. First, the Pre-Test and Post-Test results for the affect questions are plotted for each question for both Group A and B combined. As can be seen in Figure 14, 5 of 7 questions had a higher score at the Post-Test stage when compared to the Pre-Test. This could indicate that the students felt better about their general learning environment after doing their VBL II assignment, regardless of whether it was Group A (traditional assignment) or Group B (trial assignment).

A second comparison is shown in Figure 15, in which the Post-Test affect results are compared between Group A and Group B. As shown in the figure, 6 of 7 questions had a higher Post-Test score for Group B versus Group A. This could indicate that the treatment received by Group B (trial) resulted in a higher affect than the treatment received by Group A (control).

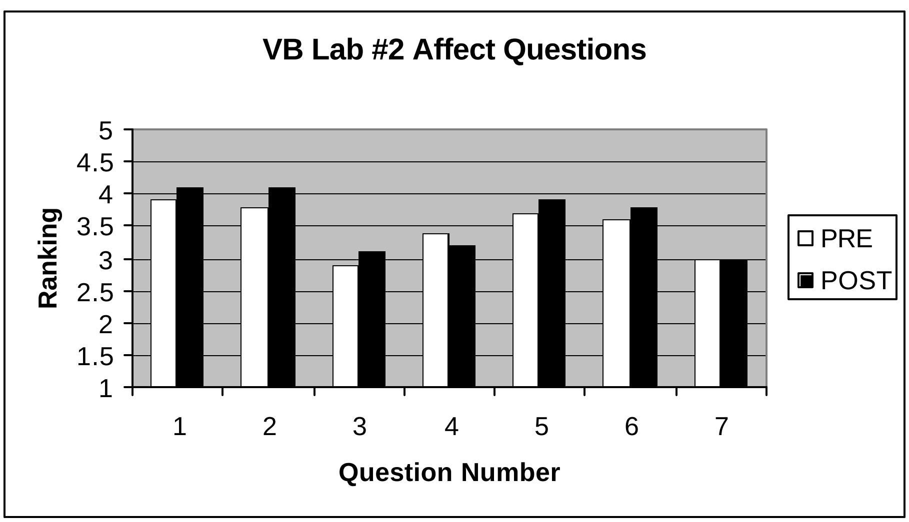

Figure 14: Pre- and Post-Test Affect Scores for VBL II.

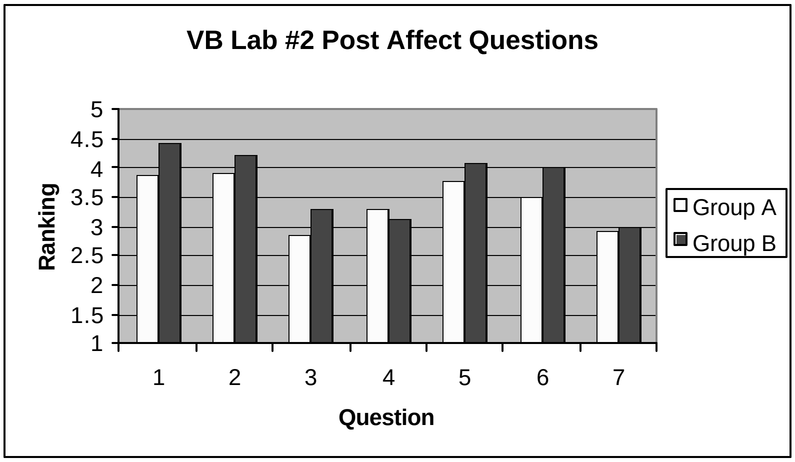

Figure 15: Post-Test Affect Scores for VBL II for Group A versus Group B.

Student Evaluation of VBL II Learning Effectiveness

An exit survey was conducted to determine the students' opinions on the learning effectiveness of different aspects of the VBL II module. The results are shown in Table 5 for Group B (website trial group). The ranking scale was 1 (not effective) to 5 (extremely effective). The students liked most of the homework exercises, except the description of kinetics data acquisition, which was an essay. They also found the background papers more useful this time than in VBL I.

Table 5: Learning Effectiveness of VBL II for Group B

Module Aspect	**Rank**
Look Ahead & Reflect Back	**3.20**
Generate Ideas: Video of Person Walking Across Force Plate	**4.00**
Multiple Perspectives: Video on Ground Reaction Forces and Measurements	**4.00**
Multiple Perspectives: Video on Moments and Torques	**3.60**
Research and Revise: Paper on Kinetics	**3.90**
Research and Revise: Paper on Phases of Gait Cycle	**4.30**
Research and Revise: Kinetic Data Collection Video Clip	**4.00**
Research and Revise: Video About Obtaining Position from Force Plate Data	**3.90**
Research and Revise: Graph of Gait and GRF Tracing Simultaneously	**3.80**
Test Your Mettle 1: Identifying the Phases of the Gait Cycle	**3.90**
Test Your Mettle 2: Interpreting the GRF Curve	**4.30**
Test Your Mettle 3: Spreadsheet Calculation of Acceleration Curves	**4.00**
Test Your Mettle 4: Question on Body Weight and GRF Curve	**3.50**
Test Your Mettle 5: Description of Kinetics Data Acquisition	**3.40**
Go Public: Assemble and Submit Work	**3.83**

Student Outcomes Survey

One final survey was conducted at the end of the semester in the course. It was an improvement in student outcomes survey as a result of taking the course. Student outcomes are defined by the Accreditation Board for Engineering and Technology (ABET) as the knowledge, skills, abilities, and attitudes that engineering undergraduates should be able to demonstrate at the time of graduation. The students were asked to "describe their improvement in each outcome as a result of learning activities provided in this course." The ranking scale was from 1 (no improvement) to 5 (very significant improvement). Table 6 lists the ten program outcomes for the Mechanical Engineering Department at the University of Texas at Austin and shows the students' average score for each. Included in the table is the mapping to the ABET prescribed *a* through *k* outcomes.[12] The same results are presented in a comparative bar chart in Figure 16.

Table 6: Results of Student Outcomes Improvement Survey

Desired Student Outcomes	Average Score
1. Knowledge of and ability to apply engineering and science fundamentals to real problems. (*a*)*	**3.46**
2. Ability to solve open-ended problems. (*e*)	**3.25**
3. Ability to design mechanical components, systems and processes. (*c*)	**2.25**
4. Ability to setup, conduct and interpret experiments and to present the results in a professional manner. (*b*)	**3.07**
5. Ability to use modern computer tools in mechanical engineering. (*k*)	**2.64**
6. Ability to communicate in written, oral and graphical forms. (*g*)	**2.68**
7. Ability to work in teams and apply interpersonal skills in engineering contexts. (*d*)	**1.82**
8. Ability and desire to lay a foundation for continued learning beyond the baccalaureate degree. (*i*)	**3.14**
9. Awareness of professional issues in engineering practice, including ethical responsibility, the creative enterprise, and loyalty and commitment to the profession. (*f*)	**2.32**
10. Awareness of contemporary issues in engineering practice, including economic, social, political, and environmental issues and global impact. (*h,j*)	**2.29**

* Mapping of ME program outcomes to the ABET prescribed *a* through *k* outcomes.[12]

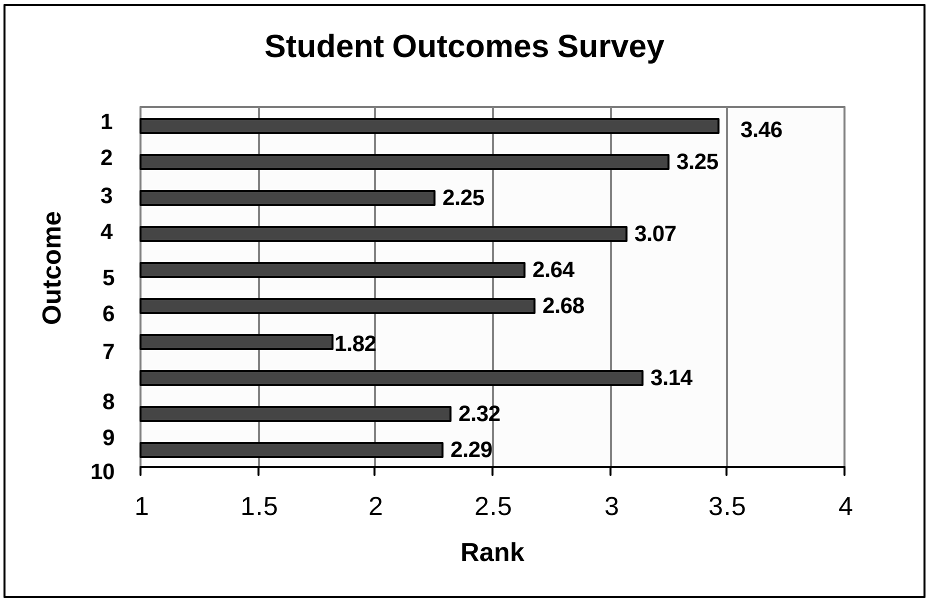

Figure 16: Results of Student Outcomes Improvement Survey.

It can be seen that four outcomes had an improvement score above 3.00 (some improvement):

Outcome 1. Knowledge of and ability to apply engineering and science fundamentals to real problems (score = 3.46).

Outcome 2. Ability to solve open-ended problems (score = 3.25)

Outcome 8. Ability and desire to lay a foundation for continued learning beyond the baccalaureate degree (score = 3.14).

*Outcome 4***.** Ability to setup, conduct and interpret experiments and to present the results in a professional manner (score = 3.07).

On the other hand, the course contributed very little to several other outcomes as seen in Figure 16. The one disturbing result is that the VBL exercises were conducted as individual assignments and thus Outcome 7 (Ability to work in teams and apply interpersonal skills in engineering contexts) received the lowest rating with 1.82. This raises the general question of whether VaNTH modules should focus on individual learning versus team learning.

Conclusions

The basic research tenet is that the VaNTH modules provide for more effective learning than the traditional approach. The two VBL challenges I and II tested in this class provide some evidence to support that belief. The Pre- and Post-Test results showed that Group B (trial group) had a higher Post-Test score and larger differential gain for both VBL I and VBL II. The affect questionnaire results also show that Group B had a slightly higher level of "enthusiasm" for the quality of learning that occurred in the course. The one negative result is that Group A (control group) had higher homework scores for both VBL I and II. Further testing of these VBL modules is warranted to affirm the results of this preliminary study.

References

1. Harris, T.R., Bransford, J.D. and Brophy, S.P. (2002): Roles for Learning Sciences and Learning Technologies in Biomedical Engineering Education: A Review of Recent Advances. *Annual Review of Biomedical Engineering,* 4: 29-48.

2. Bransford J.D., Brown A.L., and Cocking R.R., Editors (1999). *How People Learn: Brain, Mind, Experience, and School.* National Academy Press, Washington, D.C.

3. Schwartz, D. L., Brophy, S., Lin, X., Bransford J. D. (1999). Software for Managing Complex Learning: Examples from an Educational Psychology Course. *Educational Technology Research and Development*. 47(2), 39 -59.

4. Whittle, M. W. (1996): *Gait Analysis: An Introduction*, Second Edition. Oxford: Butterworth – Heinemann.

5. Winter, D.A. (1990): *Biomechanics and Motor Control of Human Movement*, Second Edition. New York.

6. Whittle, M. W. (1997): Three-dimensional motion of the center of gravity of the body during walking: *Human Movement Science*, vol. 16:347 – 355.

7. Eames, M. H. A., Cosgrove, A., and Baker, R. (1999): Comparing methods of estimating the total body center of mass in three-dimensions in normal and pathological gaits: *Human Movement Science*, vol. 18:637 – 646.

8. http://engineering.cua.edu/biomedical/courses/be522/grv/.

9. Molson Medical Informatics Project, http://sprojects.mmi.mcgill.ca/gait/normal/intro.asp.

10. Rose, J. and Gamble, J., (1993). *Human Walking*, Second Edition, Williams & Wilkins.

11. Barnes, S. and Berme, N., (1995): Measurement of Kinetic Parameters Technology, in *Gait Analysis: Theory and Application*, Craik and Oatis (Editors).

12. Engineering Accreditation Commission (2002). *Criteria for Accrediting Engineering Programs*, Accreditation Board for Engineering and Technology (ABET), Baltimore, Maryland.

Acknowledgements

This work was supported in part by the Engineering Research Centers (ERC) Program of the National Science Foundation (NSF) under Award Number EEC-9876363.

Biographical Sketches

Dr. Ronald E. Barr is a Professor of Mechanical Engineering at the University of Texas at Austin, where he has taught since 1978. He received both his B.S. and Ph.D. degrees from Marquette University in 1969 and 1975, respectively. His research interests are in Biosignal Analysis, Biomechanics, and Engineering Computer Graphics. Barr is the 1993 recipient of the ASEE Chester F. Carlson Award for innovation in engineering education. Barr is a Fellow of ASEE and a registered Professional Engineer (PE) in the state of Texas.

Dr. Marcus G. Pandy is an Associate Professor in the Department of Biomedical Engineering at The University of Texas at Austin. Dr. Pandy received a Ph.D. in mechanical engineering from Ohio State University in Columbus (1987). He then completed a two-year post-doctoral fellowship in the Department of Mechanical Engineering at Stanford University. He has been a faculty member at The University of Texas since 1990. Dr. Pandy's research interests are in biomechanics and control of human movement. Much of his research is aimed at using computer models of the musculoskeletal system to study muscle, ligament, and joint function in the normal, injured, and diseased states.

Dr. Anthony J. Petrosino is an Assistant Professor and Learning Scientist in the Department of Curriculum and Instruction at The University of Texas at Austin. He received his M.Ed. from Teachers College, Columbia University (1990) before becoming a member of the Cognition and Technology Group at Vanderbilt. He completed his Ph.D. from Vanderbilt University in 1998. Upon graduation, Dr. Petrosino moved to The University of Wisconsin as a McDonnell Postdoctoral Fellow through the Cognitive Studies in Educational Practice (CSEP) Program. While in Wisconsin, Dr. Petrosino was a contributing member to the National Center for Improving Student Learning and Achievement in Mathematics and Science (NCISLA). His research interests include the design of classroom learning environments, children's experimentation strategies and application of modern learning theory to biomedical engineering education.

Dr. Lawrence D. Abraham is an Associate Professor at The University of Texas at Austin in the Departments of Kinesiology & Health Education and Curriculum & Instruction. He presently serves as chair of Curriculum & Instruction and is also a faculty member in interdisciplinary graduate programs in Neuroscience and Biomedical Engineering. He received his A.B. from Oberlin College in 1971, his M.S. from Kansas State Teachers College in 1972, and his Ed.D. from Teachers College, Columbia University in 1975. Abraham's research interests are in the biomechanics and neural control of human movement.

Tejas Karande is a graduate student of Biomedical Engineering at The University of Texas at Austin. He received his B. S. degree from the D. J. Sanghvi College of Engineering, University of Mumbai in 1999 and M. S. degree from The University of Texas at Austin in 2002. His research interests are in Biomechanics and Musculoskeletal Tissue Engineering.

Bijal Patel is a graduate student of Kinesiology at The University of Texas at Austin. She received her B.S. in Biomedical Engineering from University of Mumbai and M.S. in Biomedical Engineering from Wayne State University in 1999 and 2001, respectively. Her research interests are in Biomechanics of Human Movement and Tissue Biomechanics.