The VaNTH Biomechanics Learning Modules

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Abstract

This paper presents the VaNTH Biomechanics learning modules and discusses their implementation in a Fall 2004 engineering course. These Biomechanics learning modules were developed as part of the VaNTH NSF educational coalition formed by multiple institutions in the USA. The pedagogical framework for these 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 educational significance of this effort is that these challenge-based Biomechanics modules were the main mode of instructional delivery in the course. The VaNTH biomechanics modules were presented in an undergraduate Mechanical Engineering course titled "Biomechanics of Human Movement" in Fall 2004. The class (N=18) was divided into three-member teams. All challenges were performed by the teams using computer-based homework assignments that were supplied by the instructor on a CD. Pre-tests, post-tests, and affect rankings were administered for each modular topic to assess the course. The students were also surveyed on the learning effectiveness of the various components of each module. At the end of the semester, the students completed a Biomechanics topics matrix that mapped the challenges to the various class topics. Results of this classroom experience and data gathering are presented in the paper. Conclusions are drawn on the pedagogical efficacy of this approach to instruction.

Introduction

The course ME 354M, "Biomechanics of Human Movement," is an undergraduate technical block elective in Mechanical Engineering (ME). In the past, the course was taught in a traditional format with chalkboard lectures and overhead transparencies, and with a few paper handouts 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 have included:

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

The participation of this class was 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 and learning objectives; 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. Recent research by the authors[4] has shown that the VaNTH Biomechanics approach increased students' conceptual knowledge as well as their ability to transfer knowledge to new situations. This suggests that challenge-based instruction can accelerate the student's trajectory from novice to expert on a given topic.

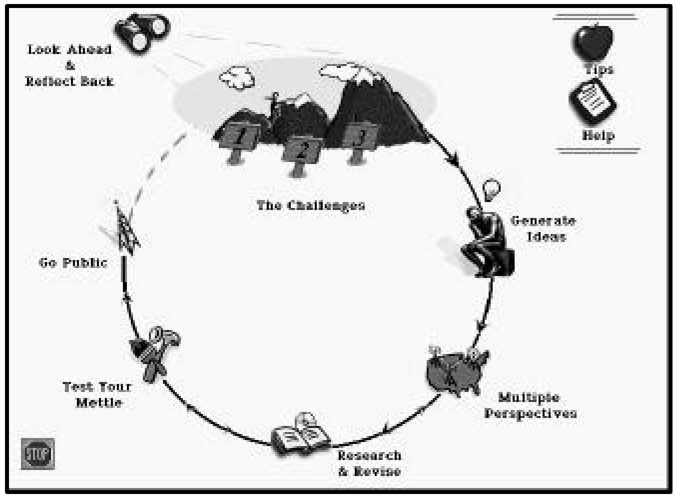


Figure 1: The Legacy Cycle Framework.[3]

Classroom Instruction and Teaching Methodology

A total of 18 students were enrolled in ME 354M in Fall 2004. A request to use students as human research subjects for the course was approved by the University of Texas Institutional Review Board (IRB). Students were asked to sign a human subject consent form and all students graciously obliged. The instructional setting for each challenge was similar and the overall course testing methodology was organized as shown in Table 1. First, the students took a pre-course test. The pre-course test consisted of thirty multiple-choice questions over a variety of Biomechanics topics. The same set of multiple-choice questions was also used at the end of the course as a post-course test. Next the students were divided into three-member teams and the course instruction began.

While there were eight Biomechanics challenges, they were organized into four topical areas:

1. The Iron Cross (IC), *one challenge*;
2. The Virtual Biomechanics Laboratory (VBL), *three challenges*;
3. Jumping Jack (JJ), *three challenges;* and
4. The Knee, *one challenge.*

The same instruction and testing methodology was used for each of these topical areas. First, some general background lectures on the topic were given using Powerpoint slide shows prepared by the first author. The students then took a pre-test and completed an affect survey (see later Table 7). The students then performed the challenge(s) posed on the CD in the form of the Legacy Cycle. After the completion of each topical area, the students took a post-test and a post-affect survey. Three times during the semester (Pre, Mid, and Post), a student outcomes survey was administered. All tests and exercises were graded using uniform grading rubrics. At the end of the semester, the students also completed a final report that included a learning effectiveness survey for each of the eight challenges and a matrix that mapped general Biomechanics topics to the modules. Table 1 summarizes this methodology.

Table 1: Summary of Classroom Instruction and Testing Methodology

Item	Date
Human Consent Form Signed by Students	August 26
Pre-Course Test Administered (30 Multiple-Choice Questions)	August 26
Pre-Outcomes Survey of UT-ME ABET Outcomes	September 7
Iron Cross Pre-Test Administered and Pre-Affect Survey Given	September 7
Iron Cross Module Presented to Class and Performed by the Teams	September 21
Iron Cross Post-Test Administered and Post-Affect Survey Given	September 21
Virtual Biomechanics Lab Pre-Test Administered and Pre-Affect Survey Given	September 23
Virtual Biomechanics Lab I Module Presented to Class and Performed by the Teams	October 12
Virtual Biomechanics Lab II Module Presented to Class and Performed by the Teams	October 14
Virtual Biomechanics Lab III Module Presented to Class and Performed by the Teams	October 26
Virtual Biomechanics Lab Post-Test Administered and Post-Affect Survey Given	October 26
Mid-Outcomes Survey of UT-ME ABET Outcomes	October 26
Mid-Semester Test (10 Problems Requiring Calculations)	October 19
Jumping Jack Pre-Test Administered and Pre-Affect Survey Given	October 28
Jumping Jack Module I Presented to Class and Performed by the Teams	November 16
Jumping Jack Module II Presented to Class and Performed by the Teams	November 16
Jumping Jack Module III Presented to Class and Performed by the Teams	November 16
Jumping Jack Post-Test Administered and Post-Affect Survey Given	November 16
Knee Pre-Test Administered and Pre-Affect Survey Given	November 16
Knee Module Presented to Class and Performed by the Teams	November 30
Knee Post-Test Administered and Post-Affect Survey Given	November 30
Post-Outcomes Survey of UT-ME ABET Outcomes	November 30
Post-Course Test Administered (same 30 Multiple-Choice Questions)	December 2
Final Report on Modules Learning Effectiveness and Biomechanics Topics Matrix	December 8

Challenge 1: The Iron Cross

The Iron Cross challenge is "How much muscle strength is required to sustain the Iron Cross position (Figure 2)." The presentation starts with short testimonials from experts in the field: a surgeon, a mechanical engineer, a sports physical therapist, and a biomedical engineering graduate student. The students also see a video of an amateur gymnast who attempts the Iron Cross maneuver. The students are next asked to formulate a free body diagram (Figure 3) of the forces and moments generated at the shoulder joint. This compels them to think about the mechanics of the position and about the information that is needed to solve the problem. Some anthropometric data, such as the shoulder muscles' origin and insertion points, are presented in the challenge (Figure 4). This leads to the major observation: the IC is a static indeterminate problem due to the multiple muscle actuators that cross the shoulder joint. Thus, the students must make initial assumptions, such as maximum muscle force activations. They must also calculate the moment arms for all these muscle actuators at the given IC arm angle. They are presented with a generic formulation of the problem (Figure 5) and are asked to solve for the forces in the muscles to maintain this IC position.

Figure 2: The Iron Cross Position.

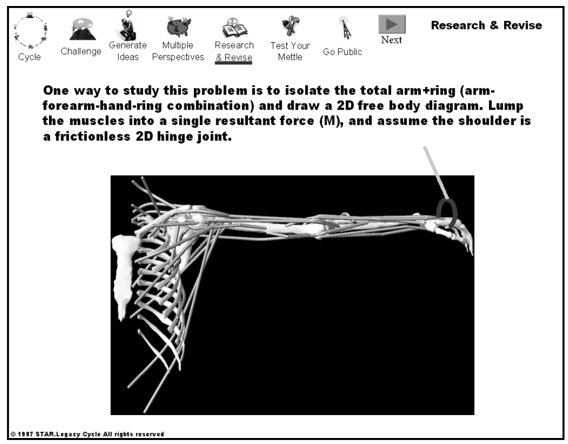
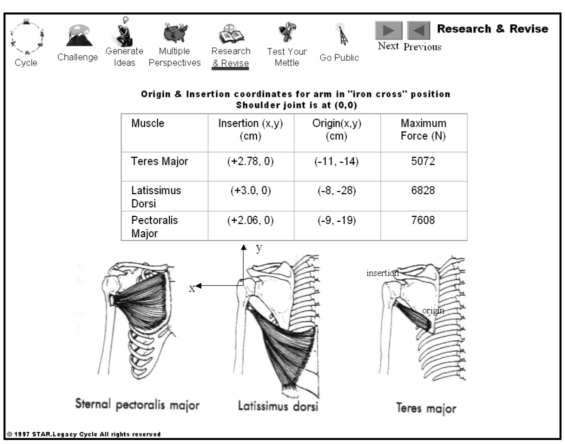


Figure 3: The Free Body Diagram Problem for the Iron Cross.



Muscle	Insertion (x,y) (cm)	Origin(x,y) (cm)	Maximum Force (N)
Teres Major	(+2.78, 0)	(-11, -14)	5072
Latissimus Dorsi	(+3.0, 0)	(-8, -28)	6828
Pectoralis Major	(+2.06, 0)	(-9, -19)	7608

Figure 4: Anthropometric Data About the Shoulder Muscles.

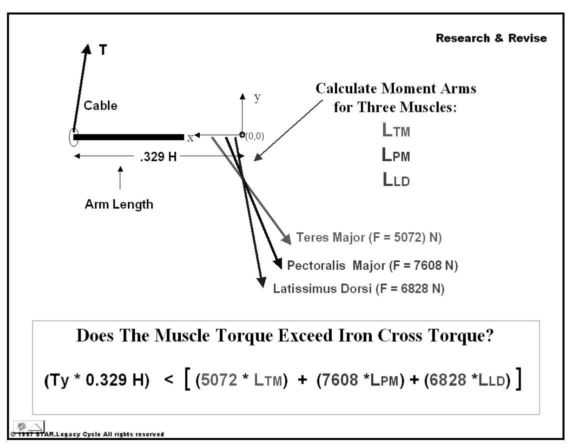


Figure 5: General Formulation of the Iron Cross Problem.

Challenge 2: The Virtual Biomechanics Laboratory I - Kinematics

The Virtual Biomechanics Laboratory (VBL) module consists of three challenges, all concerned with experimental observations (kinematics, kinetics, muscle activation) made in a gait analysis lab. The first VBL challenge is “How does your whole body center of gravity move when you walk?’ In order to obtain background information about human gait, the students are presented with several web-embedded movie clips: a stick figure walking (Figure 6), a video-audio clip of an expert professor (Figure 7), and numerous video-audio clips about data acquisition in a gait lab (Figure 8). Since the main focus of VBL I is center of gravity (CG) calculations, the students receive some background material on multi-segmental CG calculations, starting with a simple static case. They are then presented the main exercise, which is to find the whole body CG using a formula pasted into an Excel spreadsheet. The formula links the various multi-segment data in the columns, and calculates a CG for that case at each time sample point. Then they plot (Figure 9) the result of this Excel CG calculation across all samples for the entire gait cycle. In the final exercise, they answer an interesting question about “hitting their head when walking under a door exactly equal to their height.”

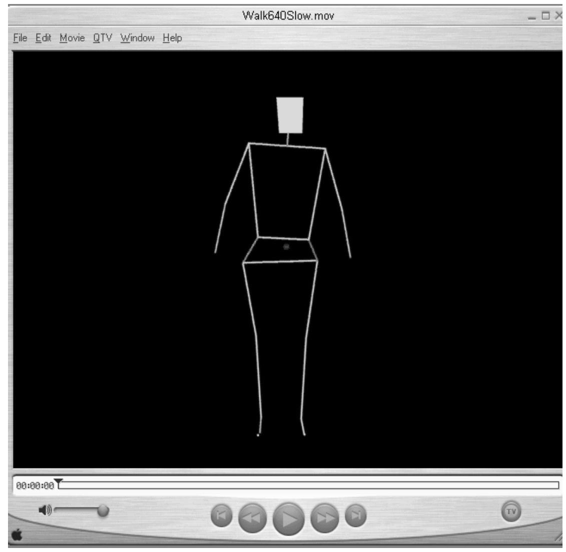


Figure 6: Human Stick Figure Walking Video Clip.

Figure 7: Multiple Perspective Video Clip from a Professor.

Figure 8: Kinematics Data Acquisition Video Clip.

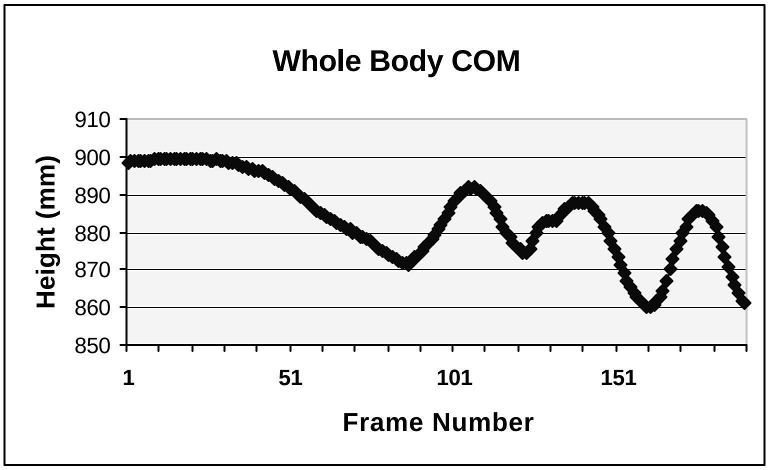


Figure 9: Solution to the Whole Body CG Spreadsheet Exercise.

Challenge 3: The Virtual Biomechanics Laboratory II – Kinetics

The second Virtual Biomechanics Laboratory challenge is "What forces do you exert on the ground when you walk?" They are presented with video-audio clips from several experts and are shown a video of someone striking a force plate on the ground (Figure 10). Some background on the gait cycle complements this presentation, since the shape of the force plate curve is highly related to the stages of the gait cycle (Figure 11). The major exercises for VBL II focus on identification of the various phases of the gait cycle and on interpretation of the ground reaction force (GRF) curve (Figure 12) that is obtained when the subject walks on the force plate. The source of the double hump in the GRF curve poses an interesting question about "whether the subject ever exerts a force on the ground that is less than body weight when walking?" The students then take a spreadsheet file of the ground reaction forces, and use it to calculate and plot (Figure 13) the acceleration of the whole body CG using the formula:

$$a = [(GRF/m) - g] .$$

This then allows them to compare this CG acceleration curve to that from VBL I.

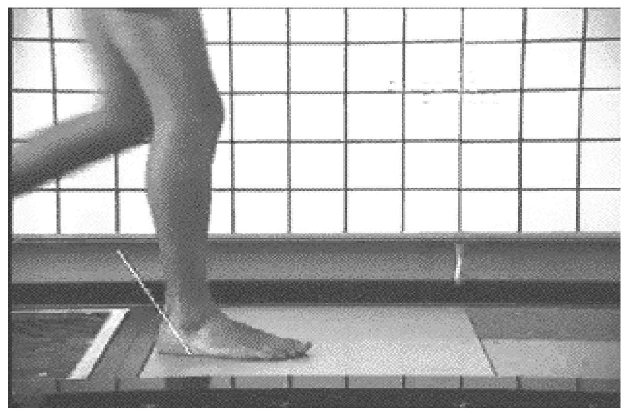


Figure 10: Striking the Force Plate.

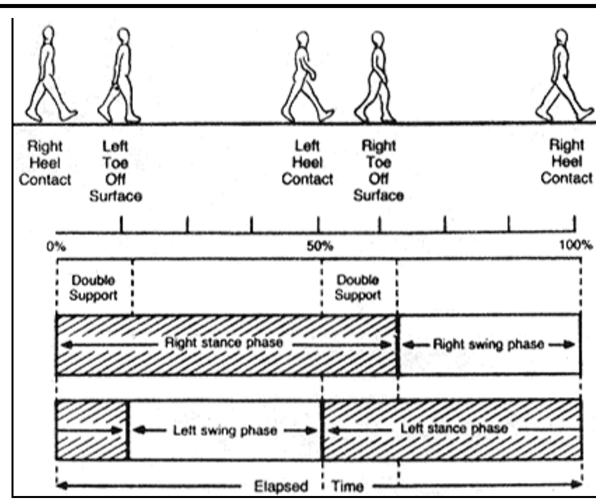


Figure 11: Stages of the Gait Cycle (from reference 5).

Challenge 4: The Virtual Biomechanics Laboratory III – Muscle Activation

The third Virtual Biomechanics Laboratory is concerned with "How do the leg muscles activate during one complete gait cycle?" The laboratory starts with the anatomy of the major leg muscles that contribute to walking: gluteus maximus, medial and lateral hamstrings, quadriceps, plantar flexors, and dorsal flexors. The students relate which muscles activate during each phase of the gait cycle studied in VBL II.

Next, they are introduced to the electromygraphic (EMG) signal, its electrical origin, and its frequency characteristics. A spreadsheet is supplied with the raw EMG signals gathered in a gait lab for five leg muscles: gluteus maximus, medial hamstring, quadriceps, gastrocnemius, and tibialis anterior. The students plot the raw signals and try to associate the EMG activations with the various phases of the gait cycle, as portrayed in the GRF curve. Next, they process the raw EMG data to get a root mean square (RMS) estimate using a 31-point sliding window formula:

$$RMS_i = \sqrt{\frac{\sum_{n=-15}^{15}(X_{i-n}^2)}{31}}$$

Figure 14 shows a typical overplot of the raw EMG and the RMS calculation for the quadriceps muscle.

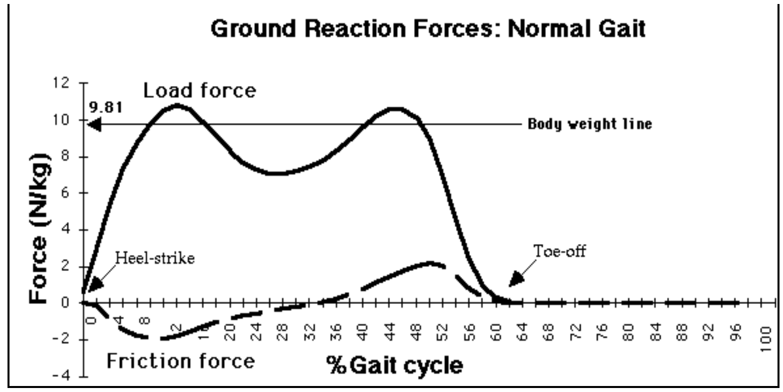


Figure 12: Typical Ground Reaction Force (GRF) Curve. The Vertical Axis is Normalized to Gravity.

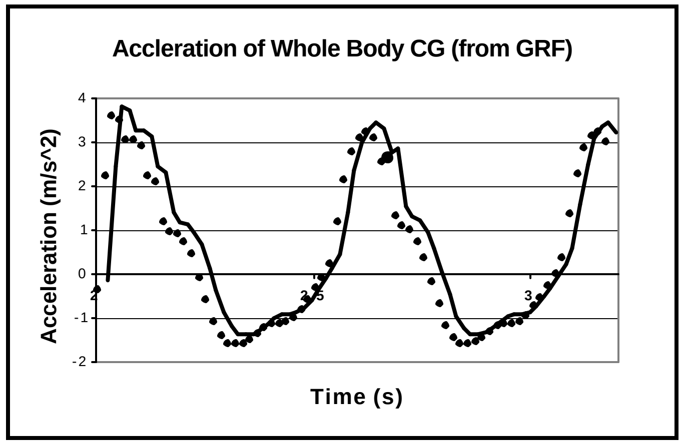


Figure 13: Student Plot of Acceleration of Whole Body CG Obtained from Experimental (GRF) Data.

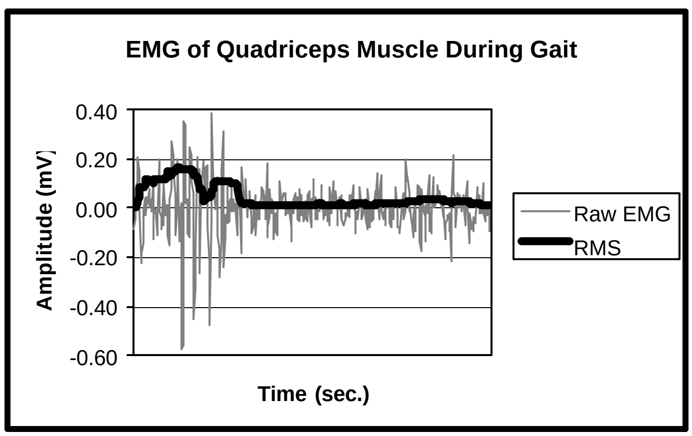


Figure 14: Student Plot of the Raw and RMS Processed EMG for the Quadriceps Muscle.

Challenge 5: Jumping Jack I – Experimental Data

The Jumping Jack (JJ) module consists of three challenges, all concerned with the biomechanics of human jumping and the equations of motion for projectile dynamics. The first JJ I challenge is "How high can you jump?" The objective is for the students to compare various ways to calculate a maximum height vertical squat jump (Figure 15). The challenge starts with some video clips of different professors, who talk about the dynamics of jumping. Several on-line documents give background and insight into the problem. A spreadsheet is given with experimental jumping data collected from a human subject. The data contains columns for: ground reaction force, and the vertical position, velocity, and acceleration of the subject's center of mass (COM).

Figure 15: Vertical Squat Jump Experiment.

The first jump height calculation is to simply scan the vertical COM position column on the spreadsheet and find the maximum value. The second method is to scan the spreadsheet file and find the velocity $\dot{y}(0)$ of the COM at lift-off, which is when the GRF curve goes to zero. Then they can apply the common projectile equation:

$$Jheight = y(0) + \left[\frac{\dot{y}^2(0)}{2g} \right]$$

A third more elaborate way of calculating the jump height is to use the impulse-momentum method. Here the students first find the COM acceleration during generation of the vertical GRF (Figure 16). They then integrate the acceleration curve to get the lift-off velocity using the formula:

$$\dot{y}(0) = \int a dt = \int \frac{F}{m} dt - \int g dt$$

They then calculate jump height with this new $\dot{y}(0)$ using the earlier projectile equation. This allows the students to compare the accuracy of the various jump height methods used for this challenge.

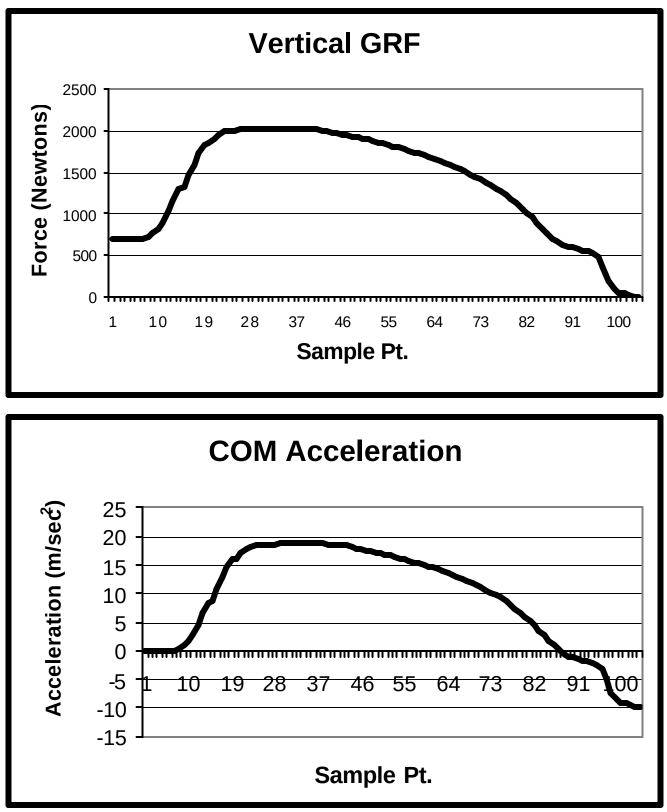


Figure 16: The Vertical GRF and Acceleration Curves for a Squat Jump.

Challenge 6: Jumping Jack II – Baton Modeling

The JJ II challenge is "What determines jump height?" The students learn about the modeling of muscle systems, and study the generalized muscle force-length and force-velocity curves. Next, they study human jumping using a simple baton (rod) mechanical system (Figure 17). Time histories are provided for the baton's joint angle and angular velocity, and muscle contraction forces are given in a spreadsheet. The students derive the equation of motion for the vertical velocity of the baton COM:

$$\dot{y} = 0.25\cos(\theta)\dot{\theta}$$

They also calculate the ground reaction force Fv as a function of the angle q :

$$Fv = mg + m(0.25)[-\sin(\theta)\dot{\theta}^2 + \cos(\theta)\ddot{\theta}]$$

When Fv goes to zero, the baton is allowed to fly up and the students can now calculate the maximum height using the angle value determined for fly off.

The second part of JJ II uses a simple optimization routine (Figure 18) to determine the contributions of maximum muscle force and maximum contraction velocity to jump height. For given parameters, the program calculates the optimum muscle activation to maximize the height to which the rod is propelled. They download the program and play around with it, changing the values of maximum force and maximum velocity to see what levels of jump height can be attained by combinations of these parameters.

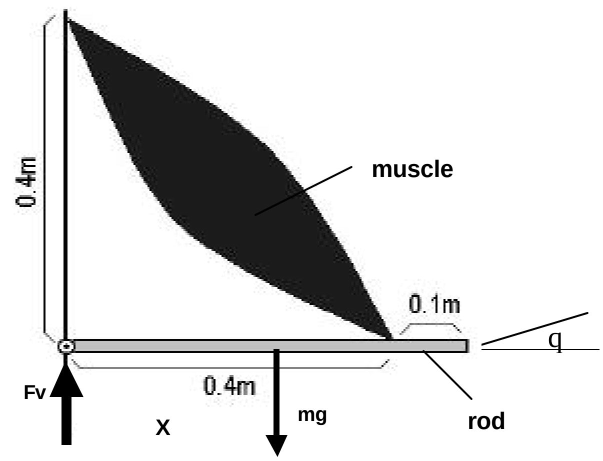


Figure 17: The Baton Model for JJ II.

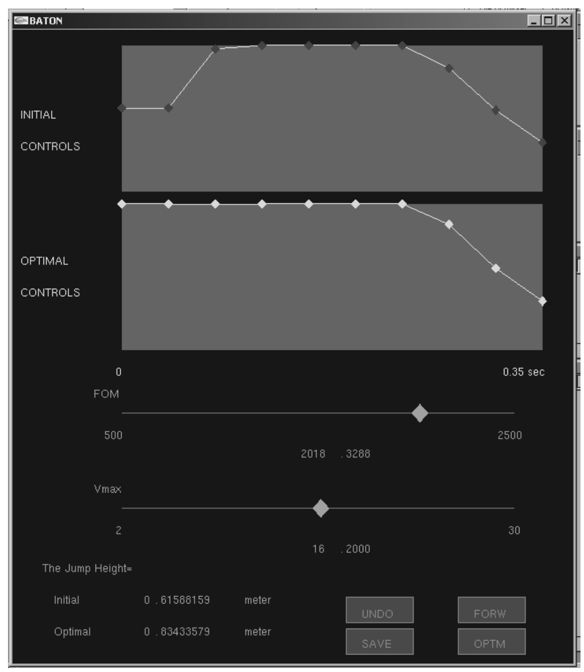


Figure 18: The Baton Optimization Program User Interface for JJ II.

Challenge 7: Jumping Jack III – Computer Graphics Modeling and Simulation

The third Jumping Jack challenge is "What determines who can jump higher?" The students read various papers on what factors result in optimal jumps, including a discussion about gravity and its effect on jumping on the moon. They then download another simulation program that allows them to set the torques histories at three joints: hip, knee, and ankle. They play around with this program interface (Figure 19) and try various values of torques to achieve a maximum jump. They then press the “Jump” button to see how high the model will jump. An accompanying stick figure simulation (Figure 20) lends some computer graphics realism to the simulation. The maximum jump values are then displayed on the interface. They try various combinations of controls, including altering gravity to jump on the moon.

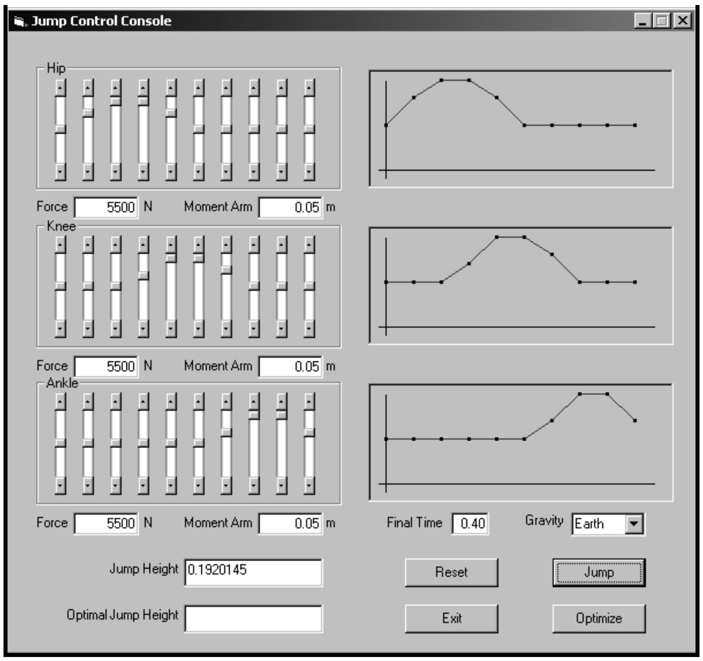


Figure 19: The Jump Control Console for JJ III.

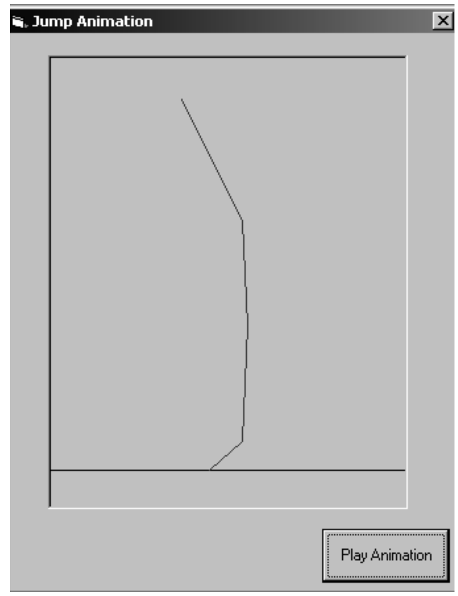


Figure 20: The Stick Figure Jump Animation for JJ III.

Challenge 8: The Knee

The final challenge involves studying the knee joint. The challenge is posed by the question “Can Voluntary Contraction of the Quadriceps Muscle Group Tear the Anterior Cruciate Ligament (ACL) During an Isometric Knee Extension Exercise.” The students review several video movies of the knee joint during flexion and extension. They learn about the major bones, muscles, and ligaments about the knee joint, and study the purposes for the ACL and PCL ligaments to keep the knee stabilized. They then use an Excel spreadsheet that contains kinematics data of the knee during a simulated flexion experiment. Using a free body diagram, they derive the forces at the knee and then calculate the force in the ACL as a function of the flexion angle. They plot the forces in the ACL and, based on this plot, determine if the ACL is torn during the experiment. They make this determination if the ACL force ever exceeds the given maximum ACL withstanding force of 2000 N.

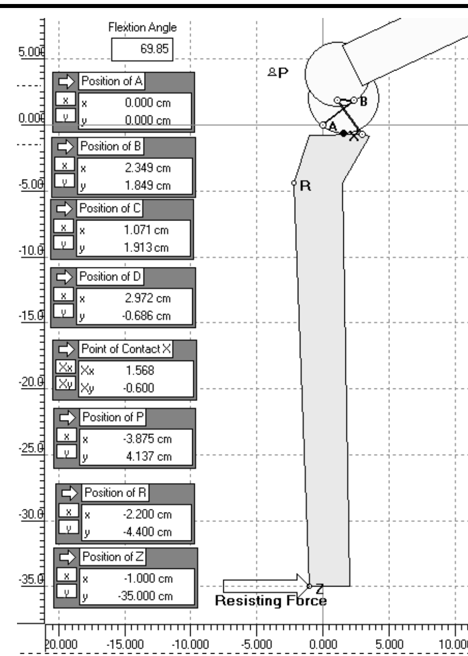


Figure 21: The Knee Diagram Used to Solve the ACL Problem.

Results of Classroom Testing

The classroom implementation and testing of the challenges were outlined earlier in Table 1. This methodology included pre-course and post-course multiple choice tests, module pre- and post-tests, module pre- and post-affect surveys, several outcomes surveys, and a final Biomechanics topics matrix assignment. This section will report the raw results of this data gathering and analysis report.

First, in order to determine if the pre-post conditions are significantly different, an Effect Size (E.S.) statistic[6] is calculated using the formula:

$$E.S. = \frac{AVE_{Post} - AVE_{Pre}}{pooled\ \ Std.Dev.},$$

where AVE_{Post} is the average post score, AVE_{Pre} is the average pre score, and *pooled Std. Dev.* is the average of the pre standard deviation and the post standard deviation. An E.S. of 1.3 is considered significant at the 90% level, an E.S of 1.6 is considered significant at the 95% level, and an E.S. of 2.5 is considered significant at the 99% level, assuming a normal distribution of scores.

Pre-Course and Post-Course Test Results

On the first class day, after signing the IRB consent form, the students took a comprehensive pre-course test to set the overall level of understanding of Biomechanics before the course begins. The test consisted of thirty multiple-choice questions that covered all topics covered in the course. The same thirty-question test was given on the last class day as a post-course test.

Table 2 shows the numerical results depicting the pre-course and post-course scores for each student, and Figure 22 is a graphical presentation of the same data. It can be seen that, on the average, there was an increase of 7.72 points in the post-course test, when measured against the pre-course test. This equates to the students answering approximately eight more questions correctly, out of thirty, at the end of the course. The only anomaly in the data is that one student (number 8) actually went down two points in the post-course test. Number 8 had a bad day. Using the E.S. statistic above, the effect size of 2.46 indicates that the post-course scores were clearly statistically better than the pre-course scores at a 99% certainty level.

Table 2: Pre-Post Course Test Scores

Student	Pre-Course	Post-Course	Gain
1	18	25	7
2	16	21	5
3	23	28	5
4	10	20	10
5	19	20	1
6	18	24	6
7	17	23	6
8	19	17	-2
9	13	25	12
10	16	27	11
11	14	22	8
12	15	20	5
13	14	22	8
14	10	26	16
15	12	23	11
16	13	22	9
17	11	22	11
18	15	25	10
Average (Std. Dev.)	**15.17 (3.47)**	**22.89 (2.81)**	**7.72**
Effect Size = 2.46			

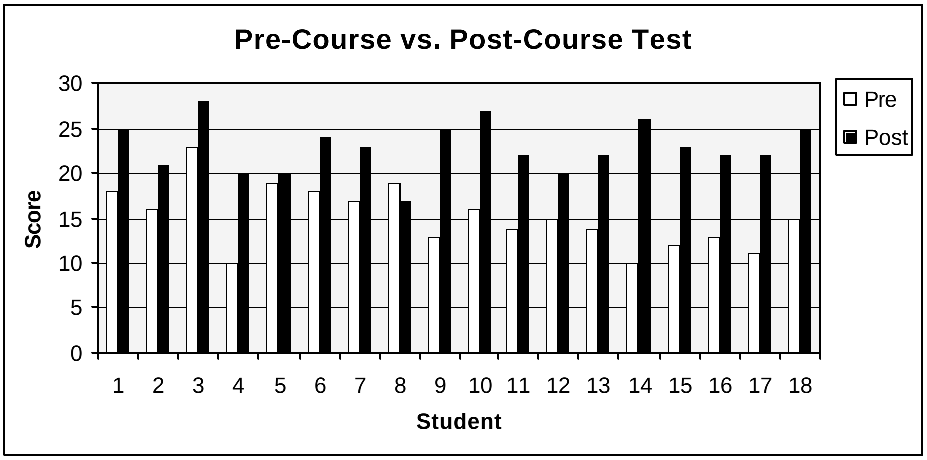


Figure 22: Scores for the Pre-Course and Post-Course Test

Module Pre -Test and Post-Test Results

As indicated earlier, four topical areas were addressed by the eight challenges. Thus there were four sets of module pre-tests and post-tests. The pre-post tests were the same for each case, and they typically had a combination of multiple choice questions, short answer questions, and problems that required some simple calculations. A grading rubric was created for each test, and the maximum score was normalized to five points for each test. Tables 3 through 6 show the results of the pre-tests and post-tests for the Iron Cross, Virtual Biomechanics Lab, Jumping Jack, and Knee modules, respectively. The same results are shown graphically in Figures 23 to 26 for the four modular areas.

It can be seen that there is improvement in the post-test scores for almost all the students in each of the four data sets. Out of 72 possibilities (4x18), there were only six instances where a student showed a decrease in the post-test scores. Five of these occurred in the final Knee module, so it may be that the grading rubric for that test was not as discriminating or else the grader was inconsistent at the end of the semester. The average gain (post minus pre scores) was 0.83 for the IC module, 0.70 for the VBL module, 1.06 for the JJ module, and 0.55 for the Knee, for a grand average gain of 0.875. Considering the tests had a 5-point maximum score, and since the grand average pre-test score was 2.91, this average gain of 0.875 represents a 30 percent improvement overall in the scores.

Table 7 consolidates the distribution of pre-test and post-test score averages for all four topical areas, along with the Effect Size (E.S.) statistic. It can be seen that the gain from pre to post-tests scores was positive for all four cases. An observation worth noting is the widely-varying range in the E.S. statistic, from a non-significant value of 0.70 for the Knee module, to a highly significant value of 2.75 for the Jumping Jack module. This suggests that the challenges' levels of difficulty, at least as represented by pre-post tests, varied somewhat. Based on the E.S. score, one would suggest that the Knee module is more straightforward than, for example, the Jumping Jack module. This might suggest a re-ordering of presentation of the modules in the course. Perhaps a more pedagogically acceptable order would be: Knee, Iron Cross, Virtual Biomechanics Lab, and Jumping Jack.

Table 3: Iron Cross Pre-Post Test Scores			
Student	**Pre-Test**	**Post-Test**	**Gain**
1	3.25	4.25	1.00
2	3.50	3.75	0.25
3	3.25	4.50	1.25
4	3.00	3.75	0.75
5	3.50	4.75	1.25
6	3.50	4.00	0.50
7	3.00	4.75	1.75
8	3.00	3.50	0.50
9	4.75	4.75	0.00
10	3.00	4.00	1.00
11	3.00	4.25	1.25
12	3.35	4.50	1.15
13	3.75	3.75	0.00
14	3.00	4.25	1.25
15	3.25	4.25	1.00
16	4.00	4.25	0.25
17	1.50	2.50	1.00
18	3.50	4.25	0.75
Average (Std. Dev.)	**3.28 (0.63)**	**4.11 (0.54)**	**0.83**

Table 4: VBL Pre-Post Test Scores			
Student	**Pre-Test**	**Post-Test**	**Gain**
1	2.85	3.25	0.40
2	1.90	3.30	1.40
3	2.10	3.25	1.15
4	2.35	3.70	1.35
5	1.85	3.20	1.35
6	2.50	3.65	1.15
7	3.05	3.05	0.00
8	2.00	3.05	1.05
9	3.15	3.35	0.20
10	2.50	3.95	1.45
11	2.05	2.50	0.45
12	2.80	2.90	0.10
13	2.75	3.35	0.60
14	3.10	3.30	0.20
15	3.30	3.15	-0.15
16	2.85	3.50	0.65
17	2.15	2.75	0.60
18	2.70	3.40	0.70
Average (Std. Dev.)	**2.55 (0.46)**	**3.26 (0.34)**	**0.70**

Table 5: Jumping Jack Pre-Post Test Scores			
Student	**Pre-Test**	**Post-Test**	**Gain**
1	2.88	3.63	0.75
2	2.75	3.43	0.68
3	3.13	4.00	0.88
4	1.75	3.38	1.63
5	2.98	3.43	0.45
6	2.50	3.30	0.80
7	2.63	3.93	1.30
8	2.75	2.88	0.13
9	2.00	3.52	1.52
10	2.38	3.63	1.25
11	2.63	2.93	0.30
12	2.00	3.68	1.68
13	2.38	3.25	0.88
14	3.00	3.95	0.95
15	2.50	4.45	1.95
16	2.00	3.63	1.63
17	2.63	3.45	0.83
18	2.38	3.80	1.43
Average (Std. Dev.)	**2.51 (0.39)**	**3.57 (0.38)**	**1.06**

Table 6: Knee Pre-Post Test Scores			
Student	**Pre-Test**	**Post-Test**	**Gain**
1	4.00	3.75	-0.25
2	2.25	3.75	1.50
3	4.00	4.00	0.00
4	4.50	4.00	-0.50
5	3.25	4.00	0.75
6	2.50	3.50	1.00
7	3.50	3.50	0.00
8	2.75	3.50	0.75
9	4.50	4.75	0.25
10	3.40	2.50	-0.90
11	2.00	3.25	1.25
12	4.40	3.25	-1.15
13	2.50	3.75	1.25
14	2.63	4.25	1.63
15	3.75	4.75	1.00
16	4.75	4.25	-0.50
17	1.25	3.75	2.50
18	3.50	4.75	1.25
Average	**3.30 (0.99)**	**3.85 (0.58)**	**0.55**

Table 7: Summary of Pre-Post Tests and Effect Sizes for the Four Topical Modules

Module Topic	Pre-Test Ave. (Std. Dev.)	Post-Test Ave (Std. Dev.)	Gain (Post-Pre)	Effect Size
Iron Cross	3.28 (0.63)	4.11 (0.54)	0.83	1.41
Virtual Biomechanics Lab	2.55 (0.46)	3.26 (0.34)	0.70	1.78
Jumping Jack	2.51 (0.39)	3.57 (0.38)	1.06	2.75
Knee	3.30 (0.99)	3.85 (0.58)	0.55	0.70

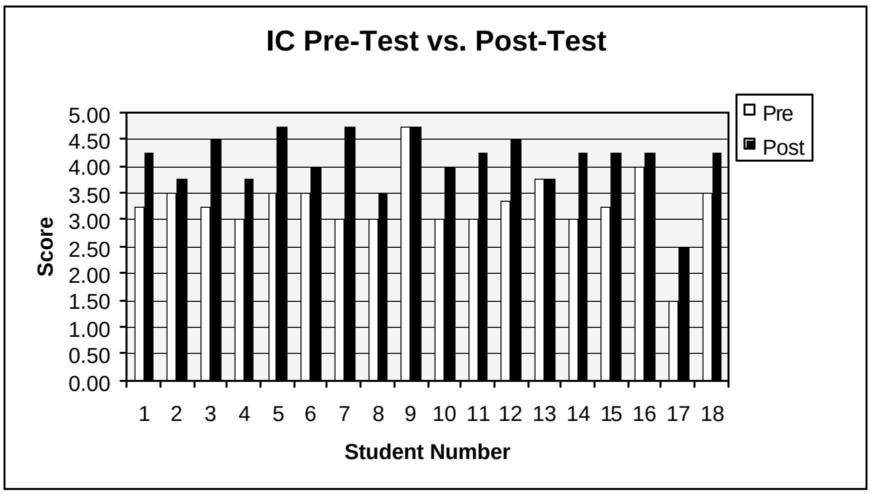


Figure 23: The Iron Cross Pre-Post Test Results.

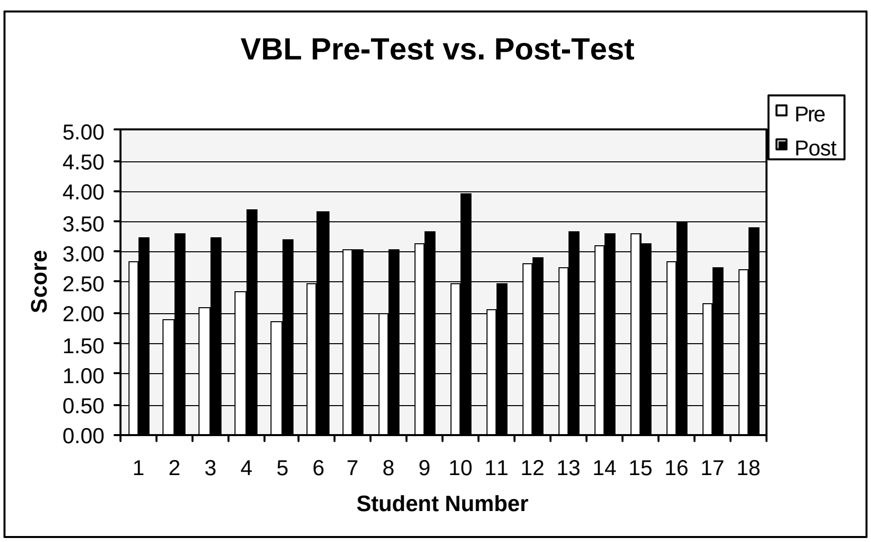


Figure 24: The Iron Cross Pre-Post Test Results.

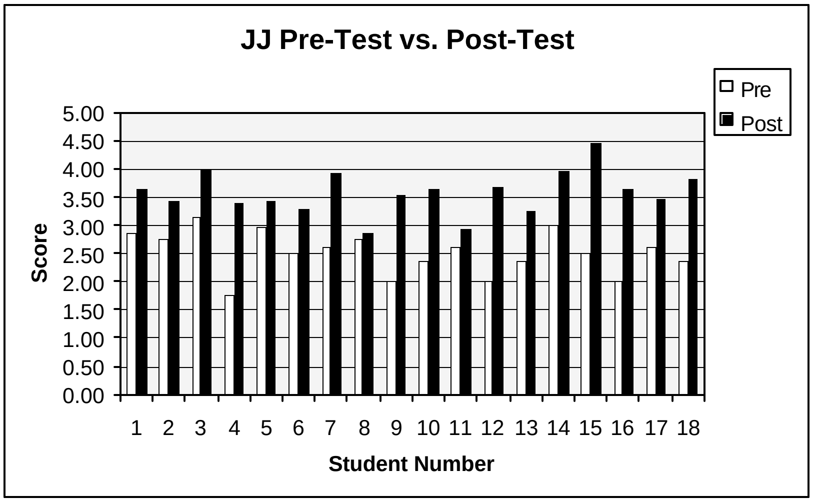


Figure 25: The Jumping Jack Pre-Post Test Results.

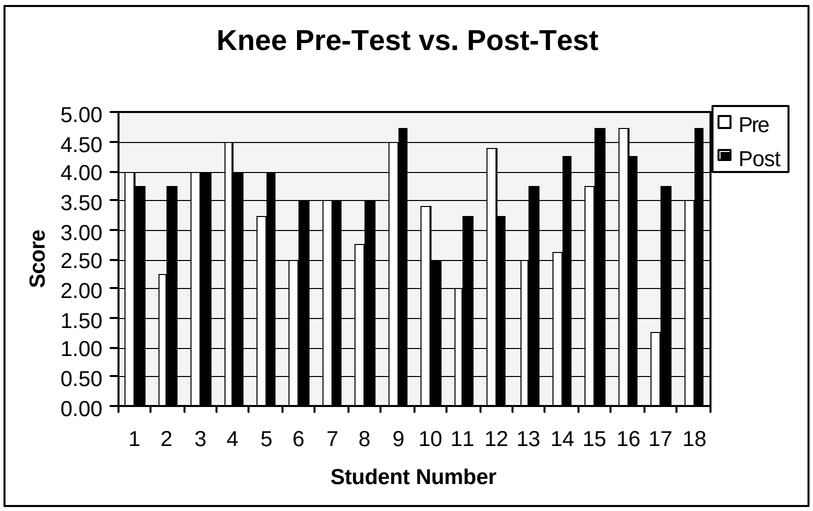


Figure 26: The Knee Pre-Post Test Results.

Pre-Affect and Post-Affect Survey Results

Sometimes a student's learning during an educational experience cannot be totally measured by a test score or graded work. The development of appropriate attitudes towards learning can be a significant factor in an educational experience. Our group has developed an affect survey to measure these subjective learning factors. Table 8 lists the seven affective learning factors that students typically would demonstrate during a positive educational experience. This same survey was administered to the students in conjunction with the pre- and post-test tests for all four topical area modules. The students were asked to rank their quality of learning in each of the seven affect factors using a scale of:

1. None
2. Below Average
3. Average
4. Good
5. Exceptional

Table 8: Learning Factors Used in the Affect Survey
1. I gain factual knowledge (terminology, classifications, methods, trends).
2. I learn conceptual principles, generalizations, and/or theories.
3. I get a chance to talk to other students and explain my ideas to them.
4. I am encouraged to frequently evaluate and assess my own work.
5. I learn to apply course materials to improve my own thinking, problem solving, and decision making skills
6. I develop specific skills, competencies, and points of view needed by professionals in the field.
7. I acquire interpersonal skills in working with others in the class.

The results of these pre-post affect surveys are given in Tables 9 to 12 for the Iron Cross (IC), Virtual Biomechanics Laboratory (VBL), Jumping Jack (JJ), and Knee modules, respectively. They are also shown in the bar charts in Figures 27 to 30. It is interesting to note that there was only one negative gain in affect out of 28 (4x7) possibilities. This demonstrates that the modules had a positive influence on the students' learning experiences.

To determine the overall affect of the class, a grand average affect gain was calculated for the learning factors and is shown in Table 13. It can be seen that the learning factors that had the highest gain from the pre-affect to post-affect state were as follows:

3. I get a chance to talk to other students and explain my ideas to them (gain = 0.764).
4. I am encouraged to frequently evaluate and assess my own work (gain = 0.559).
7. I acquire interpersonal skills in working with others in the class (gain = 0.790).

Thus it appears that working in teams and assessing the work through interpersonal relations is an important aspect to this challenge-based approach to engineering education.

Table 9: Pre-Post Affect Survey Results for IC Module

Learning Factor	Pre	Post	Gain
1	4.06	4.06	0.00
2	3.78	3.83	0.06
3	2.72	4.33	1.61
4	2.94	3.78	0.83
5	3.56	3.83	0.28
6	3.72	3.44	-0.28
7	2.50	4.28	1.78

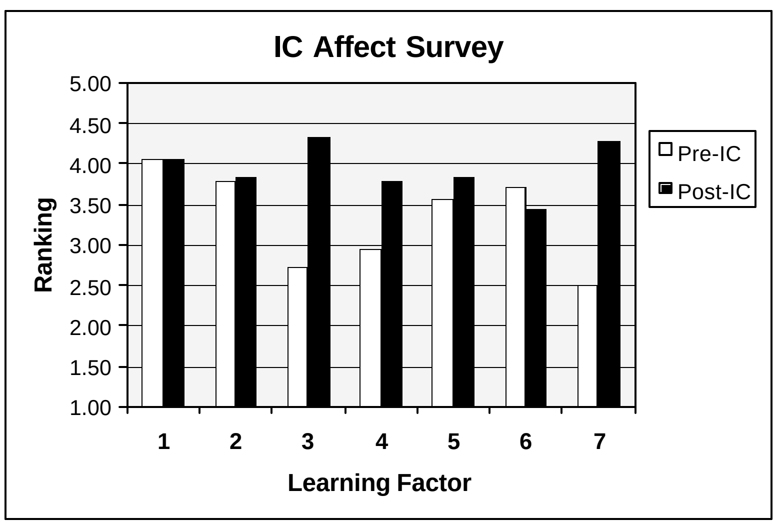


Figure 27: Results of Pre-Post Affect Survey for IC.

Table 10: Pre-Post Affect Survey Results for VBL Module

Learning Factor	Pre	Post	Gain
1	3.78	4.06	0.28
2	3.56	3.71	0.15
3	3.61	4.35	0.74
4	3.22	3.76	0.54
5	3.39	3.94	0.55
6	3.22	3.65	0.42
7	3.61	4.24	0.62

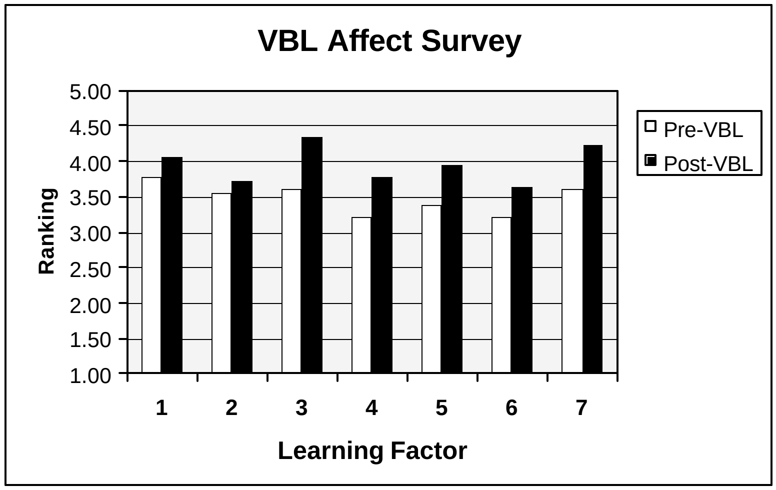


Figure 28: Results of Pre-Post Affect Survey for VBL.

Table 11: Pre-Post Affect Survey Results for JJ Module

Learning Factor	Pre	Post	Gain
1	3.71	3.76	0.06
2	3.65	4.12	0.47
3	3.94	4.24	0.29
4	3.53	4.06	0.53
5	3.65	3.88	0.24
6	3.29	3.47	0.18
7	3.76	4.18	0.41

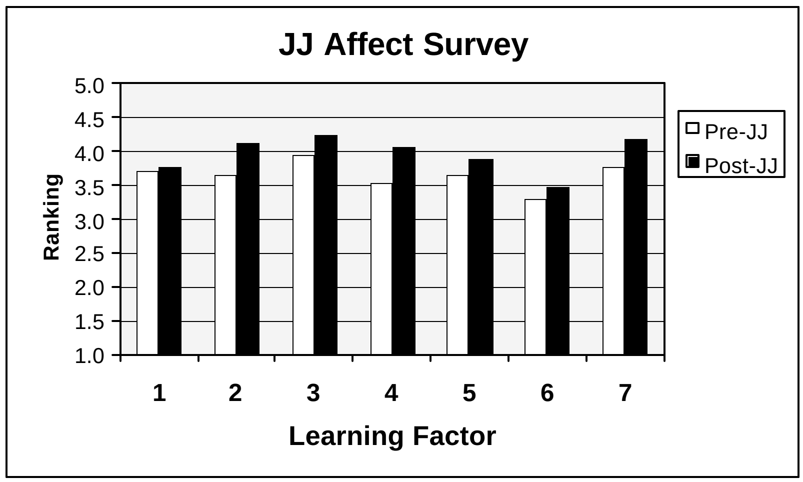


Figure 29: Results of Pre-Post Affect Survey for JJ.

Table 12: Pre-Post Affect Survey Results for Knee Module

Learning Factor	Pre	Post	Gain
1	3.72	4.12	0.40
2	3.61	4.12	0.51
3	3.94	4.35	0.41
4	3.61	3.94	0.33
5	3.83	4.00	0.17
6	3.50	3.82	0.32
7	3.89	4.24	0.35

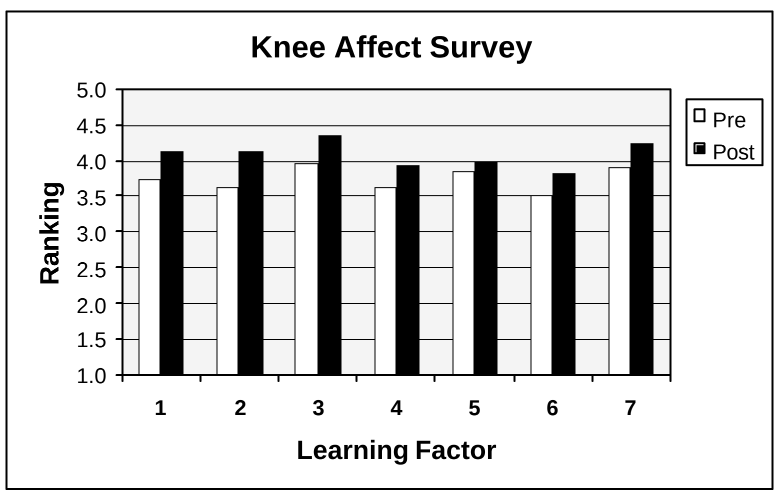


Figure 30: Results of Pre-Post Affect Survey for Knee.

Table 13: Average Post-Pre Gain in Affect Surveys.					
Learning Factor	**Iron Cross Post-Pre Gain**	**VBL Post-Pre Gain**	**Jumping Jack Post-Pre Gain**	**Knee Post-Pre Gain**	**Average Post-Pre Gain**
1	0.00	0.28	0.06	0.40	0.185
2	0.06	0.15	0.47	0.51	0.297
3	1.61	0.74	0.29	0.41	0.763
4	0.83	0.54	0.53	0.33	0.558
5	0.28	0.55	0.24	0.17	0.310
6	-0.28	0.42	0.18	0.32	0.160
7	1.78	0.62	0.41	0.35	0.790

Outcomes Surveys Results

Student outcomes are defined by the Accreditation Board for Engineering and Technology (ABET)[7] as the knowledge, skills, abilities, and attitudes that engineering undergraduates should be able to demonstrate at the time of graduation. Table 14 lists the ten program outcomes (PO's) for the Mechanical Engineering Department at the University of Texas at Austin. These ten program outcomes apply to all courses in the ME department.

Table 14: The ME Student Program Outcomes.
1. Knowledge of and ability to apply engineering and science fundamentals to real problems.
2. Ability to solve open-ended problems.
3. Ability to design mechanical components, systems and processes.
4. Ability to setup, conduct and interpret experiments and to present the results in a professional manner.
5. Ability to use modern computer tools in mechanical engineering.
6. Ability to communicate in written, oral and graphical forms.
7. Ability to work in teams and apply interpersonal skills in engineering contexts.
8. Ability and desire to lay a foundation for continued learning beyond the baccalaureate degree.
9. Awareness of professional issues in engineering practice, including ethical responsibility, safety, the creative enterprise, and loyalty and commitment to the profession.
10. Awareness of contemporary issues in engineering practice, including economic, social, political, and environmental issues and global impact.

In an effort to see how the ME354M course was achieving these departmental-wide outcomes, the students were asked to describe their improvement in each outcome as a result of learning activities provided in the course. This PO survey was conducted three times during the course: Pre, Mid, and Post. The ranking scale was:

1. No skill/ability
2. A little skill/ability
3. Some skill/ability
4. Significant skill/ability
5. Very significant skill/ability

The results of these outcomes surveys are shown in the comparative bar chart of Figure 31 and are shown numerically in Table 15. It can be seen that the students felt that some of the outcomes were achieved in the class. As seen in Figure 31, outcome numbers 1, 2, 5, 6, and 7 showed a steady rise in ranking from the pre-, through the mid-, and then to the post- conditions. The largest gains in ranking (0.56 points) were in outcomes 2 and 7. Thus it appears that that this course contributed most to the students' abilities to solve open-ended problems and to work in teams. It also addressed basic skills in science and engineering knowledge (gain = 0.33) and in computing skills (gain = 0.50).

Table 15: Results of Program Outcomes Surveys.

Outcome Number	Pre	Mid	Post	Gain (Post-Pre)
1	3.72	3.94	4.06	0.33
2	3.39	3.65	3.94	0.56
3	2.94	2.82	3.00	0.06
4	3.61	3.47	3.61	0.00
5	3.56	3.76	4.06	0.50
6	3.94	4.00	4.11	0.17
7	3.78	4.24	4.33	0.56
8	4.17	4.06	4.06	-0.11
9	3.39	3.12	3.28	-0.11
10	3.06	3.06	3.22	0.17

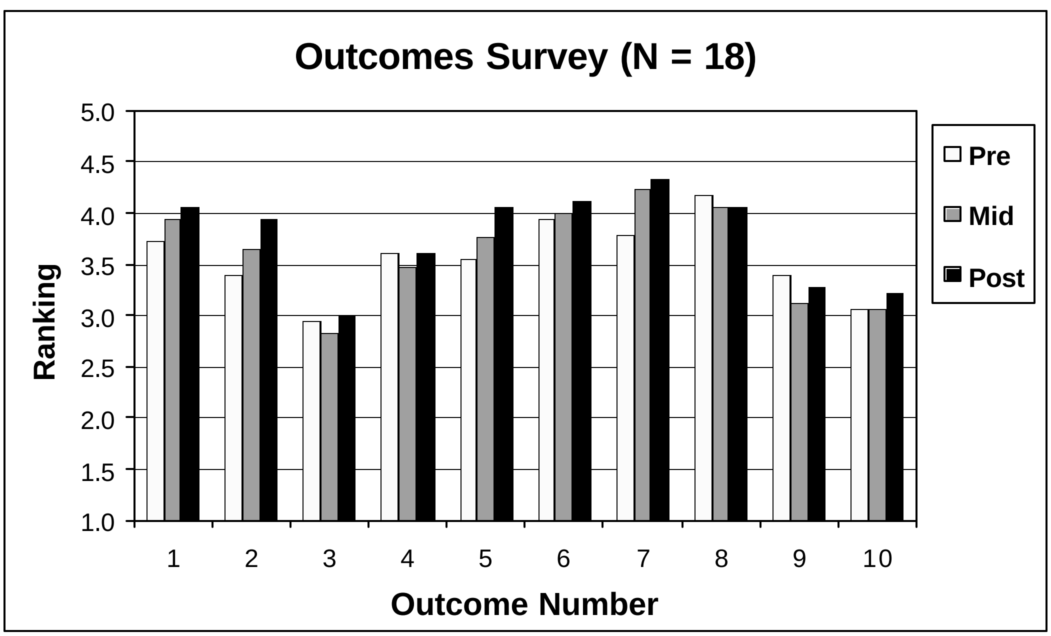


Figure 31: Results of Program Outcomes Survey (Outcome Number Refers to Table 13).

Biomechanics Topics Matrix

A final survey was conducted at the end of the course. The students were asked to complete a "Biomechanics Topics" matrix. The survey form (Table 16) had a listing in the left-hand column of all pertinent topics that should be taught in an undergraduate Biomechanics course. The students were then asked to check the appropriate cells for each challenge that they felt addressed that particular topic. The results are shown in Table 16, with the total number of mentions (counts) reported by all the students (N=18) in each cell. Those cells with 12 or more counts are shaded dark, those with 6 to 11 counts are shaded light, and those with less than 6 counts are not shaded. The total counts for each topic are summed in the final column. It can be seen that almost every topic had at least one shaded cell, with a few exceptions. The most notable topics omitted in the course were calculations for the moment of inertia and radius of gyration. However, in all, the results of this Biomechanics matrix exercise are gratifying.

Table 16: Results of the Biomechanics Topics Survey.

Biomechanics Topics	Iron Cross	VBL I	VBL II	VBL III	Jumping Jack I	Jumping Jump II	Jumping Jack III	Knee I	Total Counts
Skeletal System	11	8	4	4	3	3	3	16	52
Muscular System	18	10	10	16	11	14	13	15	107
Mechanical Properties of Muscle	12	1	2	8	8	10	10	10	61
Stress and Strain in Muscle	13	1	1	3	2	2	4	11	37
Classification of Human Movements	10	16	13	12	9	9	10	11	90
Joint Biomechanics	11	4	2	1	4	3	4	16	45
Dimensions, Units, Conversions	13	12	11	12	12	12	11	11	94
Anthropometrics	15	13	6	4	4	4	4	2	52
Center of Gravity Calculation	2	17	11	8	9	7	5	0	59
Moment Arm Calculation	18	3	3	2	6	7	6	10	55
Moment of Inertia Calculation	3	2	1	1	5	8	2	1	23
Radius of Gyration Calculation	1	1	0	0	1	4	1	0	8
Free Body Diagrams	17	8	11	4	8	10	8	18	84
Static Equilibrium Problem	18	2	2	2	1	2	0	14	41
Linear Kinematics	3	13	11	5	13	12	10	3	70
Angular Kinematics	4	4	4	2	6	12	8	6	46
Finite Difference Calculation	0	6	11	8	5	5	3	0	38
Dynamics of Link Segments	2	7	4	3	7	9	12	7	51
Reaction Forces	12	7	15	12	11	8	6	14	85
Torque Summation	15	1	1	1	3	11	7	15	54
Impulse-Momentum Problem	0	0	0	0	16	9	8	0	33
First-Order Systems	3	3	2	2	8	8	5	4	35
Second-Order Systems	0	0	0	1	5	10	10	1	27
Projectile Dynamics	0	0	0	0	13	14	10	0	37
Experimental Techniques	5	17	17	16	13	11	11	4	94
Experimental Equipment	4	17	17	16	13	9	10	3	89
Electro-physiology and Neural Control	0	4	4	12	2	2	4	1	29
Signal Processing of EMG	0	5	6	17	3	3	3	1	38
Computer Graphics Modeling and Simulation	2	8	10	10	5	11	13	9	68
Total Counts	212	190	179	182	206	229	201	203	

Summary and Conclusions

This paper presented the methodology and testing results for the challenge-based VaNTH Biomechanics learning modules. A variety of measurements, including tests and surveys, were implemented in this educational research effort. While preliminary results indicate the course had a very positive influence on the students' learning, one must caution that the class sample size (N=18) is small and a larger sample size would make the case stronger. Nonetheless, the following major observations can be made.

1. The results for the pre-course versus post-course tests showed that the students increased their knowledge and skills in the field of Biomechanics. On the average, the class was able to answer 8 more questions correctly (out of 30 multiple choice questions) after the course than before the course. The E.S. statistics showed that these results were significant at the 99% level.

2. The pre-test and post-test methodology worked well. The results are convincing that the students learned the material. Out of 72 possibilities (4x18), there were only six instances were a student showed a decrease in the post-test scores. Also, measuring the gain from pre- to post-test is a valuable instrument for accessing the level of learning in the treatment. Across all pre-post test treatments, the grand average gain was 0.875. Considering the tests had a 5-point maximum score, and since the grand average pre-test score was 2.91, this average gain of 0.875 represents a 30 percent improvement overall in the scores. The E.S. statistic for these pr-post comparisons ranged from 0.70 (76% confidence level) to 2.75 (99% confidence level).

3. The pre-affect and post-affect surveys are also valuable instruments to measure the subjective aspects of student learning and attitude development in a course. It is interesting to note that there was only one negative gain in affect out of 28 (4x7) possibilities. This demonstrates that the modules had a positive influence on the students' learning experiences throughout the course, even though the students had been asked to complete this same identical form eight times.

4. Outcomes testing is a good way to determine where a particular course fits into the overall curriculum or degree plan. Based on the results of this outcomes survey (Figure 31), it appears that the VaNTH Biomechanics modules can contribute to the following ME outcomes:

- PO #1 - Knowledge and ability to apply engineering and science fundamentals to real problems;
- PO #2 - Ability to solve open-ended problems;
- PO #5 - Ability to use modern computer tools in mechanical engineering; and
- PO #7 - Ability to work in teams and apply interpersonal skills in engineering contexts.

No doubt that by working in teams, by using the Legacy Cycle, and by discussing the "Test Your Mettle" exercises, the students realized a higher level of satisfaction and a feeling of accomplishment in the course.

5. The results of the Biomechanics Topics matrix (Table 16) are pleasing to the authors. It supports the contention that a semester-long, complete Biomechanics course could be taught using these eight challenges as the primary method of educational delivery. Almost all of the important Biomechanics topics were covered in one or more of the challenges. Thus challenge-based instruction can deliver the same body of knowledge and understanding as a traditional engineering course, while motivating students to engage in interesting problems that use the fundamental topics.

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Bio-Sketches

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