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Challenge-Based Instruction: The VaNTH Biomechanics Learning Modules

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ABSTRACT

This paper presents the methodology and results of teaching an entire engineering course using challenge-based instruction. The challenges consisted of eight biomechanics multimedia learning modules developed by the authors as part of a broader NSF educational coalition. The biomechanics modules were presented in an undergraduate mechanical engineering course titled "Biomechanics of Human Movement." The class (N = 18) was divided into three-member teams. Each team performed the eight computer-based assignments in intervals of one-two weeks per challenge during the semester. Pre-tests, post-tests, affect surveys, a biomechanics topics matrix, and student outcomes surveys were conducted during the course to determine the success of this approach. This paper outlines the challenge-based approaches used and presents assessment methods for a full, semester-long course. Thus, it is directed at faculty who may wish to use this interesting approach in their own engineering courses.

Keywords: bioengineering education, biomechanics, challenge-based instruction

I. INTRODUCTION

Challenge-based instruction is a form of problem-based education [1–2], in which the problems are posed as a series of interesting challenges that require the students to search for and acquire knowledge and expertise, as needed, to solve the challenge [3–6]. The challenge-based, team approach to learning stimulates the students to develop a deep understanding of the discipline while at the same time building problem-solving, collaboration, and communication skills. The course approach reported in this paper was an outgrowth the NSF-sponsored VaNTH Engineering Research Center for Bioengineering Education [7]. Previous research by VaNTH faculty focused on the development of adaptive expertise in solving problems that are interesting, but perhaps novel, to the learner. For example, in an earlier study by Pandy, et al. [8], student achievement in a human jumping challenge was quantified using pre- and post-test questionnaires designed to measure changes in three facets of adaptive expertise: factual knowledge, conceptual knowledge, and the ability to transfer knowledge to new areas. Results showed that this approach increased students' conceptual knowledge as well as their ability to transfer knowledge to new situations. In another study by Roselli and Brophy [9], students in a challenge-based course performed significantly better than students in a taxonomy-based course on a difficult set of knowledge-based questions about free-body diagrams.

Buoyed by these earlier findings, the eight VaNTH biomechanics learning modules were fully implemented in the course ME 354M, "Biomechanics of Human Movement," at the University of Texas at Austin, starting in Fall 2004. While the earlier reported studies had focused on research questions centered around a single module, the study reported in this paper presents the details of all eight learning modules in a semester-long course, and shows assessment methods that proved useful to determine the effectiveness of this course approach. In the past, the course was taught in a traditional format with chalkboard lectures and overhead transparencies, and with paper homework assignments. Thus, this challenged-based approach represented a significant departure from traditional instruction, as well as a new teaching direction that could prove interesting for faculty at other schools to pursue.

II. METHODOLOGY

A. Classroom Organization and Testing

A total of eighteen students were enrolled in the ME 354M course. At the start of the course, the students were briefed on the experimental nature of the course and were asked to sign a human subject consent form. A complete schedule of class events, due dates, and grading policies was also presented to the class on the first day. A pre-course test was administered, consisting 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. The students were then divided into three-member teams.

While there were eight VaNTH Biomechanics challenges, as shown in Table 1, they were organized into four topical areas: The Iron Cross (one challenge); The Virtual Biomechanics Laboratory (three challenges); Jumping Jack (three challenges); and The Knee (one challenge). The same instruction and testing methodology was used for each topical area. First, some background lectures on the topic were given using electronic slide projections. The students next took a pre-test and completed an affect survey. They then performed the challenges posed as a sequence of multimedia applications organized around a consistent instructional design [10–11]. 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. These student outcomes were patterned after the requisite ABET outcomes, but were geared towards mechanical engineering topics. All tests and exercises were graded using uniform grading rubrics. At the end of the semester, the students also filled out a matrix that mapped general biomechanics topics to the modules. The remaining paper shows details of the eight modules, and presents the major results of the assessment methodologies. A more lengthy conference proceedings paper [12], containing all the extensive data gathered during the study, is available for readers who wish to examine the more complete set of data.

1. Iron Cross Challenge: "How much muscle strength is required to sustain the Iron Cross position?"
2. Virtual Biomechanics Lab I Challenge: "How does your whole body center of gravity move when you walk?"
3. Virtual Biomechanics Lab II Challenge: is "What forces do you exert on the ground when you walk?"
4. Virtual Biomechanics Lab III Challenge: "How do the leg muscles activate during one complete gait cycle?"
5. Jumping Jack I Challenge: "How high can you jump?"
6. Jumping Jack II Challenge: "What determines jump height?"
7. Jumping Jack III Challenge: "What determines who can jump higher?"
8. Knee Challenge: "Can voluntary contraction of the quadriceps muscle group tear the anterior cruciate ligament (ACL) during an isometric knee extension exercise?"

Table 1. Summary of the eight VaNTH biomechanics challenges

B. The Eight VaNTH Biomechanics Challenges

1) The Iron Cross Challenge: The Iron Cross (IC) challenge is "How much muscle strength is required to sustain the Iron Cross position (Figure 1)." The challenge is formulated in the context of a free body diagram (Figure 2). This compels the students to think about the static mechanics of the position, which leads to the major observation: the Iron Cross is a static indeterminate problem due to the multiple muscle actuators that cross the shoulder joint. Thus, the students must make initial assumptions, calculate the moment arms for all muscle actuators at the given arm angle, and solve for the muscle forces needed to maintain the Iron Cross position. If the maximum muscle forces can not overcome the body's gravity force to sustain the Iron Cross, then the students are asked to determine what position, on a mechanical jig placed along the wrist, can be used to assist the gymnast in sustaining the Iron Cross.

2) The Virtual Biomechanics Laboratory Challenges: The Virtual Biomechanics Laboratory (VBL) module consists of three challenges, all concerned with experimental observations in a human gait analysis lab. The students start with a simulated walking figure and are asked to generate ideas about the pathway of the whole-body center-of-mass (COM) (Figure 3). Video-audio clips are given as background information on human gait by an expert (Figure 4) and by a gait laboratory technician (Figure 5). In VBL challenge one, the students must find the whole body COM by creating an equation and pasting it into an Excel spreadsheet (http://advances.asee.org/vol01/issue01/media/04-media01.xls). The Excel data contains columns of kinematics data for key body positions as a function of time.

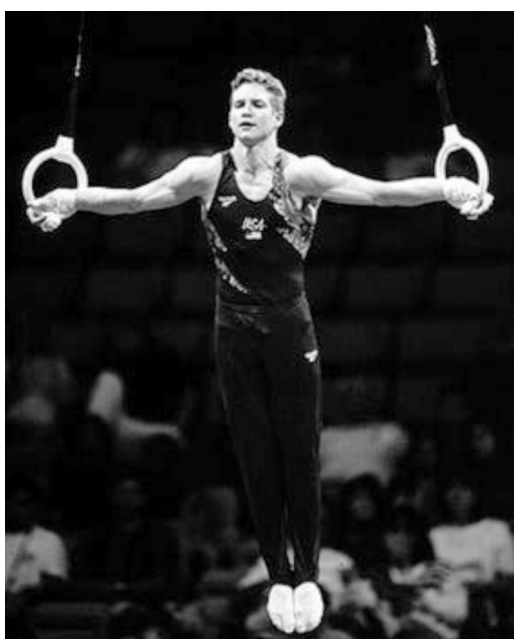

Figure 1. The Iron Cross Position.

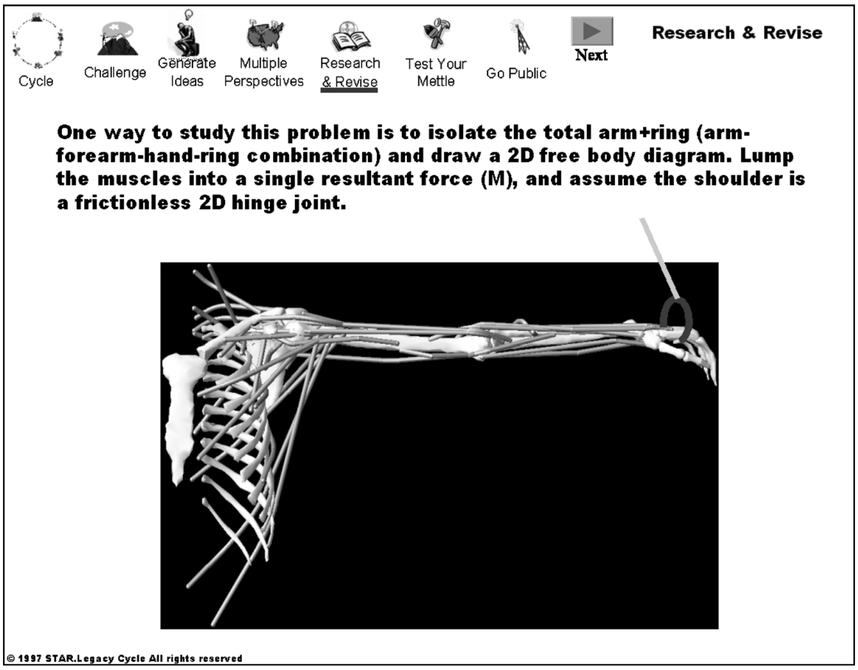

Figure 2. The Iron Cross is a statically-indeterminate problem.

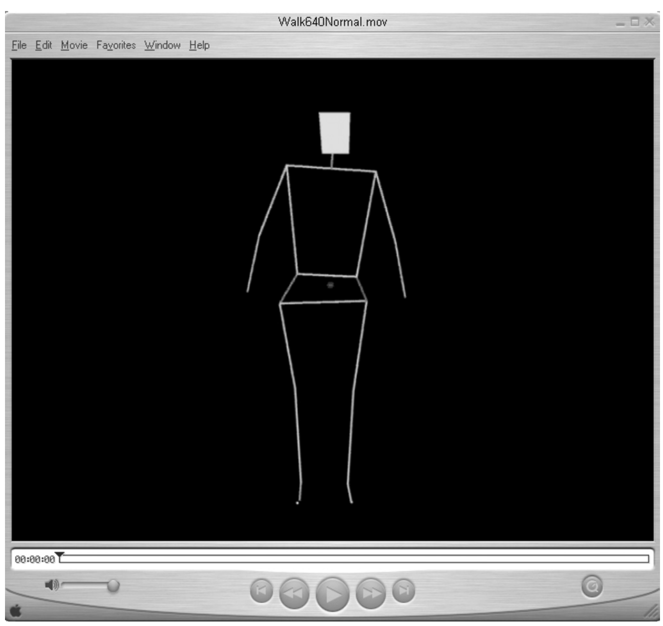

Figure 3. The students view a simulated walking figure and observe the pathway of the center of gravity, represented by a red dot. (http://advances.asee.org/vol01/issue01/media/04-media01.cfm)

***Figure 4. Multiple perspective video clips from a professor are used in the VBL challenge.* (http://advances.asee.org/vol01/issue01/media/04-media02.cfm)**

The second VBL challenge continues this inquiry into gait analysis, this time focusing on force measurements from a ground reaction plate. The third VBL challenge focuses on identifying the major leg muscles involved in gait, and then processing the electromyographic (EMG) activity from these muscles using a sliding RMS window.

3) The Jumping Jack Challenges: 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 challenge "How high can you jump" starts with a video clip of vertical jumping (Figure 6). 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 COM. The students are then asked to calculate jump height in different ways. One way is to integrate the ground reaction curve (Figure 7) 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 using a projectile equation. The second and third JJ challenges deal with computer graphics modeling and simulation of vertical jumping.

Figure 5. The Virtual Biomechanics Laboratory (VBL) focuses on human gait analysis.
(http://advances.asee.org/vol01/issue01/media/04-media03.cfm)

4) The Knee Challenge: 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 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 (see Figure 8). They plot the forces in the ACL and then determine if the ACL force ever exceeds the given maximum tearing force of 2000 N.

III. RESULTS

A. Pre-Course and Post-Course Test Results

On the first class day, the students took a comprehensive pre-course test consisting of 30 multiple-choice questions that covered all topics covered in the course. The same 30-question test was given on the last class day as a post-course test. Table 2 shows the numerical results depicting

Figure 6. The Jumping Jack (JJ) module focuses on vertical jumping and projectile dynamics. (http://advances.asee.org/vol01/issue01/media/04-media04.cfm)

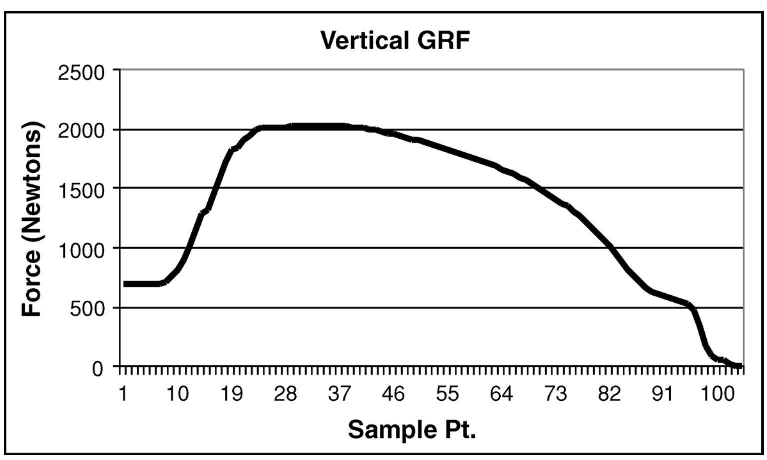

Figure 7. The vertical ground reaction force (GRF) for a squat jump.

the average pre-course and post-course scores. 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.

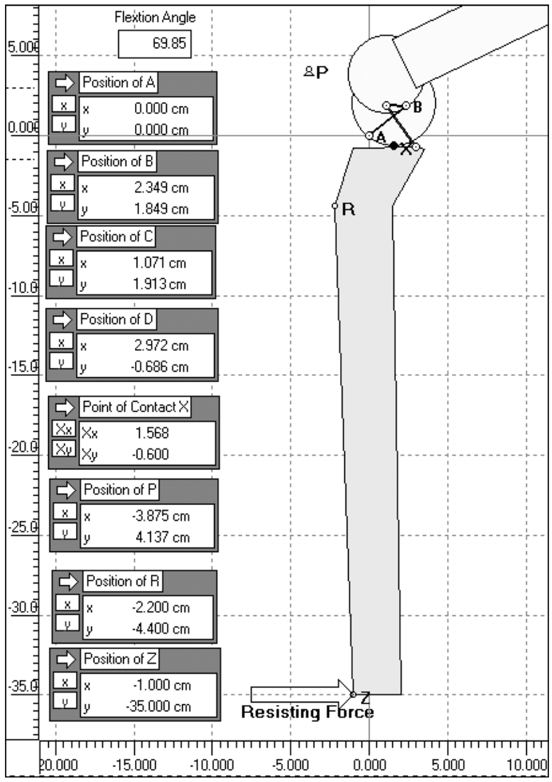

Figure 8. The Knee Diagram Used to Solve the ACL Problem.

Pre-Course Class Average (Std. Dev.)	*Post-Course Class Average (Std. Dev.)*	*Gain (Post-Pre)*
15.17 (3.47)	22.89 (2.81)	7.72
Effect Size = 2.46 (99% confidence)		

***Table 2. Pre-Post Course Test Scores* (N = 18)**

In order to determine if the pre-post conditions are significantly different, an effect size (ES) statistic [13] is calculated using the formula:

$$ES = \frac{AVE_{Post} - AVE_{pre}}{pooled\ Std.\ Dev.},$$

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 ES of 1.3 is considered significant at the 90% level, an ES of 1.6 is considered significant at the 95% level, and an ES of 2.5 is considered significant at the 99% level, assuming a normal distribution of (N) scores. For example, the ES of 2.46 in Table 2 indicates that the post-course scores were clearly statistically higher than the pre-course scores, at close to a 99% certainty level.

B. 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 module. A grading rubric was created for each test, and the maximum score was normalized to five points for each test. Table 3 shows the distribution of pre-test and post-test score averages for all four topical areas, along with the effect size (ES) statistic. It can be seen that the gain from pre- to post-tests scores was positive for all four cases, ranging from 0.55 to 1.06, on a scale of 5.00 maximum points. For an example of a pre-post test, see the Appendix.

An observation worth noting is the widely-varying range in the ES statistic, from a low value of 0.70 (76% confidence) for the Knee module, to a highly significant value of 2.75 (99.5% confidence) for the Jumping Jack module. This variation in ES is probably due to the lower pre-test scores for the two more difficult topics (VBL and JJ), which dealt with dynamics, while the Iron Cross and Knee topics dealt with more straightforward, static problems. These results might suggest a re-ordering of presentation of the modules in the course. Perhaps a more pedagogically acceptable order would be: Iron Cross, Knee, Virtual Biomechanics Lab, and Jumping Jack.

C. Pre-Affect and Post-Affect Survey Results

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

Module Topic	*Pre-Test Ave. (Std. Dev.)*	*Post-Test Ave (Std. Dev.)*	*Gain (Post-Pre)*	*Effect Size*	*Confidence Level*
Iron Cross	3.28 (0.63)	4.11 (0.54)	0.83	1.41	92%
Virtual Biomechanics Lab	2.55 (0.46)	3.26 (0.34)	0.70	1.78	96%
Jumping Jack	2.51 (0.39)	3.57 (0.38)	1.06	2.75	99.5%
Knee	3.30 (0.99)	3.85 (0.58)	0.55	0.70	76%

Table 3. Summary of pre-post pests for the four topical modules

factor in an educational experience. Our group has developed an affect survey to measure these subjective learning factors, patterned after reliable measures commonly used in the field [14]. Table 4 lists seven affect learning factors that students typically would acquire in a positive educational experience. These affect factors include experiences in talking and working with other students in the class, gaining factual knowledge and competencies, and improving critical thinking. This affect survey was administered to the students in conjunction with the pre- and post-test for all four modules. The students were asked to rank their quality of learning in these seven affect factors using a 5-point scale of 1-None, 2-Below Average, 3-Average, 4-Good, or 5-Exceptional. An example result of this pre-post affect survey for the VBL module is shown in the bar chart of Figure 9, which is typical of the results for all the other challenges.

Table 5 shows the results of all affect surveys as a function of each learning factor. As can be seen, almost all learning factors had a positive gain in all the modules. Indeed, out of 28 possible cases, there was only one learning factor that had a negative gain (learning factor six in the Iron Cross). This is true despite the fact the students completed this same pre-post affect survey eight times during the course. Thus, it can be concluded that each VaNTH module had its own positive affect experience within itself, as well as the course as a whole. Based on the magnitude of the gains, learning factors 3, 4, and 7 had the most impact on the students.

D. Outcomes Surveys Results

Student outcomes are defined by the Accreditation Board for Engineering and Technology (ABET) [15] as the knowledge, skills, abilities, and attitudes that engineering undergraduates should be

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.

Table 4. Learning Factors Used in the Affect Survey

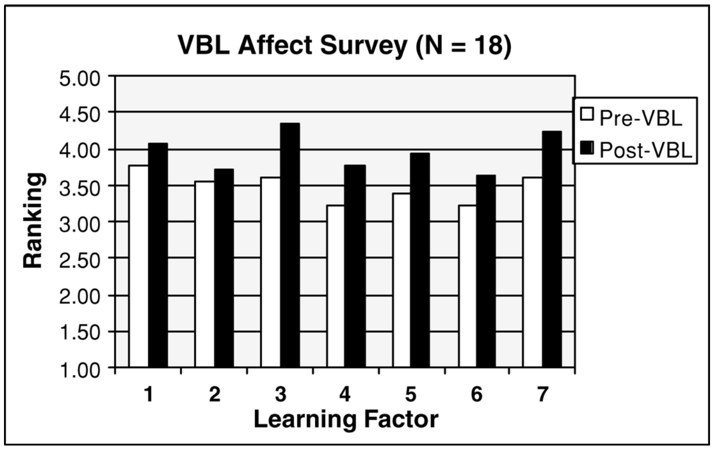

Figure 9. Results of Pre-Post Affect Survey for the VBL Modules.

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

Table 5. Average Post-Pre Gain in Affect Surveys

able to demonstrate at the time of graduation. Table 6 lists the ten program outcomes (PO's) for a mechanical engineering department. These ten program outcomes apply to all courses in the ME department, and not just the biomechanics course.

In an effort to see how the 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, and 5-Very significant skill/ability. The results of these three surveys are shown in the comparative bar chart of Figure 10. It can be seen that the students felt that some of the 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.	

Table 6. The ME Student Program Outcomes.

were achieved. In particular, 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. On the other hand, some outcomes (3, 4, 8, 9, and 10) showed little gains. Thus the commonalities of outcomes gained in this course matched closely the goals of challenge-based instruction: problem-solving, teamwork, and communication skills.

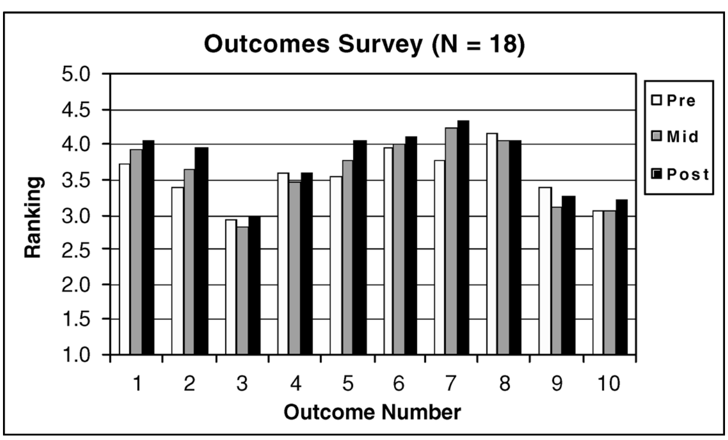

Figure 10. Results of the Pre-, Mid- and Post-Outcomes Surveys

E. 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 (Figure 11) had a listing in the left-hand column of all the topics for an undergraduate biomechanics course. This list was derived from an extensive taxonomy conducted by the VaNTH biomechanics domain leaders. The students were asked to check the appropriate cells for each challenge that they felt addressed that particular topic.

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	

Figure 11. The Biomechanics Topics Matrix

The results are shown in Figure 11, with the total number of mentions (counts) reported by all the students (N 5 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. Specifically, 23 out of 29 topics had at least one dark cell, and 28 out of 29 topics had at least one light shaded cell. The results of this biomechanics matrix exercise suggest that fundamental biomechanics topics from the taxonomy can be covered using this set of eight biomechanics challenges.

IV. DISCUSSION

This paper presented the classroom implementation of the challenge-based VaNTH biomechanics learning modules. A variety of tests and surveys were implemented in this educational research effort to demonstrate the efficacy of this approach. While preliminary results indicate the course had a very positive influence on the students' learning, one must caution that the class sample size (N 5 18) is small and a larger sample size would make the case stronger.

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, and the effect size statistic (2.46) clearly shows significance (99% confidence level). While this should not be a surprise, that students learned the material after taking the course, the 99% statistical significance of the data demonstrates it conclusively.

The pre-test and post-test methodology worked well. The results are convincing that the students learned the material. Out of 72 possibilities (4 modules 3 18 students), there were only six instances were a student showed a decrease in the post-test scores. Also, the gain from pre- to post-test showed at least a 0.55 point improvement or higher in all cases. Furthermore, three of the four effect sizes for the pre-post test results were above 1.3 (90% confidence level or higher). One interesting observation was that the Knee module, which was presented last in the course, perhaps should be moved to an earlier occurrence in the course.

The pre- and post-affect surveys are also valuable instruments to measure the subjective aspects of student learning. It is interesting to note that there was only one negative gain in average affect scores, out of 28 (4 3 7) possibilities. This demonstrates that the modules had a positive, self-reported influence on the students' learning experiences throughout the course, even though they had completed the same form eight times during the semester.

Outcomes testing is one way to determine where a particular course fits into the overall curriculum or degree plan. Based on the results of this outcomes survey, it appears that the VaNTH biomechanics modules contribute to the following student outcomes: 1 (basic science and engineering knowledge), 2 (problem solving), 5 (modern computer skills), 6 (communication), and 7 (teamwork). No doubt that by working in teams, by using consistent instructional design, and by discussing the exercises amongst themselves, the students realized a higher level of satisfaction and a feeling of accomplishment in these outcomes areas.

The results of the “Biomechanics Topics” matrix show a positive effect. It supports the contention that a complete, semester-long biomechanics course could be taught using these eight challenges as the primary method of educational delivery. Almost all of the biomechanics topics were covered in one or more of the challenges, as suggested by the “Biomechanics Topics” matrix of Figure 11.

V. CONCLUSION

This study did not prove that challenge-based instruction is better than a traditional approach, since no statistical comparisons were made between the experimental class and a traditional, control class. Nonetheless, the results of this study suggest that challenge-based instruction is an appealing way to teach an engineering course. In this approach, the traditional lectures are replaced by a series of interesting challenges that require the students to search for and acquire new knowledge, skills, and abilities to solve a specific problem. It is a way of engaging modern engineering students who otherwise may not be motivated by the traditional chalkboard lecture and note-taking approach to education. The challenge-based approach also offers a benefit for the instructor, who has the flexibility to define the interesting challenges in his or her own disciplinary specialization. Based on the results of this study, it appears that challenge-based instruction can deliver the same body of knowledge as a traditional engineering course, in total, while motivating students to engage in interesting problems that use fundamental topics.

ACKNOWLEDGEMENTS

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AUTHORS' NOTE

The VaNTH biomechanics learning modules were developed and tested over a period of several years from 2001 to 2004. Since then, the modules have been implemented in biomechanics courses at a number of schools, including Vanderbilt University, the University of Texas at Austin, the University of Texas at Pan Am, and the University of Tennessee at Memphis. The modules can be accessed at the VaNTH project website http://www.vanth.org/ under the "VaNTH Coursework" link. A special logon request will be needed and can be obtained from the VaNTH system manager. A copy of the student manual used for the eight biomechanics learning modules reported in this paper can be obtained by contacting the lead author at: *rbarr@mail.utexas.edu.*

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APPENDIX

PRE-TEST

VIRTUAL BIOMECHANICS LABORATORY MODULE

1. In Figure 1 color the circle that most closely represents the whole body center of mass (COM) of:

A) A person standing with arms by the side.

B) A person standing with the left arm extended out.

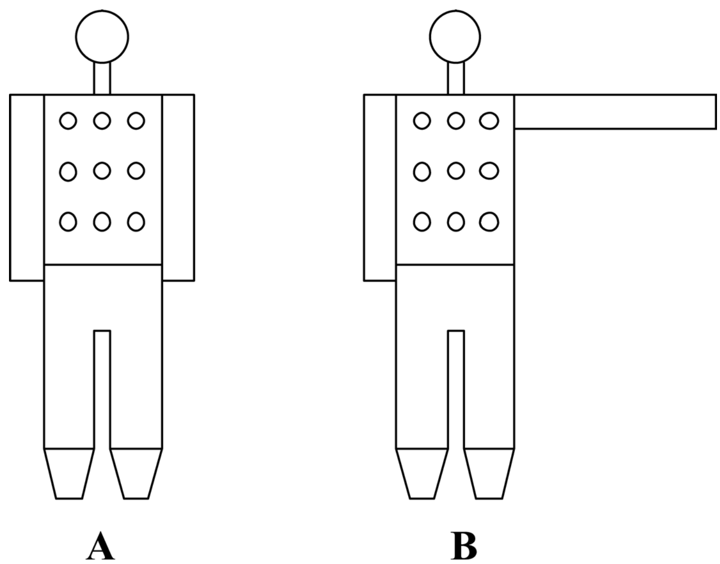


Figure 1

2. Which of the plots in Figure 2 best represents the vertical displacement of the whole body center of mass (COM) during normal walking in humans? Color the oval under the correct curve.

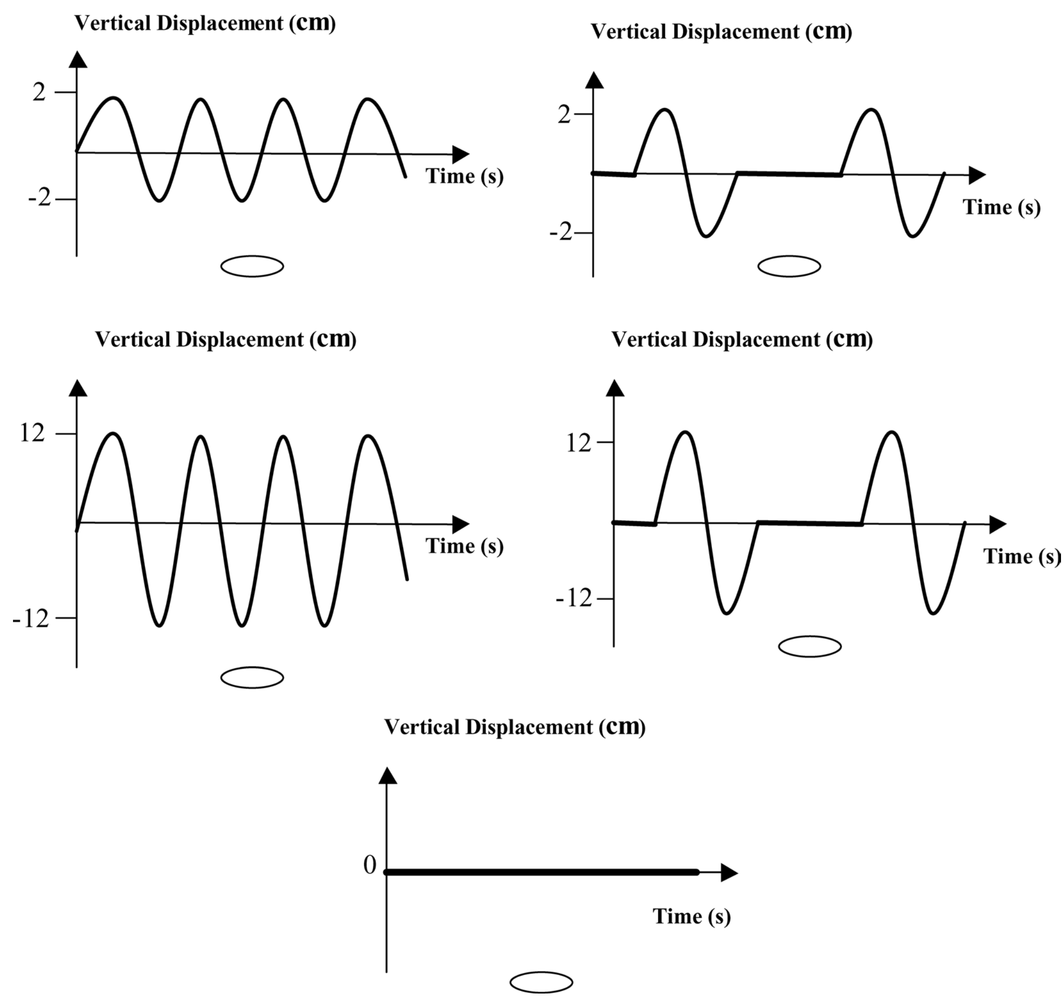


Figure 2

3. Figure 3 represents a shank that is divided into 6 sections and Table 1 lists the mass and height of each section. The mass of each section is uniformly distributed. The symbol xi is the distance from the proximal end of the shank to the center of the ith section. Use the table to calculate:

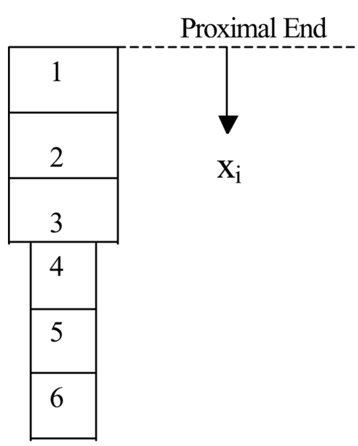
A) Length of the Shank

B) Mass of the Shank

C) Center of Mass (COM) of the Shank

Shank section	Mass (m_i) of each section in gms	Section Height in cms	COM of each section from the Proximal Side (x_i) in cms
1	1000	10	
2	900	10	
3	900	10	
4	500	10	
5	300	10	
6	200	10	

Table 1



Answers:

A. ______________________

B. ______________________

Figure 3

4. Figure 4 shows a person during certain phases of the normal gait cycle. Listed below are activities performed by the two legs during normal gait. Put the number corresponding to the appropriate activity performed by the legs in the correct boxes having the double-headed arrows, which indicates the % duration for which the activity lasts. (You can use the following choices more than once).

1. Double Support
2. Left Swing Phase
3. Left Stance Phase
4. Right Swing Phase
5. Right Stance Phase

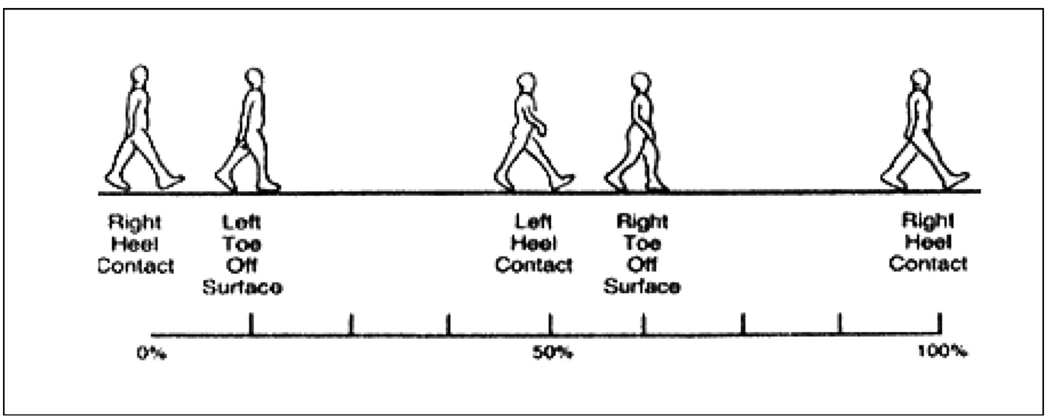
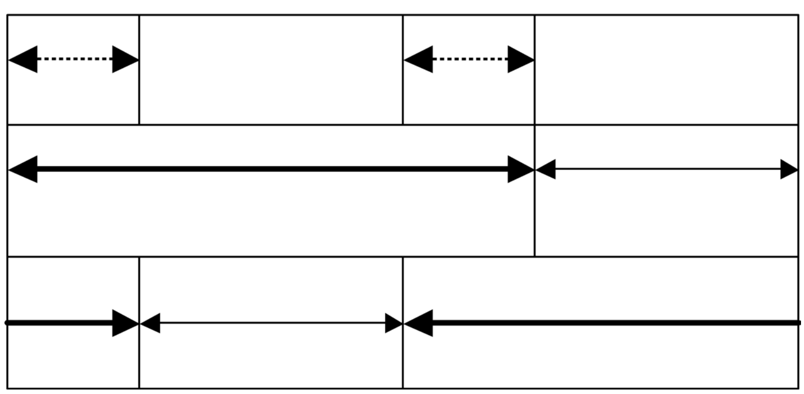


Figure 4

Percentage of gait cycle

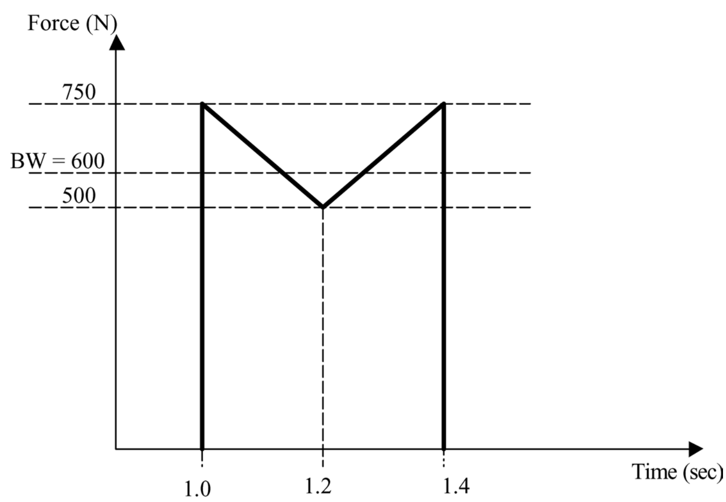


5. Calculate the velocity at 1.4 sec using the force plate curve as shown.

Given: Body weight (BW) 5 600N, downward gravity acceleration g 5 9.81m/s^2

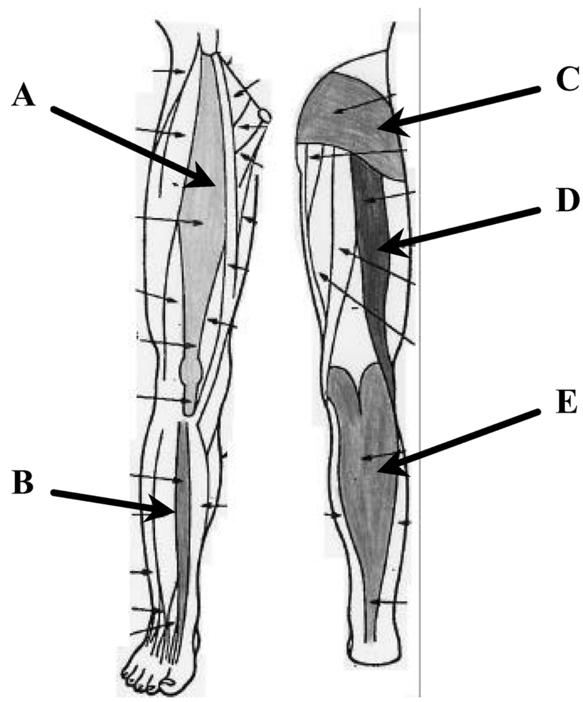
Initial velocity at time 1.0 second is Vo 5 0.0 m/s.

Hint: Find the equation for acceleration (a) from the ground reaction force (GRF) data and then integrate to find the velocity at 1.4 second.



Answer: ______________________

6. Identify the leg muscle that is pointed to by each arrow. Note: The figure shows the right leg.



Anterior view Posterior View

Major Muscles of the Leg

- Gluteus Maximus
- Sartorius
- Rectus Femoris
- Vastus medialis
- Vastus lateralis
- Biceps Femoris
- Semitendinosis
- Semimembranosis
- Tibialis Anterior
- Gastrocnemius
- Soleus
- Peroneus longus
- Extensor digitorum longus

Answers:

A. ______________________________

B. ______________________________

C. ______________________________

D. ______________________________

E. ______________________________

PRE-TEST GRADING KEY AND RUBRIC

VIRTUAL BIOMECHANICS LABORATORY MODULE

1. In Figure 1, the circle that most closely represents the whole body center of mass.

A. A person standing with arms by the side:

The COM is closet to the middle circle in the bottom row. **1 point**

B. A person standing with the left arm extended out:

The COM is closet to the right circle in the bottom row. **1 point**

2. Which of the plots in Figure 2 best represents the vertical displacement of the whole body center of mass during normal walking in humans.

A (the top left graph) **2 points**

3. Figure 3 represents a shank that is divided into 6 sections and Table 1 lists the mass and height of each section. The mass of each section is uniformly distributed. The symbol x_i is the distance from the proximal end of the shank to the center of the ith section. Use the bale to calculate the following:

A. Length of the shank:

$L_s = l_1 + l_2 + \cdots + l_6 = 10 + 10 + 10 + 10 + 10 + 10 = 60\ cm$ **1 point**

B. Mass of the shank:

$M_s = 1000 + 900 + 900 + 500 + 300 + 200 = 3800\ grams$ **1 point**

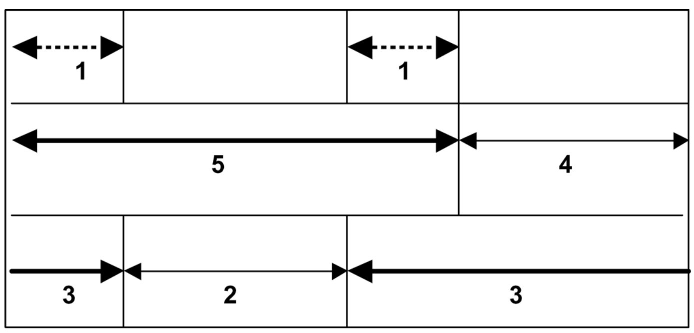
C. Center of mass (COM) of the shank:

$$COM_s = \frac{\sum m_i x_i}{M_s} = \frac{5*1000 + 15*900 + 25*900 + 35*500 + 45*300 + 55*200}{3800}$$

$COM_s = 21.84\ cm$ **2 points**

4. Figure 4 shows a person during certain phases of the normal gait cycle. Listed below are activities performed by the two legs during normal gait. Put the number corresponding to the appropriate activity performed by the legs in the correct boxes having the double-headed arrows, which indicates the % duration for which the activity lasts.

1. Double Support
2. Left Swing Phase
3. Left Stance Phase
4. Right Swing Phase
5. Right Stance Phase



0.5 points for each correct phase = 2.5 points total

5. Calculate the velocity at 1.4 seconds using the force plate curve as shown.

$$\sum F = ma$$

$$R - BW = ma$$

$$a = \frac{R}{m} - \frac{mg}{m} = \frac{R}{m} - g$$

1 point

$$V_{1.4} - V_{1.0} = \int_{1.0}^{1.4} \frac{R}{m} dt - \int_{1.0}^{1.4} g dt$$

1 point

$$V_{1.0} = 0$$

$$m = \frac{BW}{g} = \frac{600}{9.81} = 61.22\ kg$$

1 point

$$\int_{1.0}^{1.4} \frac{R}{m} dt = \frac{Area\ Under\ Curve}{m}$$

1 point

$$\left.\begin{aligned} V_{1.4} &= \frac{\mathit{Area\ Under\ Curve}}{61.22} - g^{*}(1.4 - 1.0) \\ V_{1.4} &= \frac{500^{*}0.4 + 250^{*}0.2}{61.22} - 9.81^{*}0.4 \\ V_{1.4} &= 0.159\ m/s \end{aligned}\right\}$$

1 point

6. Identify the leg muscle that is pointed to by each arrow.

A. Rectus Femoris

B. Tibialis Anterior

C. Gluteus Maximus

D. Biceps Femoris

E. Gastrocnemius

0.5 points for each correct phase = 2.5 points total

Note: All pre-post test scores were normalized to a scale of 0 to 5 points maximum for comparisons between modules.

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