Movement from a Taxonomy-Driven Strategy of Instruction to a Challenge-Driven Strategy in Teaching Introductory Biomechanics

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Abstract

Many courses adopt a traditional approach to instruction, characterized by lectures that follow a linear progression through a textbook that is organized about the general taxonomy of the subject matter. New theories of learning suggest that this taxonomy-driven instruction offers fewer opportunities for students to develop their problem solving abilities than a challenge-driven approach. We have explored a challenge-driven approach in an introductory biomechanics course (BME 101) required by sophomores in Biomedical Engineering at Vanderbilt University. The course objective is to provide the fundamental principles and biological applications of statics, dynamics, and strength of materials. Until recently, student problem solving was performed exclusively outside the classroom. Current research in the Learning Sciences, as summarized in the book "How People Learn" (HPL) edited by Bransford, et. al, 1999, shows that the most effective learning environments are those that are knowledge-centered, learner-centered, assessment-centered and community-centered. The STAR Legacy Cycle is a learning tool developed at Peabody College that promotes use of the HPL framework to help students solve challenges. We have developed a series of challenges for BME 101 that meet the current course objectives, but with the advantage of placing this instruction within the HPL framework. To ensure adequate taxonomic coverage, we compiled a detailed list of taxonomy-related course objectives and then selected a sufficient number of challenges to meet all of the objectives. Several objectives are re-emphasized by inclusion in multiple challenges. The motivation for using challenge-driven instruction is that instead of giving students problems that are strictly based on the latest taxonomy-driven lecture, we provide real life challenges that put students in the position where they need to determine which parts of the taxonomy are relevant to the problem at hand. We believe that the challenge-driven approach will better prepare students for the workplace and for life-long learning.

Introduction

Introductory Biomechanics (BME 101) is a required course in the biomedical engineering curriculum at Vanderbilt University. Students normally take this course during their sophomore year. Students are expected to have adequate preparation in mechanics from their general physics course and vector analysis and calculus from their freshman math courses. The course objective is to provide the fundamental principles and biological applications of statics, dynamics, and strength of materials. The course has been presented in a very traditional manner since 1988. This approach is characterized by the presentation of lectures and instructorcentered problem-solving during the class period. The lectures have tended to cover material in the same sequence as it has appeared in the textbook, and the textbook topics followed the traditional taxonomy of mechanics. Student problem solving was performed exclusively outside the classroom. The first quarter of the semester was devoted to reviewing fundamental concepts in vector mechanics, introducing students to the essentials of anthropometry, and an overview of musculoskeletal system physiology. The remainder of the course was devoted sequentially to biomechanics applications in statics, dynamics, and strength of materials.

Recent research in learning science is summarized in the book "How People Learn" (HPL) edited by Bransford, et. al.[1] A key finding, which we term the HPL framework, is that the most effective learning environments are those that are knowledge-centered, assessment-centered, learner-centered and community-centered. The traditional method provides an environment that is largely knowledge-centered, with some summative assessment, but with little attention to formative assessment, learner-centered activities, or community involvement. Our objective is to modify BME 101 so that it becomes more effective through the introduction of learner-centered, community-centered and assessment-centered activities.

Methods

Starting with the Spring Semester of 1999 we have attempted to refine the knowledge base of the course by systematically reflecting on the course objectives and content, and prioritizing them appropriately. Also, efforts are underway to make the classroom environment more learner-centered by making the time spent in the classroom more interactive. The time spent in formal lectures has been reduced and the time spent on student problem-solving sessions and open discussions has been increased. Lectures were used in the past as a vehicle for introducing new ideas to students in preparation for solving problems that were assigned as homework. This year, some homework has been assigned prior to class so students can explore various challenges as a method to orient them to the issues associated with solving the challenges. They aren't expected to solve these challenges on their own, but the challenges are designed to stimulate questions about what the students need to know before they can solve the problem. This builds on the idea of creating a “time for telling” [2]. By having students struggle with challenges prior to class, they will be prepared to ask appropriate questions in class. In fact, if the students have done this pre-class activity, a lecture will often be just the right vehicle to help them bring all the pieces together. In addition, this provides an opportunity for significant formative assessment through student-student and student-instructor classroom interactions. Although this approach will require less in-class lecture time, it does not necessarily imply that less material will be covered during the course of the semester. Some of the material that is currently presented in lectures has been moved to the course web site and assigned as homework, while some of the problems previously assigned for homework have been moved to the classroom.

Another learning tool that has been shown to be effective is the STAR Legacy Cycle,[3,4] (where STAR stands for Software Technology for Action and Reflection). Figure 1 illustrates the six phases of the learning cycle designed to help organize students' inquiry so they may systemically explore a challenge. This exploration could take a single class period or several days of in-class and out of class activities. These phases provide various mechanisms for designing a learning environment that takes into consideration each of the four major dimensions of the HPL framework. The initial step in the cycle is to pose a well-conceived challenge to the students that will require knowledge in several areas of the biomechanics taxonomy. For example, one challenge might relate to sports medicine, where students need to identify the muscle group that must be active at a gymnast's shoulders and to estimate the average muscle force necessary to hold the infamous iron cross position on the rings. Their goal could be to determine which muscles are the most likely to be injured during this position or to design an apparatus to help an athlete develop certain muscle groups. Solution of this problem requires familiarity with anthropometry, muscle and joint anatomy and physiology, construction of a free body diagram, application of Newton's laws, application of the method of sections, vector analysis, material properties, and other skills.

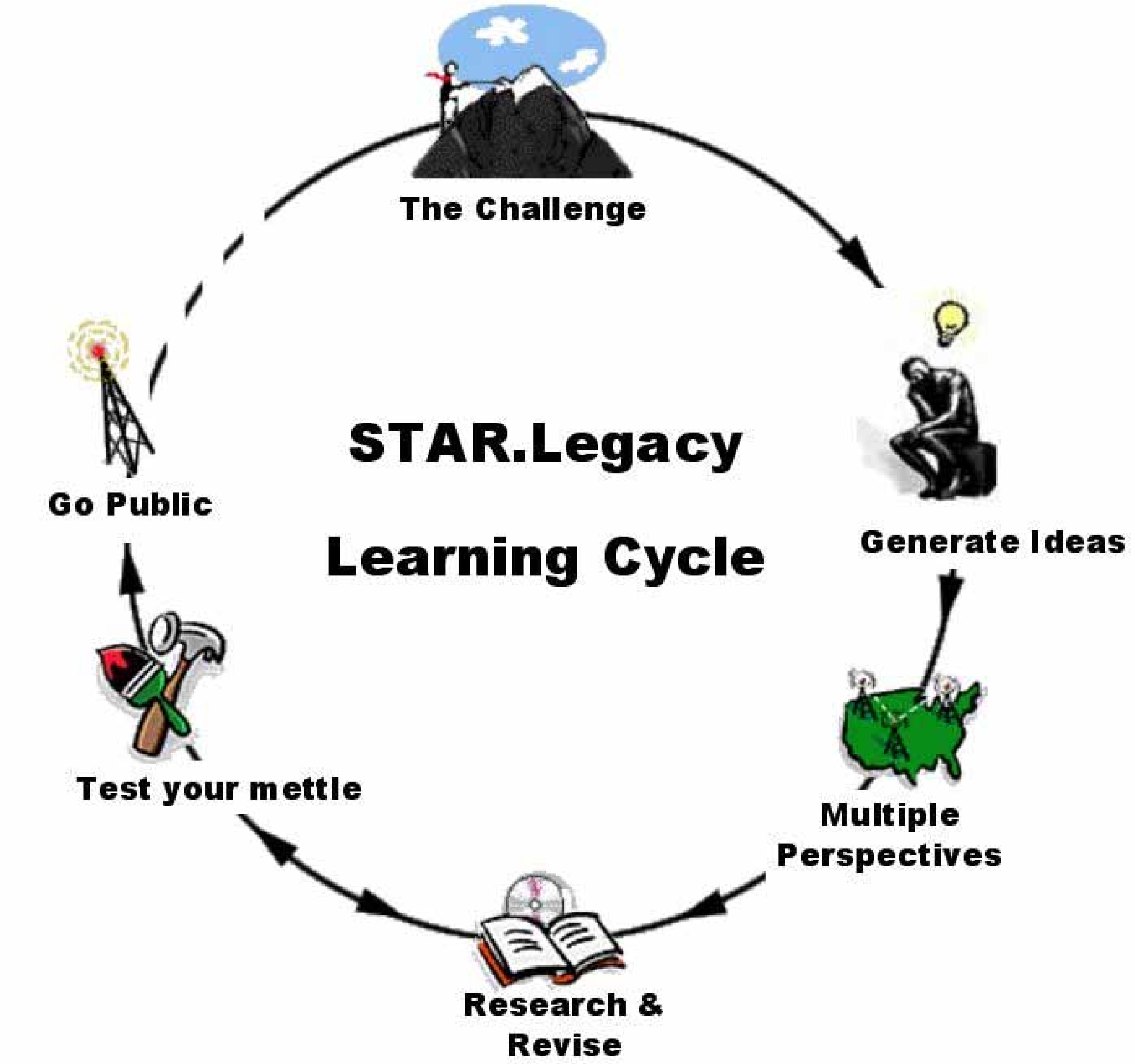

Figure 1. STAR.Legacy Cycle

The next three steps in the Legacy Cycle encourage students to think through the problem in much the same way they would when they leave school and enter the workplace. In the "Generate Ideas" step the students provide their initial thoughts on the information, assumptions, concepts and skills that are needed to solve the problem (learner-centered, knowledge-centered and assessment-centered). In class, students would be given a couple of minutes to jot these down on a sheet of paper. They could work in small groups to use each other as resources to examine the problem. Soon we will have wireless laptops for students to do some preliminary research about the problem. This provides students with the opportunity to see what they really know about the problem and what areas may need additional research. It also provides an informal pretest for the instructor to see what the students already know. Note that this one activity can have elements of all four dimensions of the HPL framework. By soliciting students' ideas we are centering on their prior knowledge in relation to the challenge at hand. We are asking them to use the classroom community (and beyond) as a resource for expanding what they know about the problem. The results of this activity can provide an informal assessment of what they currently know, and can provide a starting point for the remaining phases of the learning cycle. For example the next step in the cycle, "Multiple Perspectives" allows students to obtain new perspectives on the problem by consulting with experts in various aspects of the challenge. These perspectives could come in the form of guest visitors, movies, audio bits or text articles, and provide insights into how various experts interpret the challenge. By virtue of these new perspectives the students will usually revise their initial thoughts on the problem, and this often results in the need to find still more information. This is known as the "Research and Revise" step in the Legacy Cycle. The previous steps have helped to create this "time for telling". The Research and Revise section contains learning activities designed to help students explore the multiple perspectives on the problem. For example, in the iron cross module, one activity would be to isolate the system of interest (e.g., the hand-forearm-arm combination) and draw a free body diagram of that system. Each activity helps students explore the concepts related to the initial challenge. These activities can be either pre-class or in-class learning activities. When this step is completed the students should have accumulated all of the information they need to solve the problem. For example, they will need to determine physiologic and anthropometric information, such as the muscle groups that must be active, their strengths, and their moment arms relative to the shoulder joint. In addition they will need to identify an appropriate coordinate system, draw a free body diagram and apply the appropriate vector equilibrium equations.

The final two steps in the cycle focus on assessment. "Test Your Mettle" is a formative self-assessment step where students begin to actually work through the problem and discover that perhaps additional information is needed, or that new concepts must be introduced. Students are encouraged to consult with other people and other resources throughout this process, and relevant lecture material is provided, both in the classroom and on the web site. Hence, this step involves all four aspects of the HPL framework. Once they have mastered the material by meeting the challenge, they move to the final step, termed "Go Public". This is their opportunity to show that they understand the principles (summative assessment) by showing that they can solve a different problem that uses the same concepts (for example, solving the inverse iron cross problem).

Another new tool we have introduced into this course which promotes formative assessment is the use of a Personal Response System (PRS)[4]. This system consists of a receiver wired to the instructor's computer and several small wireless remotes with 12 button keypads. Students are assigned an individual PRS at the beginning of class. Students use their PRS device to respond to true/false and multiple choice questions asked in class. Unique signals are sent from each wireless remote to a receiver connected to the instructor's computer located at the front of the room. The students use their PRS to enter up to 10 responses, along with their confidence level (low, medium (default), or high) (see http://www.educom.edu for more details). Once all the responses are received, the computer can display a bar graph illustrating the distribution of responses. After class the remote units are collected and placed in a case, which is stored for the next class.

This system provides the instructor and the students with several major advantages. First, this process encourages students to reflect on the concepts that have just been presented and allows them to think about how they might explain or apply these new ideas. This requires that they become less passive during class and more generative. The second benefit emerges from this generative process. If students find that they can't answer the question, then they can ask the professor clarifying questions, rather than discovering that they don't understand the material while doing homework. A third benefit to the students is the opportunity to see that they are not alone in their misconceptions. A fourth benefit is that the process is anonymous, which should encourage student participation. A fifth benefit, which results from anonymous student participation, is that the professor receives immediate feedback from the entire class showing the level of understanding for the class as a whole on selected concepts. Therefore, through the use of well-designed questions and multiple-choice responses, a professor can diagnose where students may be going astray and modify the instruction appropriately. A sixth benefit is that it gives an instructor entry into students' thinking processes, and this can be used as an instructional tool. For example, the result of a survey of students' responses can be used as a discussion-starter. The professor can ask a student who responded a certain way to explain why they chose their particular response. This allows the professor to probe their reasoning and guide the students toward a more refined understanding of the concepts.

The PRS system can be used to pose appropriate questions during any phase of the Legacy Cycle or other HPL-based instructional system. One of the biggest challenges for the instructor is to phrase the questions and potential answers so they test students' understanding of key concepts in biomechanics and use students' responses to these questions to probe the misconceptions that they have of these concepts. An instructor can then determine how to best adapt instruction, based on the results of students' responses and how to alter the original presentation so that misconceptions are minimized.

Method of Evaluation

The previous discussion articulates our current plans for enhancing the instruction of an introductory course in biomechanics using a challenge-based approach. The effectiveness of this approach will be established by comparing it with a traditional approach to instruction. The evaluation process began during the Fall of 2000. A team of learning scientists observed BME 101 to establish a baseline measure of engineering education. Several different measures are used to describe the educational process and evaluate the effects on students' understanding of the content and their educational experience. First, six lecture periods were selected for observation based on the content being taught and the relationship to test time (that is, not a class just before an exam that might be more of a review session). The goal was to identify lecture periods that represent common practice on a topic that would be taught in most introductory biomechanics classes. One researcher took narrative notes using the How People Learn Framework, describing events in the classroom that provided evidence of one of the four dimensions of the HPL framework. Another researcher used an experimental quantitative method, called the VaNTH Observational System (VOS)[5] to capture the interaction between teachers and students. VOS codes a sequence of events that capture who is talking to whom, what they are talking about (academic knowledge, behavior modification, setup etc) and what technology is being used. This instrument can provide an indication of how much class time is spent on straight knowledge-centered activities (classic transmission model of instruction) and how many events and how much time is spent targeting the other three dimensions of the HPL framework. These observations will provide a description of what is happening in the two classrooms (traditional versus challenge-driven) which will help describe the difference between the two. Comparing students' knowledge across the Fall 2000 and the Spring 2001 semesters will be done using a common set of exam and homework questions. Finally, a student survey will be used to capture students' self reports on multiple dimensions of the learning environment. The survey captures their expectation of what is a good learning environment, attitudes about the instructional methods and the resources used for instruction.

Results & Discussion

We have designed several modules for BME 101, each containing a challenge or series of challenges that provide broad coverage of the taxonomy. The overall taxonomic coverage is similar to coverage obtained with the current taxonomy-driven instruction, but with the advantage of placing this instruction within the HPL framework. To ensure adequate taxonomic coverage, we have compiled a detailed list of over 125 taxonomy-related course objectives and then selected a sufficient number of modules and challenges to meet all of these objectives. Table 1 shows how general topics in an introductory biomechanics course can be adequately covered within the context of 13 modules or mosaics. Our experience in the first year has been that the learning objectives in BME 101 can actually be met by using 9 of the mosaics shown in Table 1. The depth of coverage varies from module to module, but the overall level of exposure for each topic over the course of the semester is designed to be similar to the level obtained in the traditional instructional mode at Vanderbilt. We expect the coverage to be similar for introductory biomechanics courses at other institutions.

The modules are designed for use on campus, where students meet periodically in the classroom. Several short, taxonomy-based, online lectures have been completed and more are under development. Students are asked to view these Powerpoint-based lectures as part of their pre-class preparation or as a post-class homework assignment. The modules can be used with only slight modification in an asynchronous learning environment. The granules that are based on in-class interactive activities would need to be replaced with personal or web-based activities.

Each of the modules listed in Table 1 consists of a set of challenges that can be represented using the Legacy Cycle or another HPL system. For example, the "Keeping your Balance" module has the following set of challenges:

1) A man stands with his toes facing at the edge of dock and leans over the edge to grab a buoy. Without bending his legs, how far can he reach without losing his balance and falling into the water? How might the man regain his balance once he begins to tip?

> As part of this challenge, students must gather additional information. Students break into groups and discuss what information is needed before they can solve the problem. How long are his shoes? How tall is the man? How much does he weigh? Where is his center of gravity (cog)? Group responses are listed on the board and discussed. Additional questions arise. What happens when you lose your balance? How do you find the cog of the body as the center of gravity of the torso is altered? This leads to a short lecture on the determination of the cog of the body when the centers of gravity of its component parts are known. A more comprehensive lecture is placed on the course web site and assigned for homework. The students then use these principles to find the center of gravity for similar problems. They learn how to use anthropometric tables to find the location of the cog of each body segment. Now that they know how to find the cog, they

return to the original problem. New questions arise. How do you construct a free body diagram of the man? How many independent equilibrium equations are applicable? Which point is the best for applying the moment equation? Can the ground grab onto the sole of the shoe or is the ground reaction force required to be collinear with the man's weight? Once the students have considered these questions they will recognize the spatial constraints for application of the ground reaction force. If the cog lies beyond the base of support, then the man will lose his balance. When this occurs, what can be done to regain balance and how does the body do this? (Variations of this can be given as homework problems, such as a woman on crutches, a child standing on one foot, a man using a cane, etc.).

2) A horizontal force is applied in the mediolateral direction to the right shoulder of a man as he stands with both feet on the floor. As the force is increased, will the man begin to tip over or will he slide along the floor? What can the man do to reduce his tendency to tip?

As above, the students will begin by being asked what they need to know before trying to solve the problem. In addition to the information required above, the students must know how far apart the feet are placed, know the location of the torso cog, understand the term "mediolateral", find the position of the applied force using anthropometric tables, identify the material composition of the floor and bottom of the shoes, estimate the coefficient of static friction, determine the friction force, and compare it with the maximum friction force that can be applied before slippage. They must also be able to compute the force required to tip the individual and compare this with the force needed to cause the man to slide. In the process of solving this problem, students should discover that, in contrast to the previous challenge, the man can remain balanced in this case even though his cog may fall outside of the ground reaction base of support. Through examination of the parameters of this problem, students will come to understand that a greater force can be resisted by the man if he lowers his shoulder, leans into the applied force, spreads his feet farther apart, or adds weights to his body. Students also examine the case when the external force is in the form of tension applied by a rope attached to the hand. (Variations that can be assigned for homework might be to tilt the floor, tug-of-war contest, spread the legs apart or change the orientation of the force applied at the shoulder).

3) Estimate the muscle forces needed at the hip so a woman, standing on one leg, can keep her balance as she moves her torso in the anteroposterior or mediolateral directions.

Students must be able to apply the Method of Sections to an imaginary slice made through the hip joint, understand basic joint anatomy, and familiarize themselves with abductor, adductor, flexor and extensor muscles. They will encounter a statically indeterminate force system and will need to make assumptions about which muscles are active, find the resultant muscle force and line of action, find moment arms from standard anthropometry tables, and apply equilibrium equations. (Variations might be to estimate forces at the knee or ankle, or to allow torso motion to be in both mediolateral and anterioposterior directions).

Table 1. Module Coverage of Course Topics

	Modules													
Taxonomy/Topics	Intro to BME 101, HPL	Mechanics Review	Intro to Biomechanics	Forces in Biomechanics	Modeling Biological Systems and Materials	Keeping your Balance	Muscle Strength: Iron Cross	Jumping	Impact and Injury	Locomotion, Propulsion & Fitness	Cellular Mechanics	Performance of Implant Systems	Design of a Baby Jumper	Cardiovascular Mechanics
Fundamentals														
Fundamental Laws of Mechanics		X	X								X		X	X
Dimensions, Units, Conversions		X	X		X						X		X	X
Anthropometry			X	X	X	X	X	X					X	X
Musculoskeletal System			X	X	X	X	X	X	X	X			X	
Vector Operations		X	X	X		X	X				X		X	X
Forces, Moments & Couples		X	X	X	X	X	X			X	X	X	X	
Resultant Force Systems				X	X	X	X	X	X		X	X	X	X
Equivalent Force Systems				X	X								X	
Center of Gravity, Distributed Loads					X	X	X	X				X	X	
Statics														
Equilibrium		X	X	X	X	X	X		X		X	X	X	X
Free Body Diagrams			X	X	X	X	X	X	X	X	X	X	X	X
Constraints, Supports & Reactions			X	X	X	X	X	X	X	X	X	X	X	X
Statically Indeterminate Systems					X	X	X							X
Machines, Lever Systems			X	X	X		X							
Method of Sections			X	X	X	X	X	X	X	X	X	X	X	X
Muscle and Joint Reaction Forces			X	X		X	X	X		X			X	
Dynamics														
Impulse-momentum principle		X	X			X	X	X	X	X		X	X	X
Conservation of momentum			X					X		X			X	X
Linear Kinetics		X	X	X				X		X	X		X	
Angular Kinetics, Limb Rotation			X			X	X	X	X	X		X	X	X
Mass Moment of Inertia, Radius of Gyration			X		X	X	X	X		X				
Kinematics & Kinetics of Linkage Systems		X			X	X	X	X		X				X
Strength of Materials														
Stress & Strain			X	X	X		X	X	X	X	X	X	X	X
Stress Transformation, Principal Stress				X	X	X			X			X	X	X
Properties of Biological Materials, Failure		X	X	X	X	X	X		X	X	X	X	X	X
Models of Material Behavior, Hooke's Law		X	X	X	X	X	X	X	X	X	X	X	X	X
Stress Concentration				X					X			X	X	
Axial Loading		X	X	X	X		X		X	X		X	X	X
Bending, Bending Stresses					X				X			X	X	X
Torsion, Combined Loading			X	X	X				X			X		

4) A figure skater is observed to lean toward the center of rotation while skating in a circle so her center of gravity lies beyond her base of support. Why doesn't she fall over? How far can she lean over?

> Students must realize that equilibrium equations no longer apply in this case, even when the skater's angular acceleration is zero. They are assisted as they work through the vector

> equations for motion of a particle and for a rigid body rotating about an axis. They discover that although the sum of moments about the cog is zero, the sum of moments about the skate blade is not zero in this case. The mass moment of inertia is introduced and discussed in greater detail in a supplemental online lecture. An additional online lecture presents the theory for a rigid body rotating about a fixed point. Students will be asked to use results from this presentation to show how far the skater can lean as her angular velocity is increased. This will provide a rationale for introducing banked turns to students and asking them to design a banked turn for various types of races.

5) A woman is pushed at the left shoulder for a known time interval. How large of a force can she withstand before she begins to tip? How fast will her right shoulder be moving when it hits the ground and what is the likelihood that she will be injured?

> This challenge can be used as a lead-in to the Impact and Injury module, or can be transferred to that module. The impulse-momentum principle is introduced and students use this to compute angular acceleration of the body about the foot as a function of the force at the shoulder. Students will learn how to find the appropriate radius of gyration and compute the mass moment of inertia. They will need to identify the minimum push necessary to bring the center of gravity beyond the base of support, and compute the angular velocity of the body as it hits the floor. Experimental data will be introduced so students can estimate the time it takes for the shoulder to come to rest. The impulse-momentum principle can be used again to estimate the impact force, stresses can be estimated, and models of failure applied.

All of the challenges presented above are directly related to the module theme of maintaining one's balance. However, each challenge emphasizes different parts of the taxonomy. Although these challenges may be found in a standard biomechanics textbook, it is unlikely that they would be found in the same chapter or even the same section of the book. The challenges are certainly not unique. Many other challenges could be developed for this module that cover the same set or a similar set of topics. Additional challenges can be added to the module to provide either less quantitative (K-12) or more in-depth (graduate level) coverage of the taxonomy. The objective is to use the module theme to teach students a broad spectrum of the biomechanics taxonomy.

After using the Personal Response System in class for eight weeks, the preliminary results appear to be very promising. Its greatest strength is that students can respond anonymously. Use of the PRS system ensures that virtually 100% of the students respond to a question asked in class. This is in contrast to under 50% participation when a show of hands is requested. The direction the class takes is often dictated by the response to a PRS question. When the response shows a clear understanding of the material, we move on to the next topic. However, if a substantial number of students choose one of the incorrect answers (chosen on the basis of misconceptions demonstrated by students in the past), then additional time is spent on the current topic. In this case, the PRS question will sometimes be repeated before moving on to the next topic. In other cases the PRS system has been used to ascertain the students' knowledge about a topic before it is introduced, and the same questioned asked at the end of a challenge. The PRS system has great potential for use as a formative assessment tool.

The motivation for using challenge-driven instruction is to encourage students to think through engineering problems before trying to solve them. Instead of assigning students problems that are strictly based on the latest taxonomy-driven lecture, we provide real life challenges that put students in the position where they need to sort out for themselves what parts of the taxonomy are relevant to the problem at hand. Students may find this approach more demanding at first, but we believe that this will better prepare them for the workplace and for life-long learning.

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