Interactive Web-based Instructional Modules concerning Human Joint Mechanics using the Legacy Cycle

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Abstract

In this work we describe the integration of an interactive, web-based instructional approach with the Legacy Cycle learning algorithm for the investigation of human joint mechanics. The interactive web-based approach was developed as an instructional aid for an Engineering Graphics course and has repeatedly been used with great success. This approach is based on the use of Lotus ScreenCam tutorials and interactive exercises, games, and quizzes. The ScreenCam exercises interactively guide the student through examples using modeling software such as Working Model 2-D and MathCad. The instructional material is organized using the Legacy Cycle algorithm, which has been shown to be highly successful in K-12 instruction and is based on a sequence of challenges of increasing difficulty.

An example demonstrating the delivery and instructional techniques used is given. The example deals with a simple, planar Hinge Joint model of the Human Elbow. The challenges begin with determining which of the three muscle groups (biceps, brachioradials, and brachialis) is most efficient with respect to muscle force magnitude for an isometric curl lift, and progress to the proposition of an appropriate load distribution scheme for the prediction of muscle-group activation force for an isometric curl lift.

Introduction

In this work we describe the integration of an interactive, web-based instructional approach with the Legacy Cycle learning algorithm for the investigation of a specific task involving human joint mechanics. The Legacy learning cycle[1] is based on a sequence of contextually related challenges of increasing difficulty. A brief description of this cycle is given below in outline format with the italicized comments being the opinions of the authors.

Look ahead: The learning task and desired knowledge outcomes are described here. This step also allows for pre-assessment and serves as a benchmark for self-assessment in the Reflect Back step.

Challenge 1: The first challenge is a lower difficulty level problem dealing with the topic. The student is provided with information needed to understand the challenge. The steps shown below represent the remainder of the cycle, which prepares the students to complete the challenge.

    a. **Generate ideas**: Students are asked to generate a list of issues and answers that they think are relevant to the challenge; to share ideas with fellow students; and to appreciate which ideas are "new" and to revise their list.

    b. **Multiple perspectives**: The student is asked to elicit ideas and approaches concerning this challenge from "experts". *Describing who came up with certain approaches and theorems and when they developed them can place historical perspective here. This*

will underscore the utility and necessity of sharing ideas and leaving legacies for the development of community knowledge. It will also be beneficial to include experts from other domains discussing the same concepts but applied in different contexts. This will hopefully assist students in framing the knowledge goals to be attained in a broader context.

c. **Research and revise**: Reference materials to help the student reach the goals of exploring the challenge and to revise their original ideas are introduced here. *Again it will be beneficial to include materials from other domains dealing with the same concepts but applied in different contexts. This will also assist students in framing the knowledge gained in a broader context.*

d. **Test your mettle**: Formative instructional events are now presented. *Quizzes can be structured such that incorrect responses to problems send the student to specific review materials based on the particular response, and correct responses send the student to new material expanding on the concept in question. Including quizzes with problems from other domains will again illustrate to the student the multi-disciplinary nature of the knowledge gained.*

e. **Go public**: This is a high stakes motivating component introduced to motivate the student to do well.
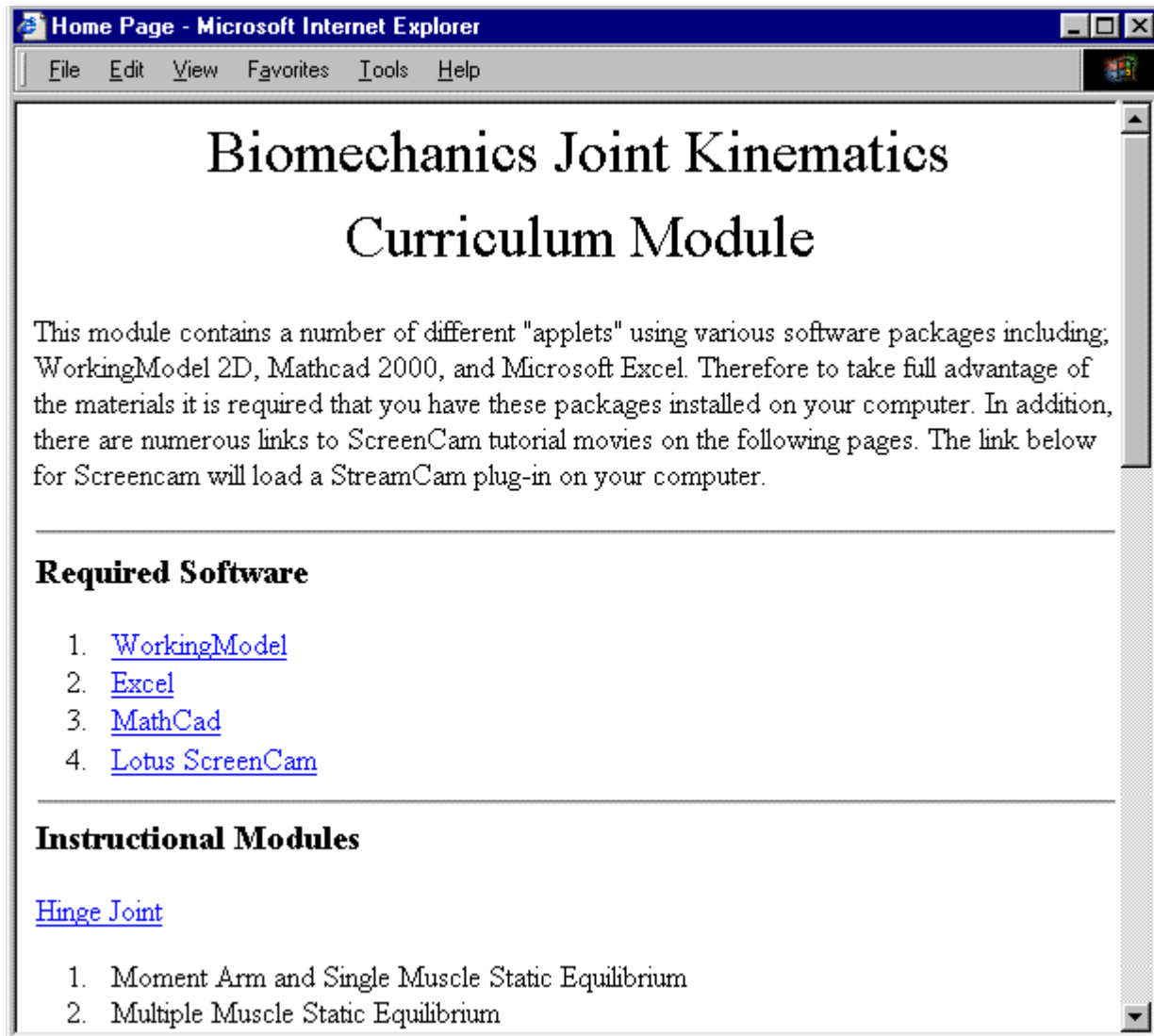
Challenge 2: The following progressively more ambitious challenges enable the student to progressively deepen their knowledge of the topic being explored. They are to repeat the complete cycle (a-e) for each challenge.

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Challenge N: The number of challenges is dependent on the richness of the topic. Up to 5 challenges are included in the STAR.Legacy[1] software shell.

Reflect back: This gives student the opportunity for self-assessment. *Perhaps the student should be encouraged to "reflect back" after only a few challenges are completed, especially in situations involving large numbers of challenges.*

Leaving Legacies: The student is asked to provide solutions and insights for learning to next cohort of students as well as to the instructor(s). *One technique that students can use is to create their own ScreenCam materials.*

The **interactive, web-based instructional approach**[2] (http://imej.wfu.edu) being integrated into the Legacy learning cycle is based on the use of Lotus ScreenCam tutorials and interactive exercises, games, and quizzes. Lotus ScreenCam allows for the creation of files containing a recording of what is on the computer screen synchronized with audio. Thus, beyond the learning framework provided by the Legacy cycle, scripting and creation of appropriate ScreenCam materials is paramount. Once created the ScreenCam exercises interactively guide the student through examples using modeling software such as the mechanical systems simulation software Working Model 2-D (WM2D) and MathCad. In general, the student first watches a ScreenCam tutorial and is then asked to explore certain questions "by hand" and by using different software application "scripts" designed specifically to address the underlying concept(s) involved. These materials specifically address steps c and d of the cycle but also provide a medium for step b, part of step a, and Leaving Legacies as students can create their own ScreenCam materials. These materials are accessed via a web site **TBA** whose first page is partially shown in the following graphic.

Biomechanics Joint Kinematics Curriculum Module

This module contains a number of different "applets" using various software packages including; WorkingModel 2D, Mathcad 2000, and Microsoft Excel. Therefore to take full advantage of the materials it is required that you have these packages installed on your computer. In addition, there are numerous links to ScreenCam tutorial movies on the following pages. The link below for Screencam will load a StreamCam plug-in on your computer.

Required Software

1. WorkingModel
2. Excel
3. MathCad
4. Lotus ScreenCam

Instructional Modules

Hinge Joint

1. Moment Arm and Single Muscle Static Equilibrium
2. Multiple Muscle Static Equilibrium

The body of the paper is structured according to the Legacy Cycle. Detail of the specific learning materials and techniques made available to the student via the WWW for Challenge 1 are provided. The remainder of this particular "cycle" is then addressed in a more general sense, followed by conclusions. The "cycle" is under development on a hard drive as of this writing and as such is not yet available in its entirety on the Web.

Legacy Cycle for the development of knowledge concerning the Human Elbow

Looking ahead:

This "cycle" currently deals only with a simple, planar Hinge Joint model of the Human Elbow containing the bicep, brachioradialis, and brachialis muscle groups. It consists of 4 challenges beginning with determination of which of the three muscle groups is most efficient with respect to muscle force magnitude for an isometric curl lift, and progress to the proposition of an appropriate load distribution scheme for the prediction of muscle-group activation force for an

isometric curl lift. The following graphic is illustrative of a frame of a WM2D ScreenCam movie that the student will view to get an idea of the "big picture" before beginning the first challenge.
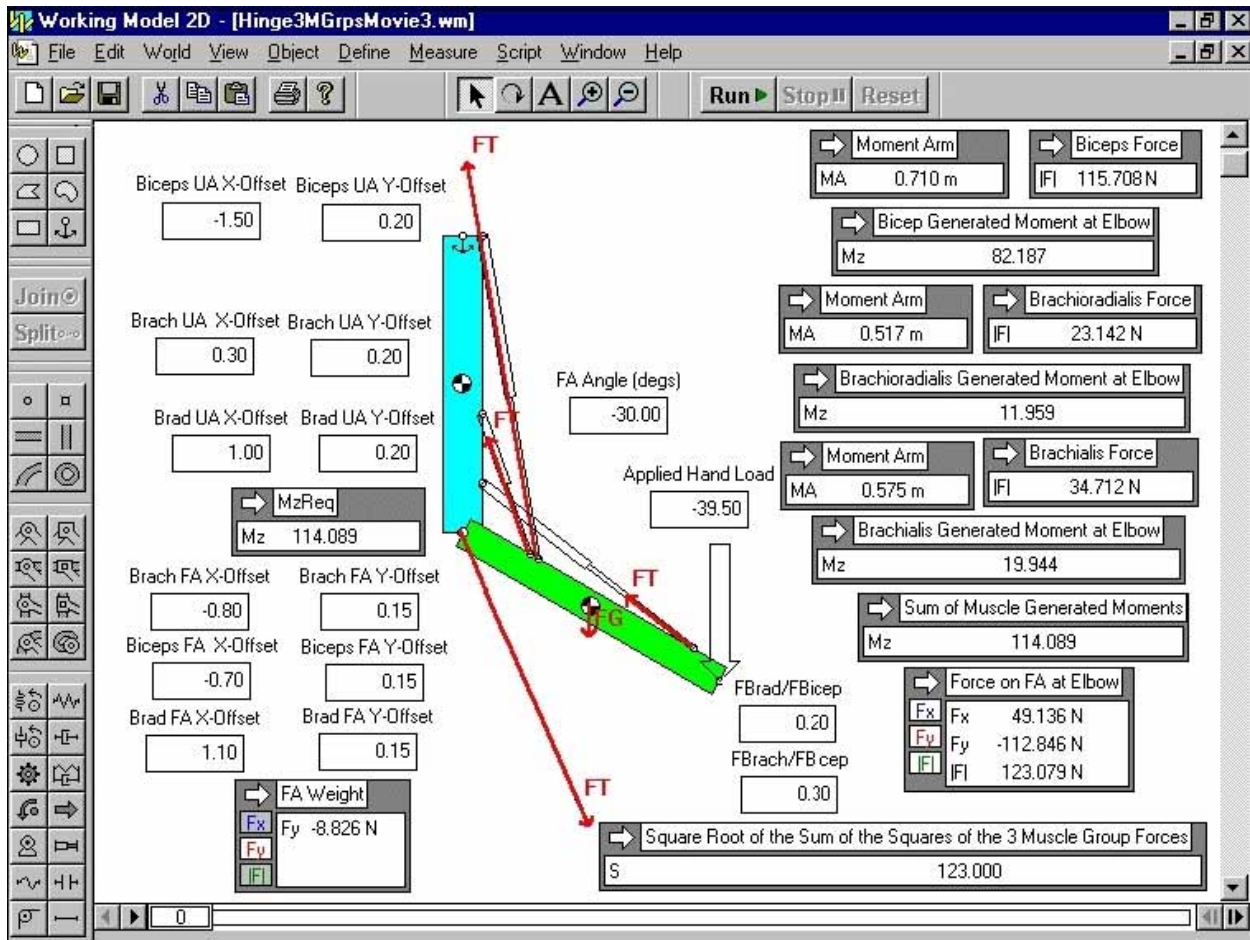

The student is also told/shown that the specific knowledge outcomes of this "module" include; 1) understanding of the concept of static equilibrium, 2) the understanding of moment arms and their role in the determination of the moment generated about a point by a force, 3) the ability to compute moment arms, 4) the ability to apply this knowledge to determine the required equilibrium torque at the elbow due to a load applied at the hand, as well as, to determine the force required by a single muscle group to place the arm in static equilibrium, 5) the understanding that when two or more muscle groups are actively applying force to this kinematically simple model it becomes what is referred to as a statically redundant/indeterminate system, and that there are an infinite number of mathematically possible sets of muscle-group forces that will place the arm in static equilibrium, 6) the understanding and use of various load distribution techniques for redundancy resolution, and 7) the awareness of the numerous proposed distribution schemes as applied to biomechanical models as a whole, including their shortcomings[3]. At this stage the student's understanding of the knowledge goals and their application to the upcoming challenges can be pre-assessed.

Challenge 1:
Of the three muscle groups (biceps, brachioradials, and brachialis), which is the most efficient with respect to muscle force magnitude for an isometric curl lift?
The student is now referred to a ScreenCam movie of a WM2D simulation of a single muscle-group hinge joint model of the elbow. The following graphic illustrates what the student will see. The arm oscillates back and forth while the forearm weight and hand load remain constant and the muscle-group force varies as a function of length.
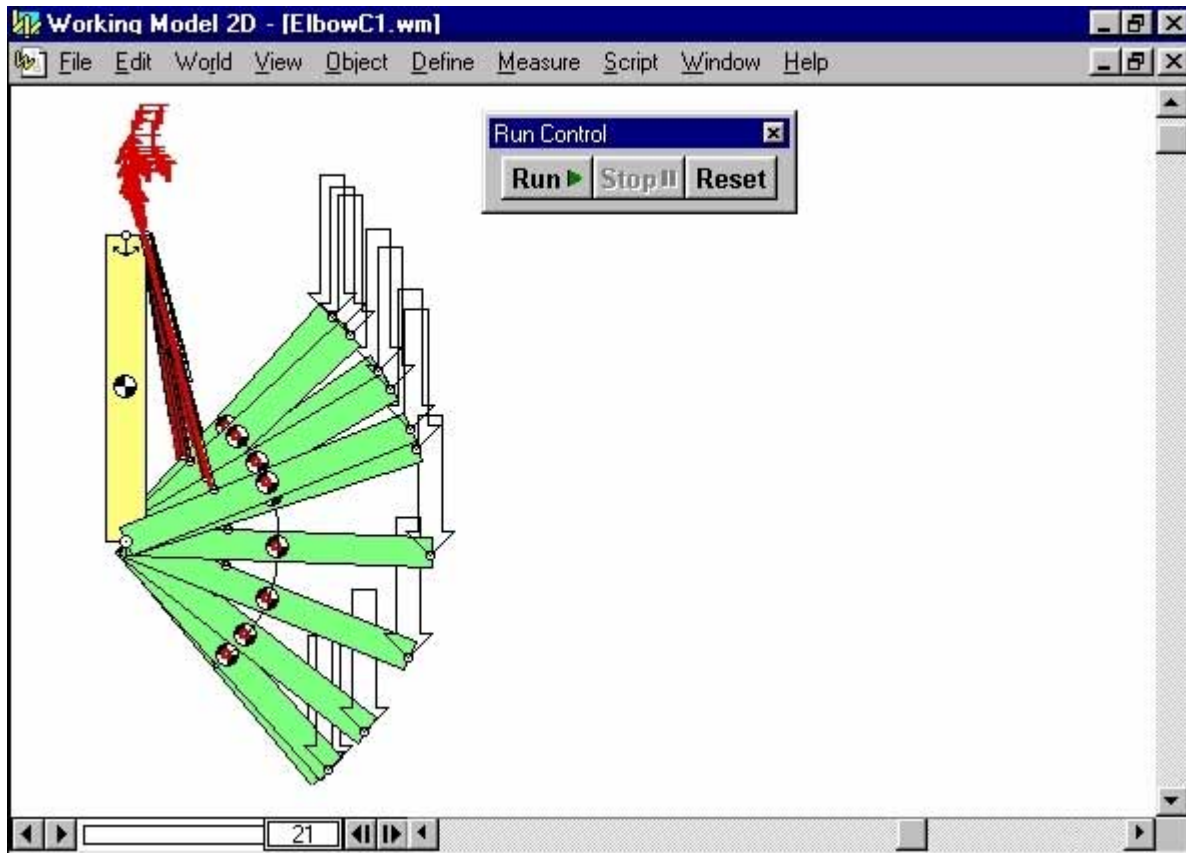
a. **Generate ideas**
The student is now asked to list what model parameters they think are important with respect to the given challenge. They are then to discuss the issue with fellow students and revise their list as appropriate.

b. **Multiple perspectives**
The student has a number of options at this stage but the main idea is that they obtain information concerning the challenge from "experts." One option will be for them to view a few short ScreenCam movies illustrating the effects of changes in various parameters including; joint angle, muscle force, and muscle insertion points. These movies use the WM2D script shown below which allows the user to arbitrarily select each of the parameters mentioned above and view how these selections affect the resulting motion of the arm. Comments are also made concerning moments, moment arms, the requirements for static equilibrium, and the effect of muscle length on muscle force.

Working Model 2D - [ElbowC1b.wm]

File   Edit   World   View   Object   Define   Measure   Script   Window   Help

FT

Biceps UA X-Offset | -1.50
Biceps UA Y-Offset | 0.20

Run Control
Run ▶ Stop ❚❚ Reset

Muscle Force | -5.00

FA Angle | -50.00

Req. Equil. Moment | M   4.930

Biceps FA X-Offset | 0.50
Biceps FA Y-Offset | 0.15

Hand load | -1.50

Moment Arm | MA   0.977 m

Muscle Length | l   4.595 m

Muscle Force | |F| 5.000 N

Muscle Generated Moment | Moment   4.884

FG

c. **Research and revise**

The student is now referred to standard textual information concerning static equilibrium and moment determination, and the following interactive tutorial material.

Hinge Joint; Moment Arm and Single Muscle Static Equilibrium

1. Watch the instructional movie to understand the calculation of the moment arm and resultant moment about the hinge joint and how they vary as a function of arm position.

2. Follow along in Working Model as the instructional movie walks you through an example showing the effect of varying the muscle insertion point along the forearm.

3. Follow along in MathCad as the instructional movie walks you through an example showing you how to use a MathCad script to solve for the moment arm and resultant moment.

4. Use the Working Model and Mathcad examples to explore concepts given on the interactive quiz.

Selection of the first **instructional movie** launches a tutorial ScreenCam movie shown below using WM2D to graphically illustrate what a moment arm is and the resultant moment due to the muscle force. This movie also shows where the moment arm and resultant moment are maximized, and includes treatment of muscle force as a function of length.
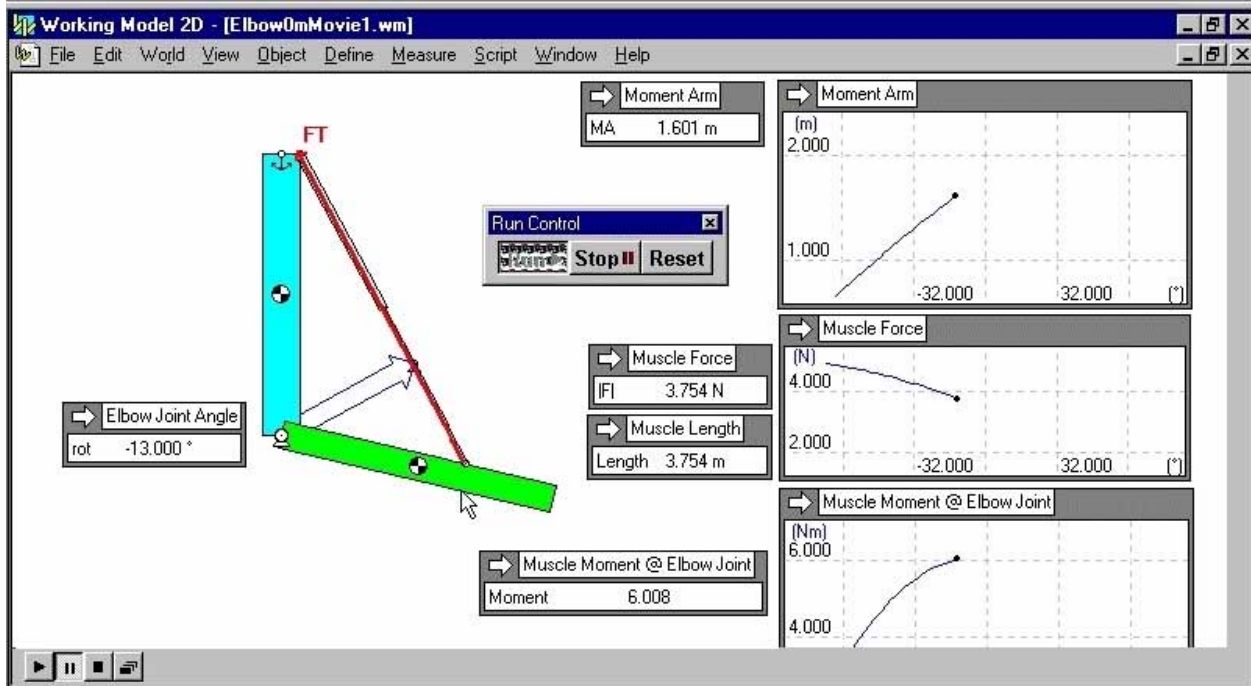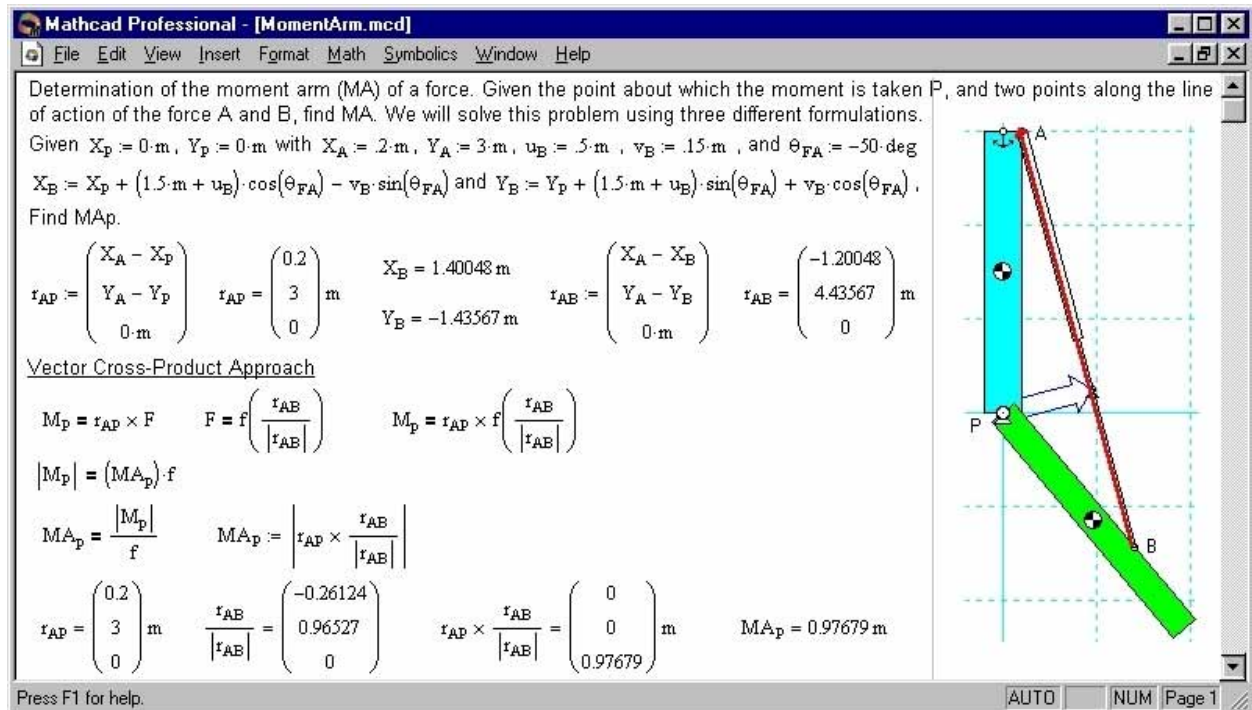

The second **instructional movie** shown below illustrates the effect of changing the location of the insertion point on the forearm.

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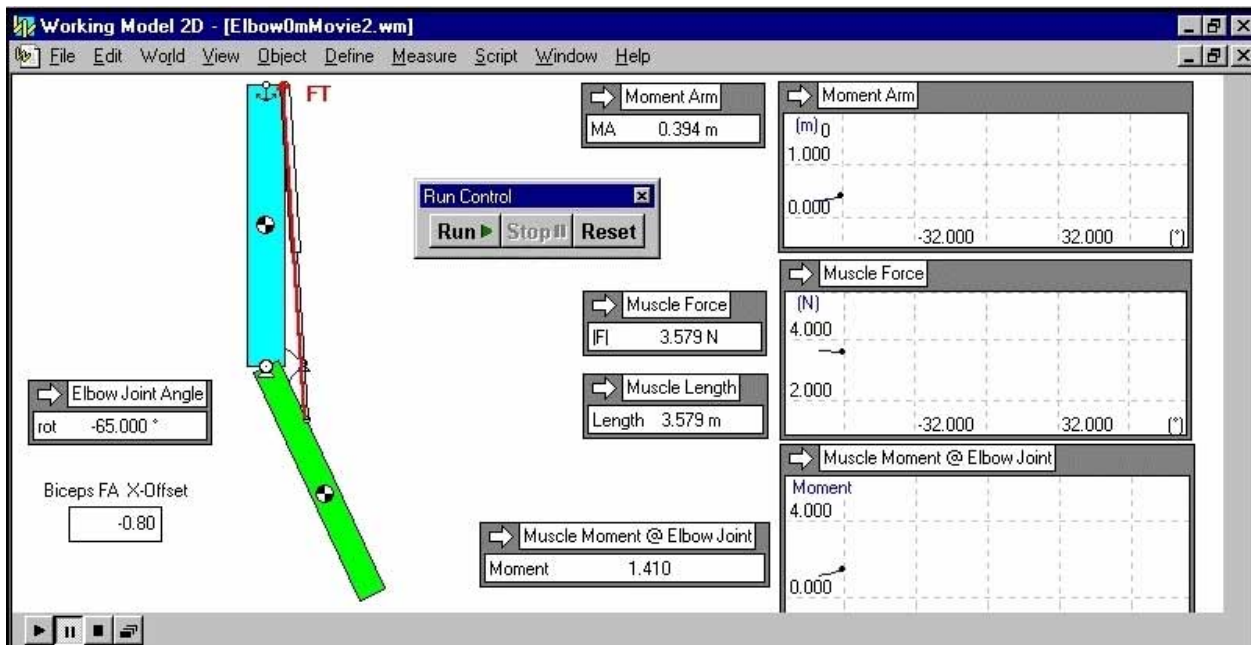
The student is then asked to use a WM2D **example** script shown below to change the insertion point and determine at what joint angle(s) are the moment arm and resultant moment maximized.
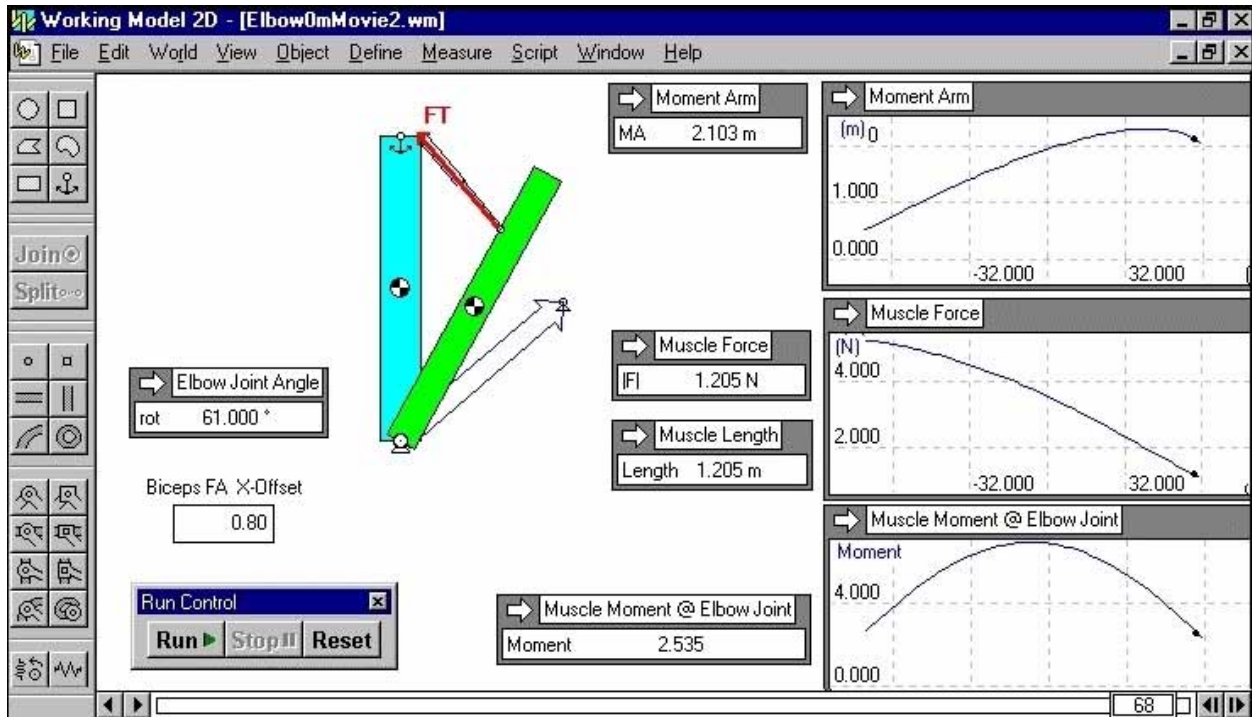
The third **instructional movie** discusses the computation of the moment arm and resultant moment with the aid of the MathCad script shown below.

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d. **Test your mettle**

The student is first asked to compute the moment arm and moment for a given set of conditions "by hand" and to then check their answer using both the MathCad example script and the WorkingModel script. They are then referred to a set of interactive, formative quizzes shown in part below to test their understanding of the concepts, as well as their ability to use the WorkingModel and MathCad scripts.
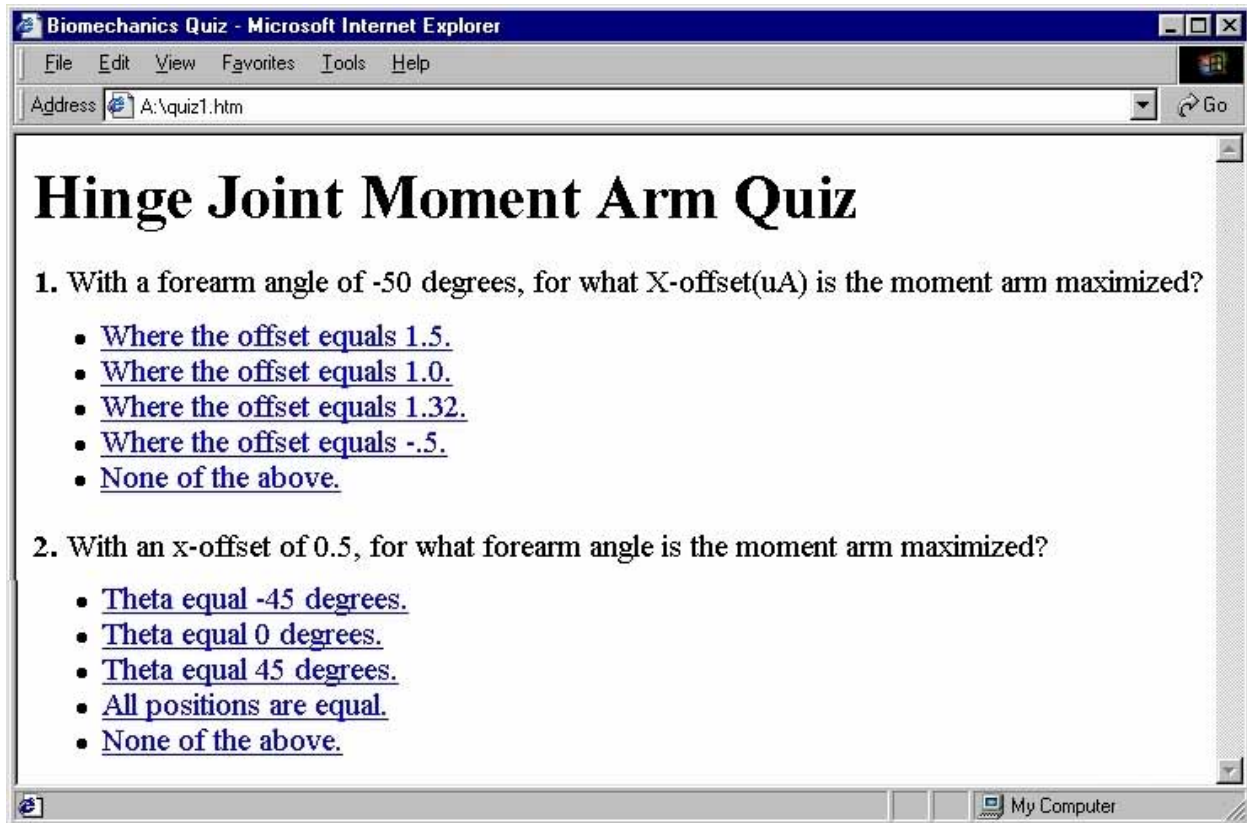
Depending on their answers to the quiz questions different tutorial movies are launched that either guide them (hopefully) to the correct response, or introduce new, more challenging material. For example, the correct response to problem 1 is the first one. Selection of this answer launches a ScreenCam movie reinforcing the students understanding that the moment arm is the perpendicular distance between the line-of-action of the force and the elbow joint. They are also guided to the fact that the forearm angle has nothing to do with the answer. On the other hand, selection of an incorrect answer launches a ScreenCam movie shown below that reviews the concept of the moment arm and then suggests that they return to the WM2D and MathCad scripts to reevaluate their response.
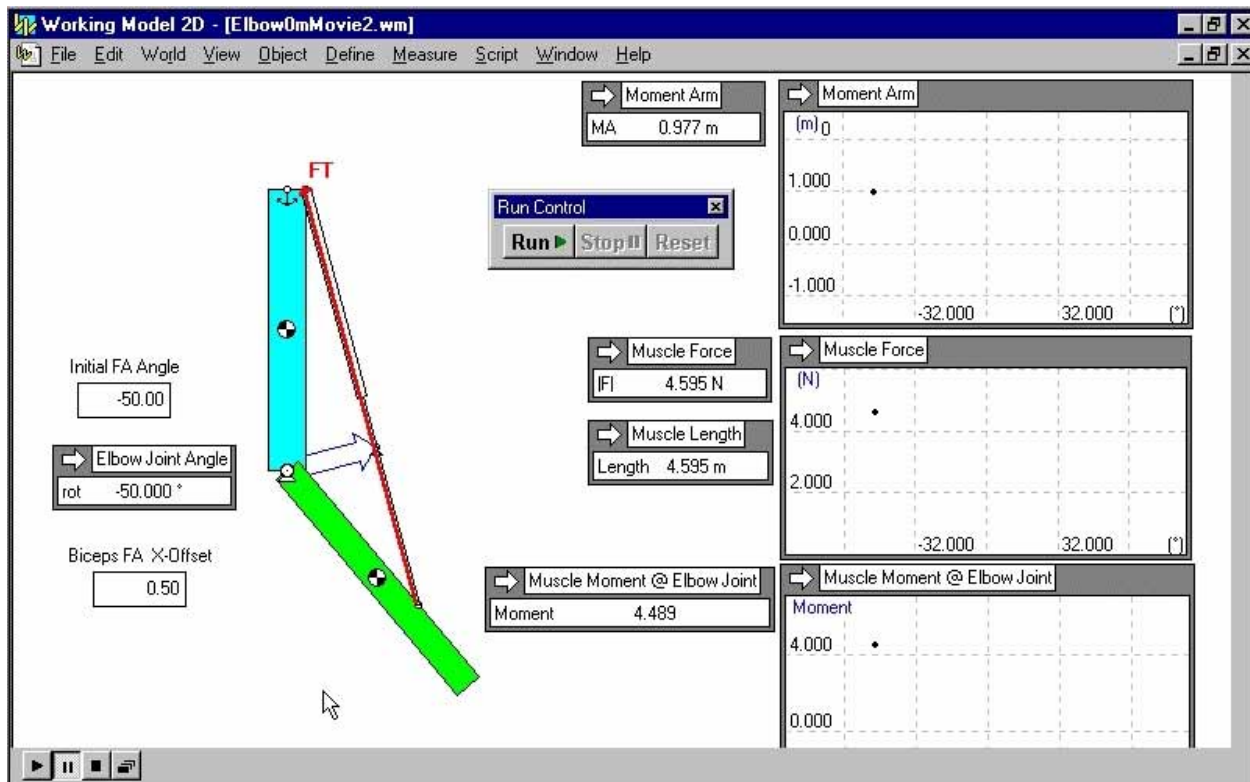
For problem 2 the correct response is the last one. An incorrect response launches a ScreenCam movie reviewing the use of the WM2D script to visually observe and obtain the correct answer. A correct response launches a ScreenCam tutorial using MathCad that shows how the moment arm can be expressed as a function of the joint angle and then maximized using the classical optimization approach of calculus. The equations that follow represent the development that the student is taken through using the symbolic manipulation capabilities of MathCad. The tutorial movie not only discusses the solution approach but also the use of MathCad to perform the math. This information will be useful when addressing the fourth challenge.

$$X_p := 0 \quad Y_p := 0 \qquad X_A := .2 \quad Y_A := 3 \qquad u_B := .5 \qquad v_B := .15$$

$$X_B = X_p + (1.5 + u_B) \cdot \cos(\theta_{FA}) - v_B \cdot \sin(\theta_{FA}) \qquad Y_B = Y_p + (1.5 + u_B) \cdot \sin(\theta_{FA}) + v_B \cdot \cos(\theta_{FA})$$

$$MA_p = \left| \begin{pmatrix} X_A - X_P \\ Y_A - Y_P \\ 0 \end{pmatrix} \times \frac{\begin{bmatrix} X_P + (1.5 + u_B) \cdot \cos(\theta_{FA}) - v_B \cdot \sin(\theta_{FA}) - X_A \\ Y_P + (1.5 + u_B) \cdot \sin(\theta_{FA}) + v_B \cdot \cos(\theta_{FA}) - Y_A \\ 0 \end{bmatrix}}{\left| \begin{bmatrix} X_P + (1.5 + u_B) \cdot \cos(\theta_{FA}) - v_B \cdot \sin(\theta_{FA}) - X_A \\ Y_P + (1.5 + u_B) \cdot \sin(\theta_{FA}) + v_B \cdot \cos(\theta_{FA}) - Y_A \\ 0 \end{bmatrix} \right|} \right|$$

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$$MA_p = \frac{.85 \cdot \sin(\theta_{FA}) - 5.970 \cdot \cos(\theta_{FA})}{\left(4.0225 \cdot \cos(\theta_{FA})^2 - 1.70 \cdot \cos(\theta_{FA}) + 4.0225 \cdot \sin(\theta_{FA})^2 - 11.940 \cdot \sin(\theta_{FA}) + 9.04\right)^{\left(\frac{1}{2}\right)}}$$

$$\frac{d}{d\theta_{FA}} \frac{.85 \cdot \sin(\theta_{FA}) - 5.970 \cdot \cos(\theta_{FA})}{\left(4.0225 \cdot \cos(\theta_{FA})^2 - 1.70 \cdot \cos(\theta_{FA}) + 4.0225 \cdot \sin(\theta_{FA})^2 - 11.940 \cdot \sin(\theta_{FA}) + 9.04\right)^{\left(\frac{1}{2}\right)}} = 0$$

$$\begin{pmatrix} 1.4293683153083059532 + .96163549123739544987i \\ 1.4293683153083059532 - .96163549123739544987i \\ 2.2699113922786688986 \\ .58882523833794300786 \end{pmatrix}$$

$\theta_{FA1} := 2.2699113922786688986$

$\theta_{FA2} := .5888252383379430078$

$\theta_{FA} := 2.2699113922786688986 \qquad \theta_{FA} = 130.056 \text{deg} \qquad$ Not physically realizable.

$$MA_p := \left| \begin{pmatrix} X_A - X_p \\ Y_A - Y_p \\ 0 \end{pmatrix} \times \frac{\begin{bmatrix} X_p + (1.5 + u_B) \cdot \cos(\theta_{FA}) - v_B \cdot \sin(\theta_{FA}) - X_A \\ Y_p + (1.5 + u_B) \cdot \sin(\theta_{FA}) + v_B \cdot \cos(\theta_{FA}) - Y_A \\ 0 \end{bmatrix}}{\begin{bmatrix} X_p + (1.5 + u_B) \cdot \cos(\theta_{FA}) - v_B \cdot \sin(\theta_{FA}) - X_A \\ Y_p + (1.5 + u_B) \cdot \sin(\theta_{FA}) + v_B \cdot \cos(\theta_{FA}) - Y_A \\ 0 \end{bmatrix}} \right| \qquad MA_p = 2.006$$

$\theta_{FA} := .58882523833794300786 \qquad \theta_{FA} = 33.737 \text{deg} \qquad MA_p = 2.006 \qquad$ Physically correct answer.

At this point the student is asked to solve the challenge (*Of the three muscle groups, which is the most efficient with respect to muscle force magnitude for an isometric curl lift?*). To assist them, in addition to the MathCad script accompanying the third instructional movie, they are referred to the richer WM2D script shown below in which the insertion points for the muscle-group can be specified, along with the forearm angle and hand load. Note that they will also have to obtain realistic values for the musculo-skeletal geometry. In addition, secondary questions will be posed. For example, "*Does hand load affect your answer?*" and "*Does the elbow angle affect your answer?*"
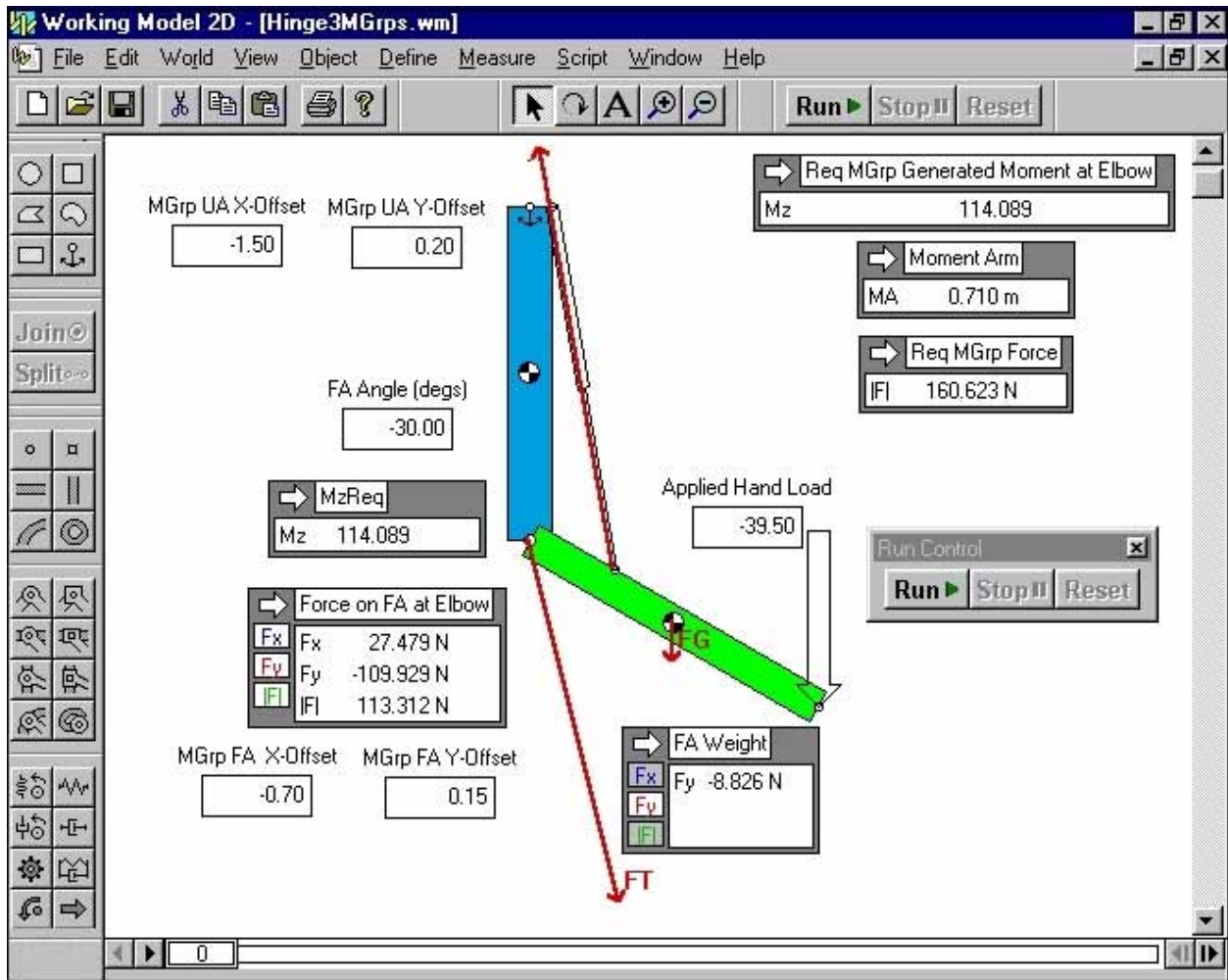
e. **Go public**
The student is then required to describe their results and any other observations to their classmates, and to post them on the Web.

Challenge 2:
Given force-length relationships representative of each of the three muscle groups, what is the maximum hand load that can be curled by each group independently? The student is to repeat steps a-e for this challenge. In terms of the **Research and revise** component the student is guided through a 2-step process to accomplish this challenge. Step 1 basically reverses Challenge 1 restated as: For a given joint configuration, musculo-skeletal geometry, and a given muscle-group force what is the greatest hand load that can be supported? The tutorial materials here are much the same as for Challenge 1, only the roles of the hand load and muscle force as input/known and output/unknown are switched. This underscores the utility of the moment arm approach and illustrates that the requirements of equilibrium are independent of which parameter is considered the input and which the output. Step 2 introduces a force-length relationship for each muscle group and asks the challenge. Again the materials are similar, with the main difference simply being that muscle-group force value is a function of its length and hence joint

angle. These materials are accessed from the following web page (under development). The subsequent graphic shows the first **Working Model Example** script.

Hinge Joint; Multiple Muscle Equilibrium

1. Follow along in Working Model as the instructional movie illustrates how to determine the maximum hand load for a given configuration and bicep force. (Working Model Example)

2. Follow along in Working Model as the instructional movie illustrates how to determine the maximum hand load for a given range of motion of the elbow, with the bicep force a function of its length. (Working Model Example)

3. Use the Working Model and Mathcad example scripts to explore concepts given on the interactive quiz.

Challenge 3:
What is the maximum hand load that can be curled with all three groups active?

The student is again to repeat steps a-e for this challenge. In terms of the **Research and revise** component the student is referred back to a slightly enriched version (shown below) of the previous materials containing all three muscle-groups. They will be lead through numerous issues concerning the distribution of the required elbow torque to the different muscle-groups, including; 1) "*For a given angle and assuming maximally activated muscles, what percentage of the required joint torque is provided by each of the three muscle-groups?*" and 2) "*How does this percentage vary during the full curl?*"
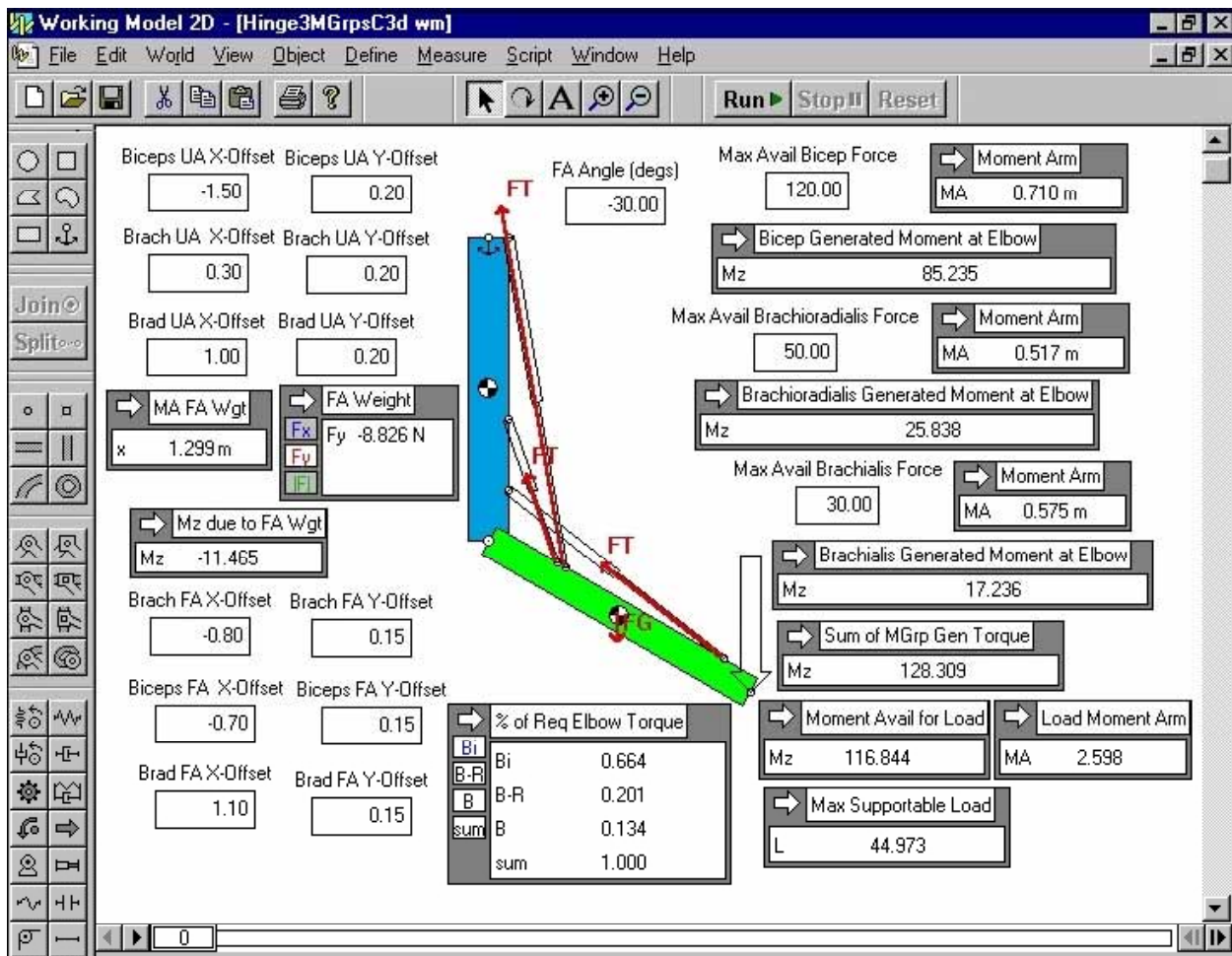

Challenge 4:
Propose an appropriate load distribution scheme for the prediction of muscle-group activation force for an isometric curl lift.

The student is again to repeat steps a-e for this challenge. In terms of the **Research and revise** component the student is referred to textual material[3], and interactive materials such as that shown below. Here the force distribution is simply specified in terms muscle-group force ratios normalized with respect to the bicep force. The effect of these selections on the particular criterion "square-root of the sum of the square of the muscle-group forces" is shown. This

challenge is different from the first three in that it is a current area of research. Thus, the student is encouraged to investigate numerous previously proposed schemes, such as the one just mentioned, as well as to attempt to develop their own.
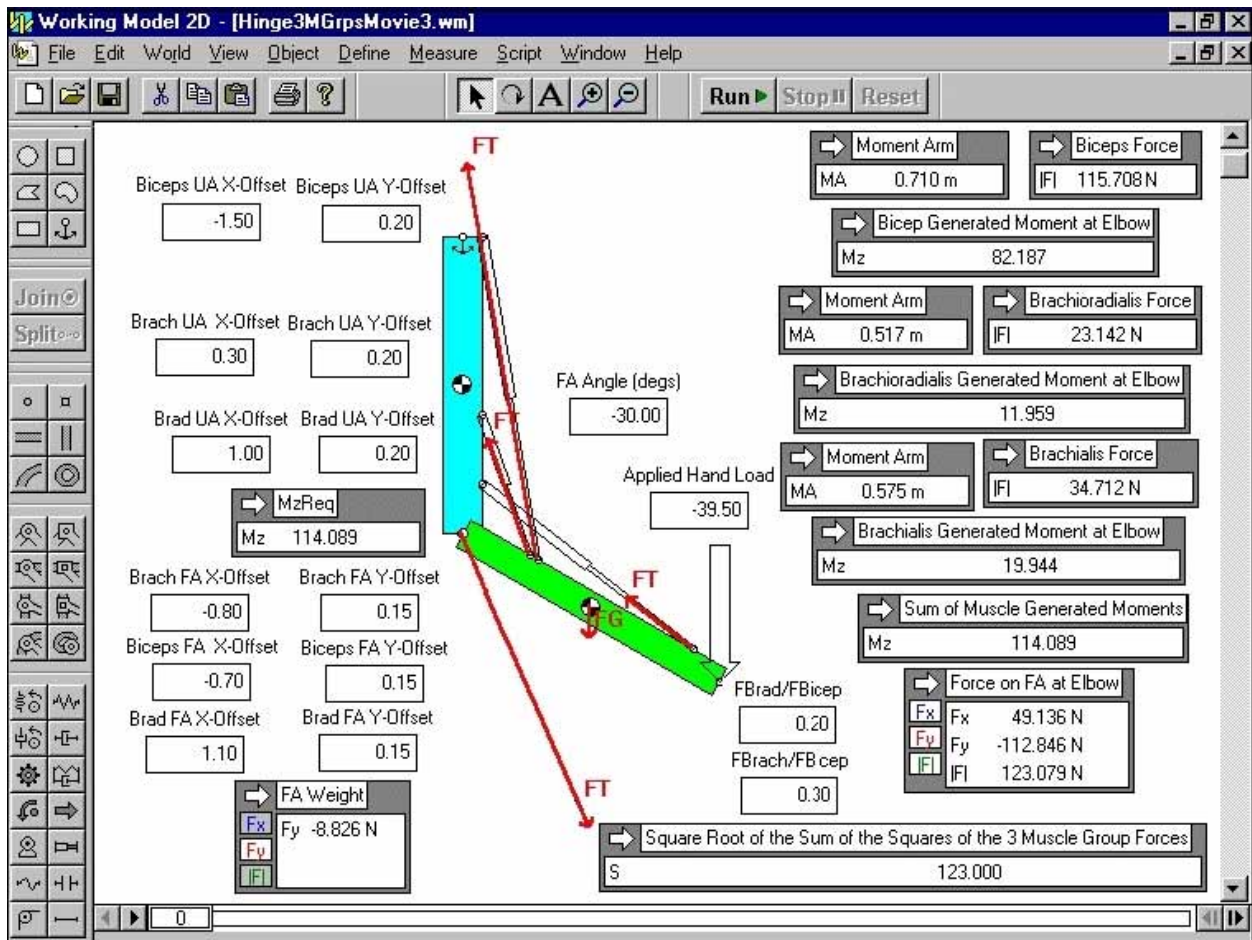
Reflect Back
The student will be asked to revisit and revise their original list of "relevant" parameters for this particular model of the elbow. They will then be asked to consider the sufficiency of the given model and to discuss parameters and relationships that they think should be included in a more realistic model of the human arm. This self-assessment will reinforce their feeling of accomplishment and set them on a course for the next level of fidelity in biomechanics models.

Leaving Legacies
After completion of the cycle the student is required to leave a "legacy". They will be given a short tutorial on the use of the ScreenCam software and asked to create a tutorial movie, with the accompanying textual and software scripts, that they think will be a useful additional source of information for future students and for the faculty involved in the development of this "cycle".

Conclusion

The integration of the interactive multi-media tools into the Legacy Learning Cycle provides an excellent framework for the development effective teaching materials. The materials presented

here were developed in a modular fashion so that they could be integrated with other modules being developed for a complete Biomechanics taxonomy[4]. Indeed, the modules can be mapped to other contexts requiring the development of similar knowledge outcomes. The example discussed herein specifically addresses an area of interest in biomechanics, however the materials for the first challenge are appropriate as they stand for a standard Statics course and all the materials are appropriate for a course in Robotics. Authors whose interests lie in many different areas can develop knowledge-outcome based modules that can be intermixed across disciplines according to student interests and needs. With a sufficient diversity of these knowledge-outcome based modules it is conceivable that a student could tailor their own curriculum, much less course. The authors are considering using the Legacy cycle challenge-based approach in the development of a multi-level, modular, knowledge-outcome based, Dynamics course. Here the student would choose one cycle from a set of three or four from each of N levels. Once they complete one cycle from level one they go on to level two, and so on. Once they complete level N, they have completed the course, as they will have "mastered" all of the required knowledge outcomes for that course. Assessment will take a multi-contextual form.

Finally, the authors will be utilizing the interactive web-based approach for the development of materials concerning the instruction of various software application packages including WM2D and MathCad. This work is to be funded by an NSF CCLI-EMD program grant.

Acknowledgments

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