

Challenge-Based Instruction in Biomechanics Using the VANTH Internet Modules

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Abstract

This paper discusses the biomechanics learning modules developed as part of the VaNTH educational coalition. 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.” Seven VANTH challenges were tested in an undergraduate Mechanical Engineering course in Fall 2003. These challenges were:

1. Iron Cross Muscle Strength
2. Virtual Biomechanics Lab I: Center of Gravity During Gait
3. Virtual Biomechanics Lab II: Ground Reaction Force During Gait
4. Virtual Biomechanics Lab III: Muscle Contraction During Gait
5. Jumping Jack I: How High Can You Jump?
6. Jumping Jack II: What Determines Jump Height?
7. Jumping Jack III: Why Can an NBA Player Jump Higher Than a Student?

This paper discusses the classroom implementation of the seven challenges and presents some results of student testing of this pilot project. Upon successful evaluation, the biomechanics modules will be made available for dissemination and use at other schools, both inside and outside the coalition.

Introduction

The course ME 354M, “Biomechanics of Human Movement,” is an undergraduate technical block elective in Mechanical Engineering (ME) that has been offered every year since 1987. During those previous years, 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 ad hoc 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.

In the Fall 2003 semester, the class was used for 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.

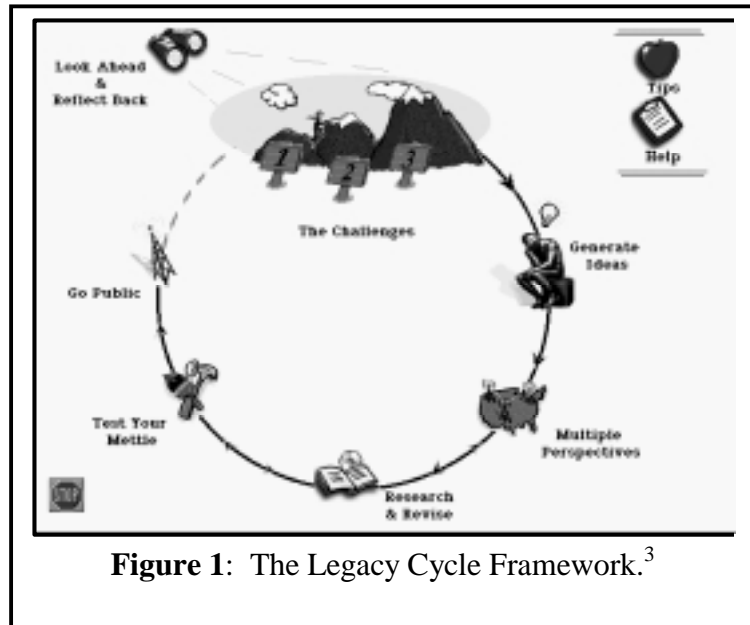


Figure 1: The Legacy Cycle Framework.³

A total of 32 students were enrolled in the class for the Fall 2003. 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. For the testing of the VaNTH learning modules, students were randomly assigned to either a trial group or the control group by drawing the assignment slip from a hat. The trial group used the VaNTH website material for the exercise, and the control group used a hardcopy paper version of the same material. The course instructor recorded the students’ names in each group, but also assigned a random two-digit ID number to each student with no correlation between the ID number and the group assignment. This ID number was subsequently used for all data to assure anonymity. Since there were three modules tested, this random assignment procedure was conducted three times during the semester, resulting in Groups A and B, C and D, and E and F (see Table 1).

Classroom Testing Methodology

Three Biomechanics modules, covering seven specific challenges, were tested in this classroom setting. They were:

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

The same testing methodology was used for each module. First, a general background lecture on the module's topic was given using a Powerpoint slide show prepared by the first author. The students were then randomly assigned to their group and were given a pre-test that included a pre-affect survey. Depending on their group assignment, the students showed up at different times for the next lecture assignment. At that lecture, they were presented the modular material, either as a hardcopy paper handout (control group) or as a website location (trial group). As part of their assignment for each module, the students performed a set of homework exercises and also completed a module learning effectiveness survey. After the completion of each module, the students took a post-test and a post-affect survey. Three times during the semester, a student outcomes survey (Pre, Mid, and Post) was administered. All tests and homework exercises were graded by a VaNTH Graduate Teaching Assistant (TA), who used uniform grading rubrics for each case. At the end of the semester, the students also completed a final report that included a matrix that mapped general Biomechanics topics to the modules. Table 1 summarizes this testing methodology.

Table 1: Summary of Classroom Testing Methodology			
Module Name	Group Assignments	Tests and Surveys Conducted Before	Tests and Surveys Conducted After
Iron Cross (IC) <i>(One challenge)</i>	Group A (Control)	<ul style="list-style-type: none"> • Pre-Test • Pre-Affect Survey • Pre-Outcomes Survey 	<ul style="list-style-type: none"> • Module Effectiveness Survey • IC Homework • Post-Test • Post-Affect Survey
	Group B (Trial)		
Virtual Biomechanics Laboratory (VBL) <i>(Three challenges)</i>	Group C (Control)	<ul style="list-style-type: none"> • Pre-Test • Pre-Affect Survey 	<ul style="list-style-type: none"> • Module Effectiveness Survey • VBL Homework • Post-Test • Post-Affect Survey • Mid-Outcomes Survey
	Group D (Trial)		
Jumping Jack (JJ) <i>(Three challenges)</i>	Group E (Control)	<ul style="list-style-type: none"> • Pre-Test • Pre-Affect Survey 	<ul style="list-style-type: none"> • Module Effectiveness Survey • JJ Homework • Post-Test • Post-Affect Survey • Post-Outcomes Survey • Topics Matrix
	Group F (Trial)		

Description of the VaNTH Biomechanics Modules

The objective of the VaNTH coalition is to develop a new set of instructional materials that emphasize the HPL learning theory. As part of the strategy, a modular structure for each identified bioengineering domain was implemented. In the Biomechanics domain, the three modules listed in Table 1 were available for testing in Fall 2003. Each module addresses a specific aspect of the domain's taxonomy (e.g. static equilibrium, projectile dynamics, experimental methods). In order to stimulate student interests in learning the material, a challenged-based approach using the Legacy Cycle was adopted. This approach served as the framework for the web-based challenges used in the ME354M classroom testing.

The Iron Cross Module

The Iron Cross (IC) module consists of one challenge: “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 equal stress in all muscles or 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.

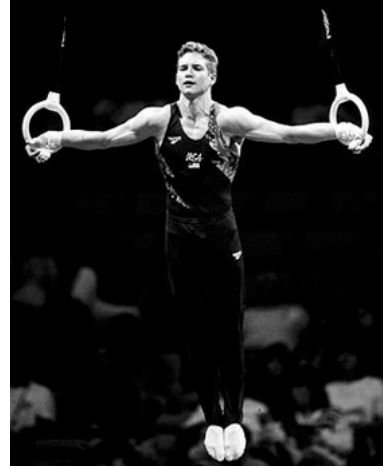


Figure 2: The Iron Cross Position.

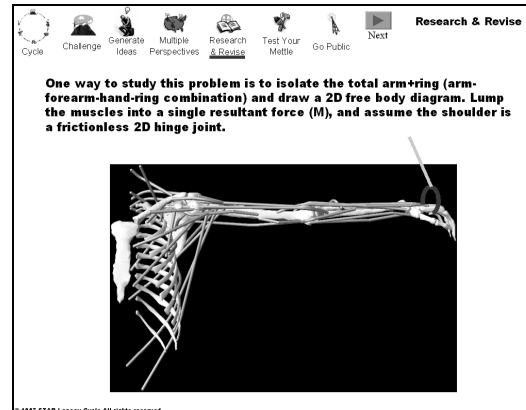


Figure 3: The Free Body Diagram Problem for the Iron Cross.

Origin & Insertion coordinates for arm in "Iron cross" position Shoulder joint is at (0,0)			
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.

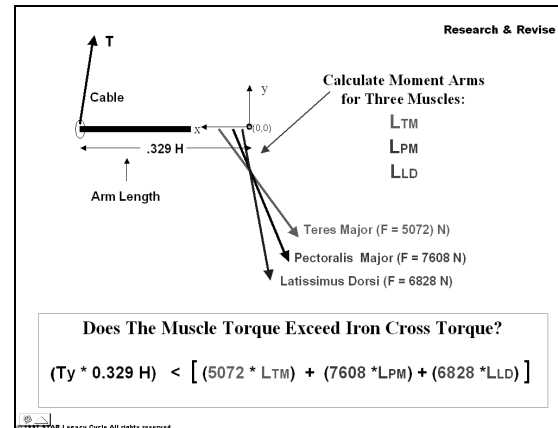
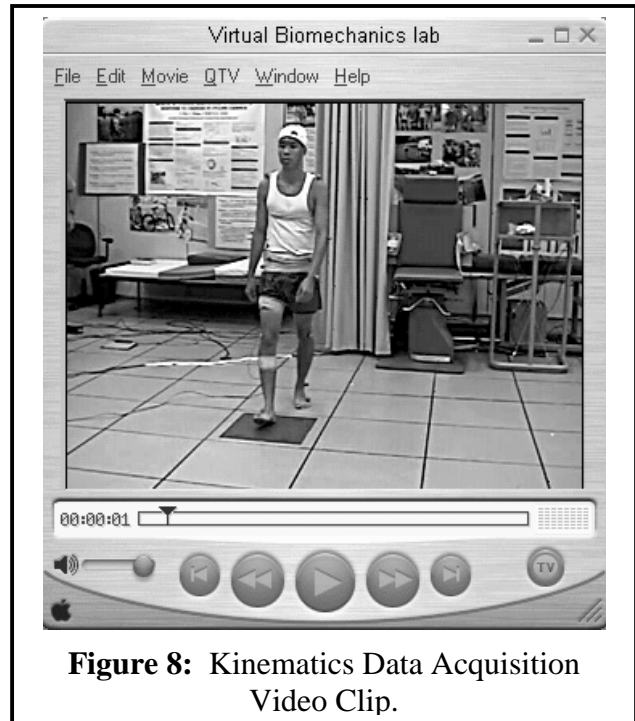
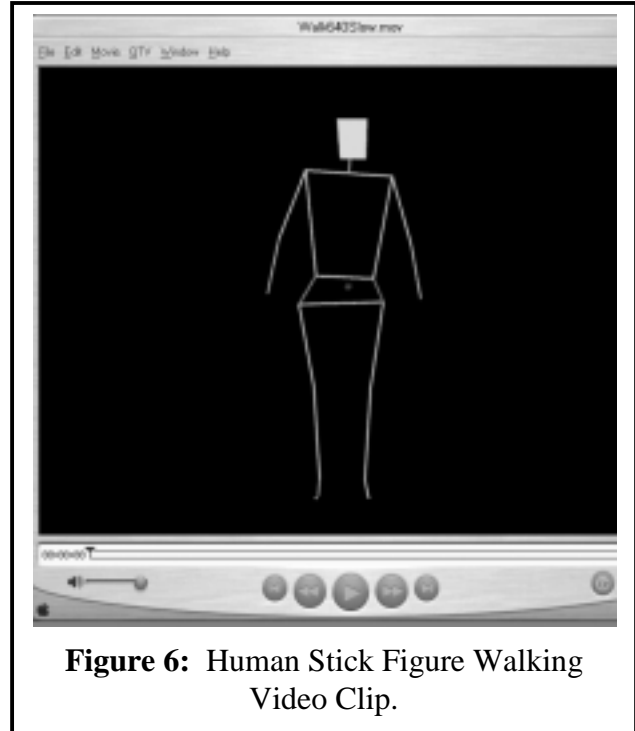
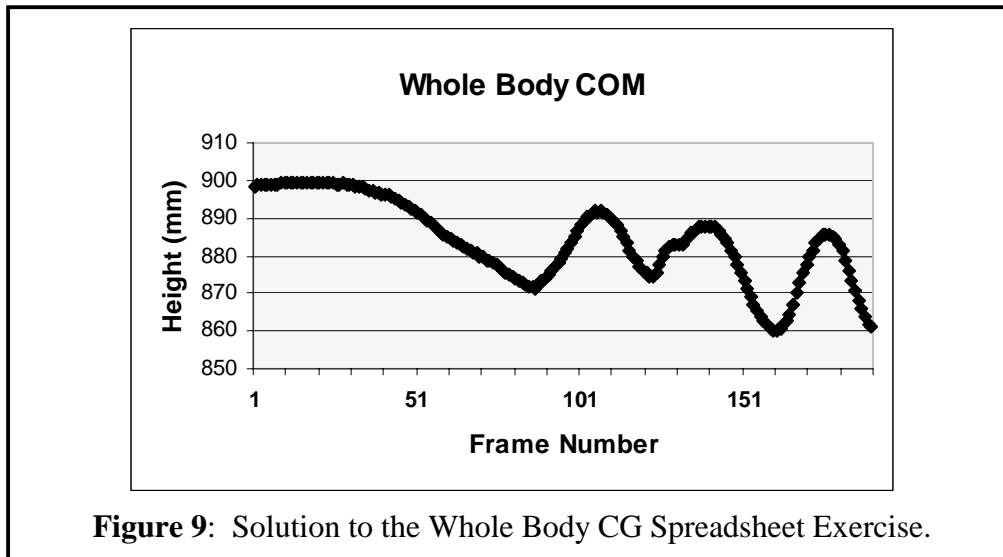


Figure 5: General Formulation of the Iron Cross Problem.

The Virtual Biomechanics Laboratory Module

The Virtual Biomechanics Laboratory (VBL) module consists of three challenges, all concerned with experimental observations commonly 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 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 the result of this Excel CG calculation across all samples for the entire gait cycle (see Figure 9) and answer an interesting question about “hitting their head when walking under a door exactly equal to their height.”





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).

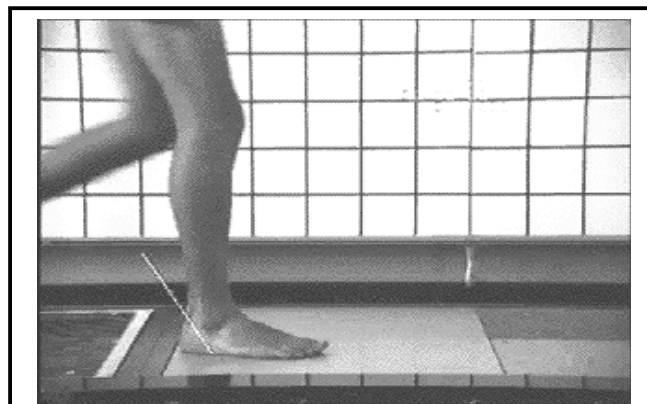


Figure 10: Striking the Force Plate.

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.

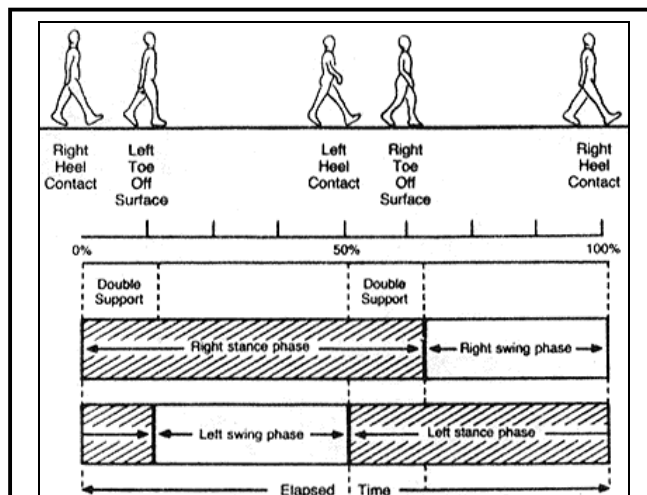


Figure 11: Stages of the Gait Cycle.

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 electromyographic (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.

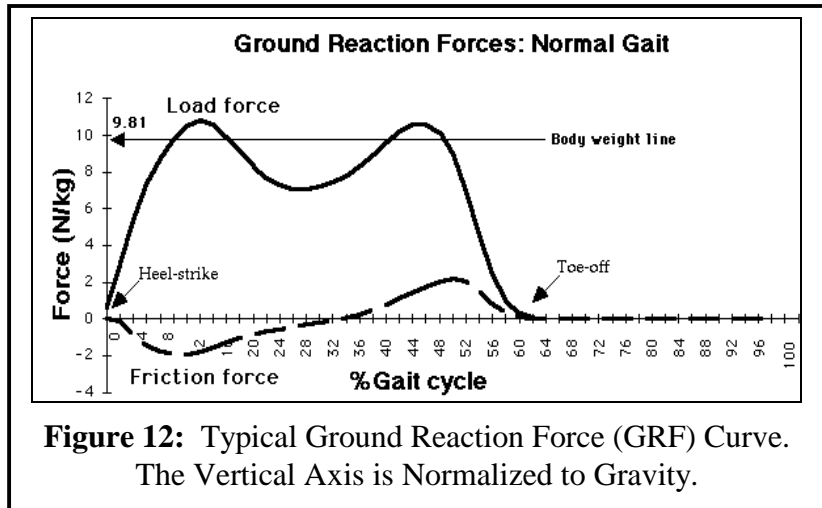


Figure 12: Typical Ground Reaction Force (GRF) Curve. The Vertical Axis is Normalized to Gravity.

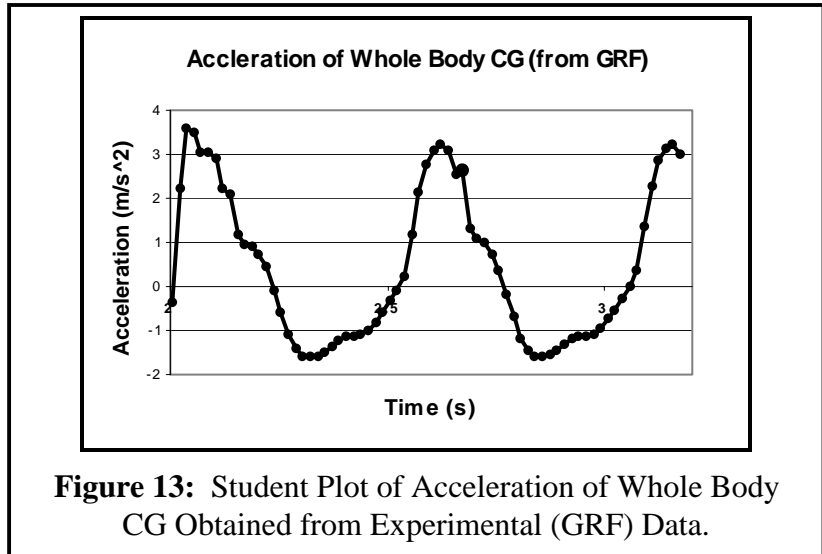


Figure 13: Student Plot of Acceleration of Whole Body CG Obtained from Experimental (GRF) Data.

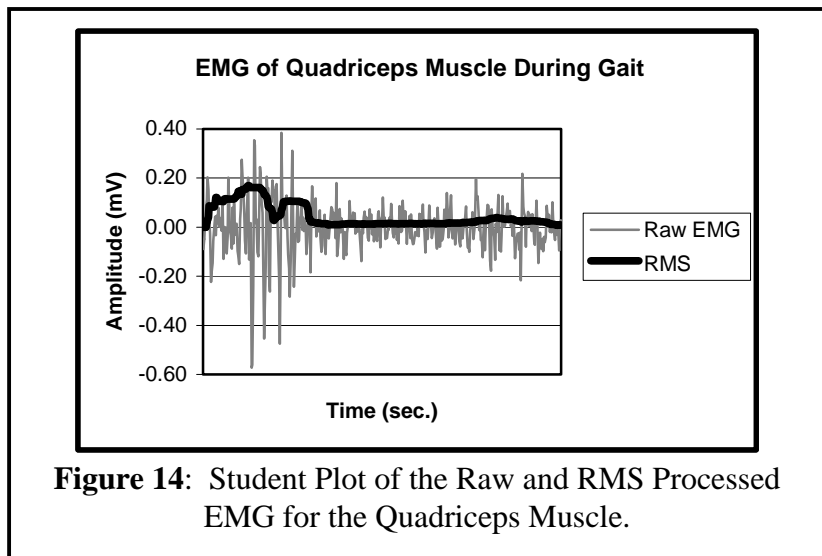


Figure 14: Student Plot of the Raw and RMS Processed EMG for the Quadriceps Muscle.

The Jumping Jack Module

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).

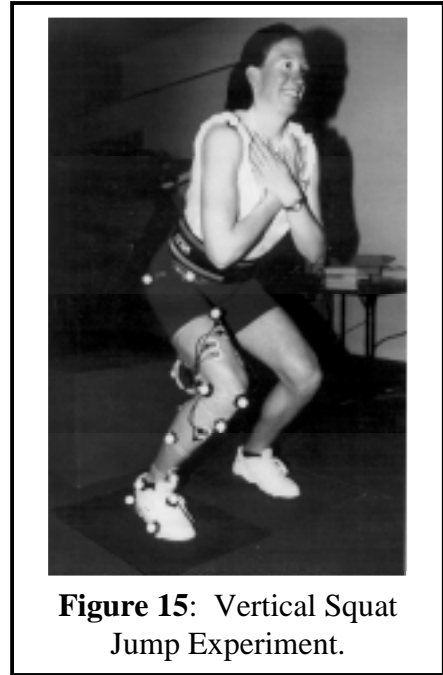


Figure 15: Vertical Squat Jump Experiment.

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.

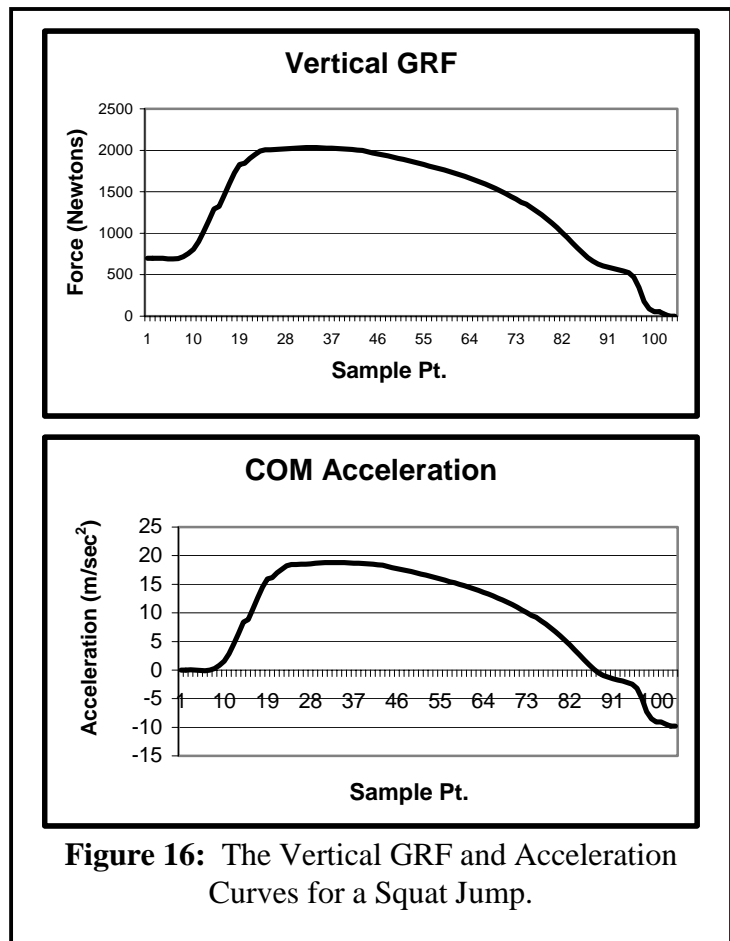


Figure 16: The Vertical GRF and Acceleration Curves for a Squat Jump.

The second 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 force 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 F_v as a function of the angle θ :

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

When F_v 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.

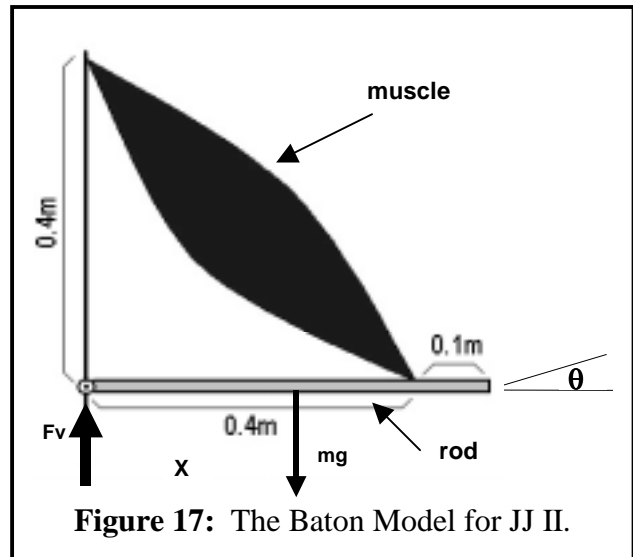


Figure 17: The Baton Model for JJ II.

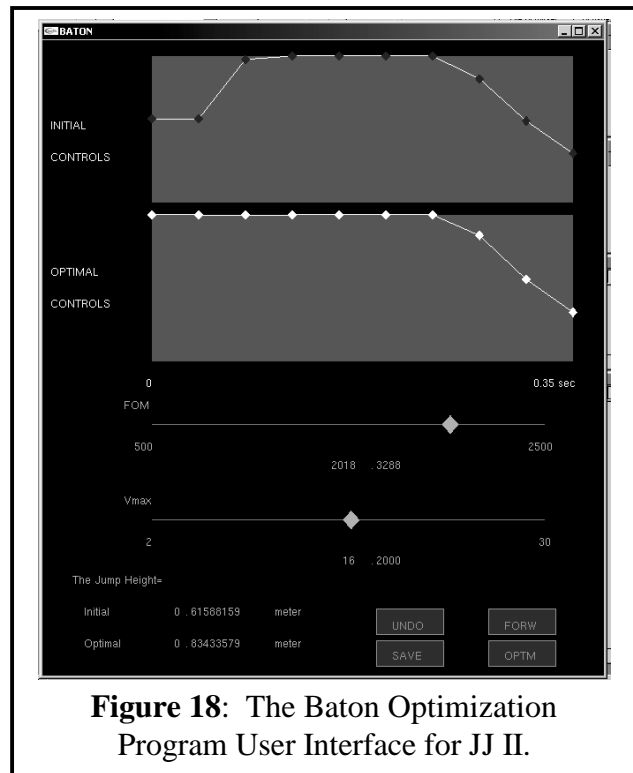


Figure 18: The Baton Optimization Program User Interface for JJ II.

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. After trying various combinations, including altering gravity to jump on the moon, they submit a report.

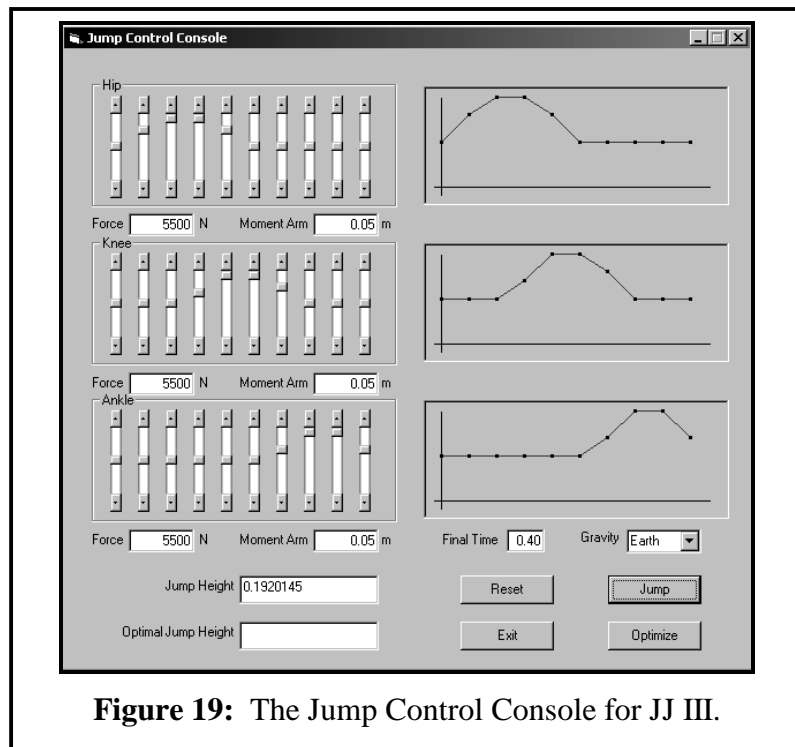


Figure 19: The Jump Control Console for JJ III.

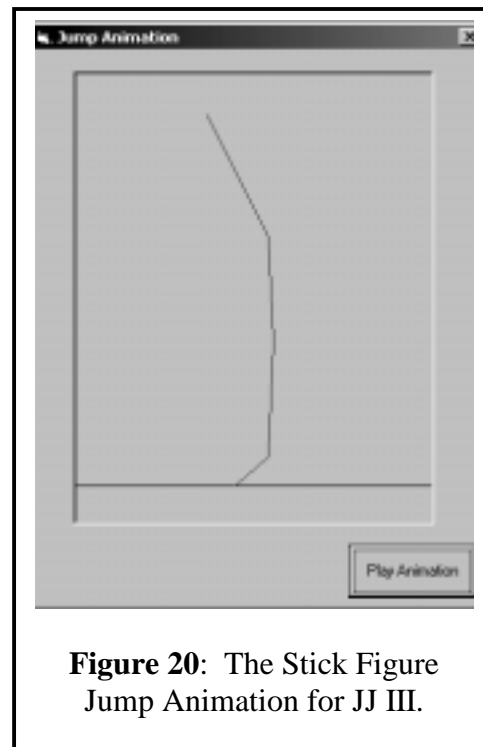


Figure 20: The Stick Figure Jump Animation for JJ III.

Results of Classroom Testing

The classroom testing methodology was outlined earlier in Table 1. This methodology included pre- and post-tests, pre- and post-affect surveys, outcomes surveys, module learning effectiveness surveys, homework grading, and a final topics matrix assignment. All data was gathered for both control and trials groups for all three modules. This section will report the raw results for some of this data gathering. A full paper on all the results will be presented at the 2004 ASEE Annual Summer Conference.⁴

Pre-Test and Post-Test Results

Before each module assignment, a short electronic slide lecture was given. The students were randomly assigned to either a control or trial group, and all students then took a pre-test. The pre-tests contain about five to seven questions or problems related to the module topic. Typically, the students were given about 20 minutes to complete this short test. The pre-tests were gathered, were coded by the instructor, and then given to the TA for grading. After the completion of the module, the same test was administered again as a post-test to the students, and the coding/grading process was repeated. *Note:* The post-test was given after the completion of challenge one for the IC module, and after completion of challenge three for both the VBL and JJ modules.

The results of this pre-post testing phase are shown in the bar graphs in Figures 21 to 23 for the Iron Cross (IC), Virtual Biomechanics Laboratory (VBL), and Jumping Jack (JJ) modules, respectively. The charts are separated into control groups (A, C, and E) and trial groups (B, D, and F) for each module.

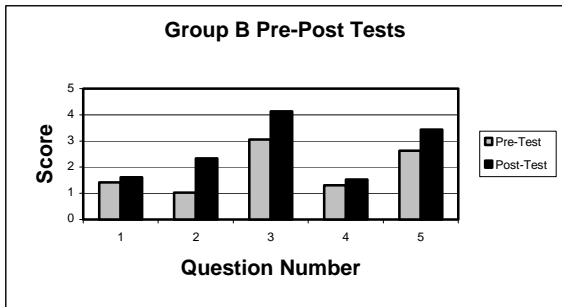
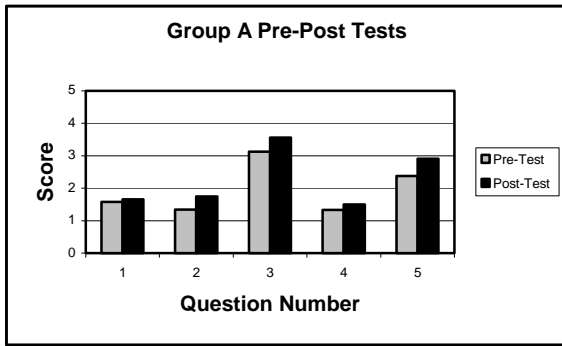


Figure 21: Results of the Pre-Post Testing for the IC Module (A = control group, B = trial group). Dark Bars are for Post-Tests.

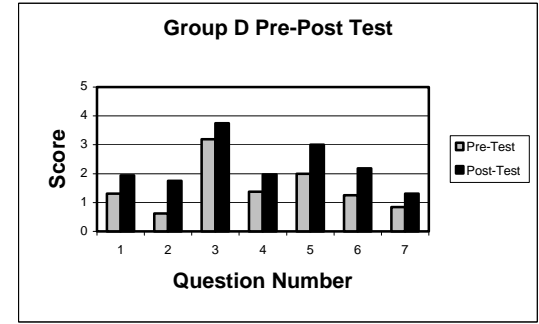
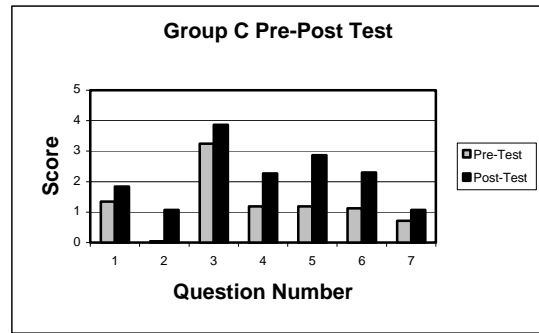


Figure 22: Results of the Pre-Post Testing for the VBL Module (C = control group, D = trial group). Dark Bars are for Post-Tests.

The most obvious observation from the bar graph data is that all scores improved in the post-test when compared to the pre-test. This is true for both the control groups and trial groups. This should not be surprising, since the students did learn enough from the modules to improve their testing score on the subject matter. A second comparison is to determine the level of improvement, or gain, when going from the pre-test to the post-test. Table 2 depicts these gains in the pre-post test scores. In comparing the gain between the control and trial group, it can be seen that:

1. For the IC module, the trial group B had a higher gain in all five questions.
2. For the VBL module, the control group C had a higher gain in four of the seven questions.
3. For the JJ module, the control group E had a higher gain in five of the seven questions.

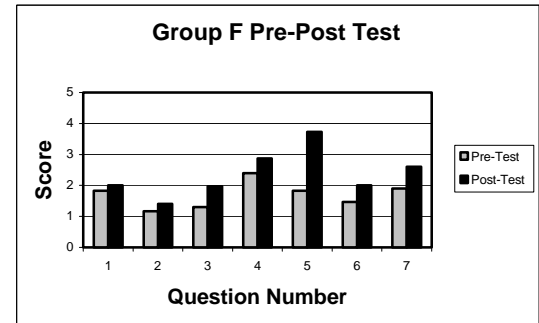
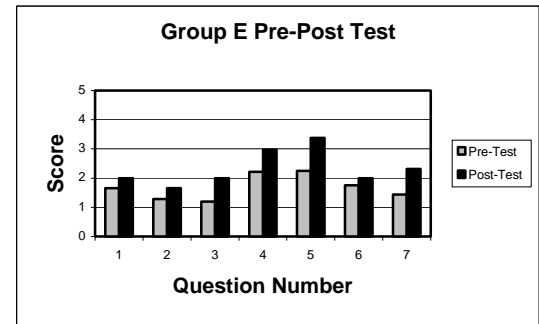


Figure 23: Results of the Pre-Post Testing for the JJ Module (E= control group, F = trial group). Dark Bars are for Post-Tests.

Results of Outcomes Surveys

Student outcomes are defined by the Accreditation Board for Engineering and Technology (ABET)⁵ as the knowledge, skills, abilities, and attitudes that engineering undergraduates should be able to demonstrate at the time of graduation. Table 3 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.

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

	Control Group Gain in Pre-Post Test	Trial Group Gain in Pre- Post Test
Question No.	Group A	Group B
1	0.08	0.19*
2	0.41	1.31
3	0.43	1.07
4	0.17	0.22
5	0.53	0.81
Question No.	Group C	Group D
1	0.49	0.63
2	1.03	1.13
3	0.62	0.56
4	1.08	0.59
5	1.68	1.00
6	1.18	0.94
7	0.35	0.47
Question No.	Group E	Group F
1	0.34	0.17
2	0.38	0.23
3	0.81	0.67
4	0.75	0.47
5	1.13	1.90
6	0.25	0.53
7	0.87	0.70
* Bold gains are the higher for each case		

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.

The results of these outcomes surveys are shown in the triple bar graph of Figure 24. It can be seen that there was improvement in some of the outcomes in going from the Pre- to Mid-Outcome surveys. In particular, the following outcomes show that improvement:

- a. Outcome 2, solve open-ended problems;
- b. Outcome 4, conduct experiments and interpret the results;
- c. Outcome 5, use of modern computing tools; and
- d. Outcome 6, communicate in written, oral, and graphical forms.

Since the Mid-Outcomes survey was administered right after the VBL module, it is not a surprise that experimental, computing, and communication (graphical) outcomes rose noticeably from the Pre-Outcome experiences. Also, the last four outcomes (7, 8, 9, 10) seem to decrease linearly in going from the Pre- to Mid- to Post-Outcomes surveys. These latter outcomes (teamwork, life-long learning, professional issues, and societal issues) are softer engineering skills that were not addressed in the course, and the student's reflected this fact with their rankings.

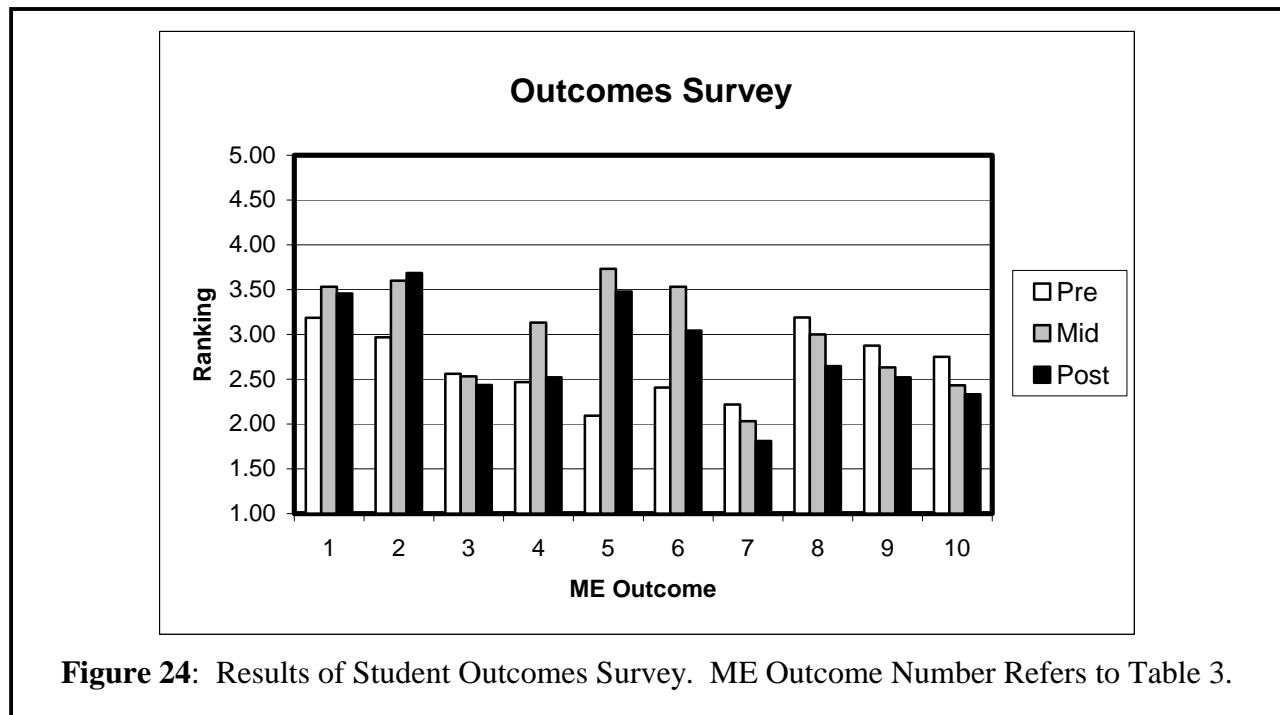


Figure 24: Results of Student Outcomes Survey. ME Outcome Number Refers to Table 3.

Results of Biomechanics Topics Matrix

A topics matrix survey was conducted at the end of the course. The students were asked to complete a “Biomechanics Topics” matrix. The survey form (Table 4) 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 4, with the total number of mentions (counts) reported by all the students (N=32) in each cell. Those cells with 20 or more mentions are shaded dark, those with 10 to 19 mentions are shaded light, and those with less than 10 mentions 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.

Table 4: Results of Biomechanics Topics Matrix Ranking

Biomechanics Topics	Iron Cross	VBL I	VBL II	VBL III	Jumping Jack I	Jumping Jack II	Jumping Jack III	Total Counts
Skeletal System	22	12	9	7	6	6	7	69
Muscular System	28	18	16	26	12	17	17	134
Mechanical Properties of Muscle	22	9	8	15	7	17	19	97
Stress and Strain in Muscle	22	6	7	10	4	8	8	65
Classification of Human Movements	15	18	24	17	12	9	12	107
Joint Biomechanics	19	14	11	7	9	10	11	81
Dimensions, Units, Conversions	21	21	17	17	18	17	15	126
Anthropometrics	14	21	9	8	6	5	7	70
Center of Gravity Calculation	9	28	19	10	10	4	4	84
Moment Arm Calculation	26	9	6	4	5	9	9	68
Moment of Inertia Calculation	4	5	8	5	10	14	4	50
Radius of Gyration Calculation	5	4	7	3	3	3	1	26
Free Body Diagrams	27	17	11	8	11	12	8	94
Static Equilibrium Problem	26	7	5	4	2	4	4	52
Linear Kinematics	2	19	18	9	17	14	10	89
Angular Kinematics	1	8	6	5	15	22	12	69
Finite Difference Calculation	3	10	14	6	8	6	4	51
Dynamics of Link Segments	5	18	12	10	9	8	10	72
Reaction Forces	22	13	23	16	17	16	7	114
Torque Summation	21	2	3	4	7	14	11	62
Impulse-Momentum Problem	1	3	3	3	16	14	8	48
First-Order Systems	8	10	9	4	12	9	3	55
Second-Order Systems	0	2	3	3	14	14	8	44
Projectile Dynamics	1	2	2	1	18	18	11	53
Experimental Techniques	12	23	23	19	12	10	12	111
Experimental Equipment	9	24	28	24	13	11	12	121
Electrophysiology and Neural Control	0	3	5	13	7	8	10	46
Computer Graphics Modeling and Simulation	2	11	15	16	17	25	24	110

Summary and Conclusions

This paper presented the methodology and some preliminary results for classroom testing of the VaNTH Biomechanics learning modules. A variety of measurements, including tests, surveys, and homework exercises, were implemented in this educational research effort. In order to evaluate the efficacy of this VaNTH approach to instruction, as opposed to a traditional lecture, the class (N=32) was divided into control and trial groups. In preliminary review of all the testing materials and surveys gathered, some preliminary observations can be made.

1. The results comparing the trial group performance versus the control group are very mixed. In retrospect, there was very little difference between the educational materials delivered to the control group versus the trial group. The only difference was the availability of the video clips on the website, which were in some cases not highly regarded by the students anyway. So it is unclear whether the control group received a traditional approach.

2. The pre-test and post-test methodology worked well. The results are convincing that the students learned the material. Also, measuring the gain (Table 2) from pre- to post-test is a valuable instrument for accessing the level of learning in the treatment.

3. 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 24), it appears that the VaNTH Biomechanics modules can contribute to the following ME outcomes:

PO #2 – Ability to solve open-ended problems;

PO #4 - Ability to setup, conduct and interpret experiments and to present the results in a professional manner;

PO #5 - Ability to use modern computer tools in mechanical engineering; and

PO #6 - Ability to communicate in written, oral and graphical forms.

On the other hand, it is disappointing that PO # 7 “Ability to work in teams and apply interpersonal skills in engineering contexts” received such a low rating in this course. For sure, teamwork is an issue that must be addressed within the VaNTH coalition.

4. The results of the Biomechanics Topics matrix (Table 4) are pleasing to the authors. It supports the contention that a semester-long, complete Biomechanics course could be taught using these seven challenges as the primary method of educational delivery. For sure, adding one or two more challenges will complete the Biomechanics domain and lead to achievement of the VaNTH goals for the domain.

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