Design, Implementation, and Assessment of an HPL-inspired Undergraduate Course on Biomechanics

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Introduction

New developments in learning theory suggest that instructors can improve student understanding by changing their teaching practices. Innovations in instructional design such as problem-based, case-based, and project-based learning have been designed to combat students' inability to apply learning to relevant situations. Instead of assigning fact-based readings or providing lectures, students begin their inquiry with challenging problems and learn relevant information as the need arises. Much of the research and educational activities on-going in the VaNTH ERC (Vanderbilt-Northwestern-Texas-Harvard-MIT Engineering Research Center) is based on this challenge-based approach, which we refer to here as the How People Learn (HPL) model. There are currently four major domains under development in VaNTH, biomechanics being one of these.

An overall goal of the VaNTH ERC is to assemble new materials to recommend for undergraduate curricula in biomedical engineering. Thus, a major focus of our current activities in the biomechanics domain is the design, implementation, and assessment of a new undergraduate course on biomechanics of human movement. This new course, which is currently offered as an elective in the Department of Biomedical Engineering at The University of Texas at Austin, is based entirely on the HPL model and draws on all the latest learning materials developed within the biomechanics domain. The course is centered on three challenge-based modules, each targeted to freshman- and sophomore-level engineering students. The overall goals of the course are to (a) teach students about the relationships between musculoskeletal structure and function in the context of human movement; (b) provide real-life examples of biomechanical situations which are familiar, relevant, interesting, and engaging; and (c) teach students to think abstractly about complex problems which lie at the intersection of engineering, medicine, and biology. To achieve these goals, we developed five criteria on which to base our instruction: first, students should be encouraged to develop their own thoughts and ideas about complex problems; second, students should be given a compass for their own learning by making the learning outcomes explicit at the very beginning of the course; third, students should be encouraged to work in groups so that they may explore the different facets of a problem together; fourth, students should be given opportunities to test their own hypotheses using hands-on experiments and interactive computer simulations; and fifth, we, as instructors, should provide a well-defined structure for our students' learning activities. Each of these requirements are met by implementing the HPL model.

Below, we first describe the main elements of the HPL model and the delivery of our learning materials via a flexibly adaptive instructional design called STAR-Legacy. Next, we give an overview of the various modules used in the new undergraduate course on biomechanics. We then describe the experimental design on which the assessment and evaluation of the course is based, and finally present some results obtained from our classroom assessment studies.

The How People Learn (HPL) Model

There is some evidence to suggest that learning with understanding is enhanced when instruction is designed with four types of learning environments in mind[1]: (1) learner-centered environments focus on the knowledge, skills, and attitudes that students bring to the learning situation; (2) knowledge-centered environments focus on content that is organized around big ideas or core concepts; (3) assessment-centered environments help students' thinking to become more visible so that both they and their teachers may assess and revise their understanding; (4) community-centered environments capitalize on local expertise to create a sense of collaboration among students. When these four environments are combined with flexibly adaptive instructional design (e.g., STAR-Legacy), research has shown that students' ability to learn with understanding is increased, at least at the K-12 educational levels[2]. One hypothesis currently being in VaNTH is that the HPL model also enhances students' ability to learn with understanding at the college level. In offering a new course on undergraduate biomechanics based entirely on the HPL model, we are interested specifically in quantifying whether this approach accelerates the development of expertise in biomechanics among college engineering undergraduate students.

STAR-Legacy is a software shell used to develop and deliver instructional materials consistent with the HPL model. It promotes flexibly adaptive instructional design in two main ways. First, the HPL approach helps teachers adapt complex curricula by including a model of inquiry that draws attention to each of the learning environments within a Legacy cycle. The Legacy Cycle, in turn, provides a framework for making pedagogically sound decisions. Second, STAR-Legacy supports flexibility by including a suite of software tools which are simple and easy to use. At the moment there is not a substantive literature on the use of these complex instructional approaches at the college level. Thus, in teaching this new HPL-based course on biomechanics, we are also interested in incorporating project-based instructional approaches that utilize modern learning theory in a university setting.

The Legacy Cycle uses challenges as anchors for learning. The challenges are designed to create an increasing depth of knowledge in a specific subject, with each challenge presented as one cycle of the Legacy shell. The combination of well-designed challenges and meaningful learning activities provides a rich environment for both the students and the instructor. The six steps constituting each cycle of Legacy are (see Figure 1): (1) *Look Ahead and Reflect Back*, which allows students to see where they are going and to reflect back on where they have been; for example, students are able to see how the concepts underlying any given challenge map into the taxonomy of knowledge for solid biomechanics; (2) *Generate Ideas* allows students to explore, within a group setting, their initial thoughts and ideas about the challenge at hand; (3)

Multiple Perspectives gives students the opportunity to listen to experts in the field describe their own hypotheses and ideas about the same problem; (4) *Research and Revise* allows students to test their own hypotheses concerning a challenge; for example, through advanced computer-based simulations, students are able to vary parameters of a model and study the effects that these changes have on model performance; (5) *Test Your Mettle* provides a means of formative assessment, allowing students to reflect on what they have learned thus far, and to identify any weaknesses or misconceptions they still may have; and (6) *Go Public* encourages students to share their thoughts and ideas with their peers and provides a summative assessment.

HPL-inspired Course on Movement Biomechanics

The senior author has previously developed and taught an undergraduate biomedical engineering course titled “BME 342: Computational Biomechanics”. This course was designed to teach students about the relationships between musculoskeletal structure and function in the context of human movement, and to expose them to the use of computational modeling in movement biomechanics. Topics covered over the course of a semester included the relationships between muscle force, length, velocity, and activation; the interaction between muscle lever arms and muscle moments; angular velocity and instant centers of joint rotation; and muscle, ligament, and joint function in multi-joint movement. We have now re-designed this course in order that it may be taught in an entirely new format, based on the HPL model. There are perhaps two aspects of the course which are most significant. First, it brings together all of the most significant learning materials under development in VaNTH’s biomechanics domain. Second, we are conducting a classroom evaluation using an assessment instrument based on three different facets of adaptive expertise: factual knowledge, conceptual understanding, and transfer.

The new course is centered around four modules and one granule, altogether accounting for 12 weeks of instruction (see Figure 2). Modules are challenge-based; granules are not. Each module has multiple challenges, with some having as many as four. Each challenge is delivered as one cycle of Legacy, with subsequent challenges designed to probe students’ understanding of underlying concepts more deeply. For each challenge, students begin their cycle of inquiry by generating their own ideas. They then receive feedback from experts in the field, which helps them to explore the many dimensions of the challenge from multiple vantage points. We use these multiple perspectives not only to guide students’ thinking about a specific problem, but more importantly to draw boundaries around the problem so that they don’t feel overwhelmed by the complexity. For example, in the Research and Revise portion of a challenge, students’ are often presented with abstract models which they use to test their own hypotheses as well as the hypotheses of experts’ they have heard from previously (in Multiple Perspectives).

By way of introduction to the course, students are first asked to complete a set of interactive computer-based exercises called the Free-Body Diagram (FBD) Assistant. The FBD Assistant is designed as an asynchronous web-based tool and teaches students how to construct free-body diagrams by looking at specific examples in biomechanics such as muscle forces acting about a joint. After selecting a system to be analyzed, the student begins by clicking on locations at which muscle, external, and joint-reaction forces are applied to a body segment. The student then decides on how the various forces ought to be oriented according to anatomical and mechanical considerations. The student's solution is checked against the correct answer and, if there is disagreement, feedback is provided in the form of appropriate explanations. The FBD Assistant is completed within the first week of the course (two lecture periods plus time spent outside class writing up their answers more formally in a report).

Students then encounter their first challenge-based module, the *Virtual Biomechanics Laboratory*, which emphasizes experimental methods in human movement biomechanics. The learning outcomes associated with this module are (a) to be able to combine kinematic data with anthropometric tables in order to calculate the position of the whole body center of mass during human gait; (b) to be able to describe how individual joint movements contribute to sagittal-plane movements of the center of mass and the head during gait; and (c) to be able to describe methods commonly used to record kinematic data in a gait laboratory. There are two challenges, with one week of classroom instruction allocated to each challenge (2 lecture periods plus time spent outside class); thus, the VBL module accounts for two weeks of the entire course syllabus. Challenge 1 is "How does the center of mass of your body move when you walk?", while Challenge 2 is "What pattern of force do you exert on the ground when you walk?". Each challenge focuses on a specific method used to measure biomechanical performance of walking; specifically, high-speed video systems used to record body motions in 3D; and force plates used measure the position and orientation of the forces exerted by the ground on the feet.

Next, students encounter a module focused on understanding muscle function during movement. The overall goal of Jumping Jack is to introduce concepts in mechanics and physiology as they relate to human performance. The learning outcomes include (a) to be able to define and calculate the velocity and acceleration of a point on a body segment; (b) to be able to apply the Impulse-Momentum principle of mechanics to calculate jump height; and (c) to be able to describe and explain the dependence of muscle force on length, contraction velocity, and activation level. The module is based on three challenges, each leading to an increasingly deeper inquiry of jumping biomechanics: (1) How high can you jump?, (2) What factors determine jump height in humans?, and (3) Why is Michael Jordan a good jumper? Multiple perspectives consists of videotapes and web-delivered interviews of experts describing their hypotheses and explanations related to human jumping performance. In Research and Revise, students are asked to read various textbook and journal articles on how jump height is measured, how factors such as muscle strength, quickness, and coordination can affect jumping ability, and how mathematical (computer) models may be used to study vertical jumping performance in people. Finally, in Test Your Mettle, students complete formative assessment exercises aimed at testing their understanding of how mechanical and physiological properties of the musculoskeletal system interact to determine overall jumping performance. Five weeks are allocated to all 3 challenges, with Challenge 1 occupying 1 week and Challenges 2 and 3, two weeks each.

The Iron Cross module focuses on the relationships between muscle forces, muscle lever arms, and joint moments during human activity. Specific learning outcomes include (a) to be able to define and calculate a muscle lever arm; (b) to be able to explain the relationship between a muscle lever arm and a joint moment; (c) to be able to formulate and solve static equilibrium problems in biomechanics; and (d) to be able to describe and explain the musculoskeletal anatomy of the shoulder joint. The grand challenge is "How much muscle force is required to hold the iron cross position in gymnastics". A computer model of the arm is used to calculate muscle and joint reaction forces associated with the iron cross. Students are required to construct appropriate free-body diagrams of the iron cross position and to perform analyses of static equilibrium in order to calculate the forces applied by the muscles crossing the shoulder. A particularly interesting aspect of the module is the transfer question posed at the end. Here, students are asked to analyse the inverted iron cross position in which the legs point upward rather than downward. This is a good example of testing a student's ability to transfer, because this new exercise requires the use of a completely different set of muscle groups (which are most likely unfamiliar to most students), yet the problem is presented in the familiar context of the iron cross. Two weeks of classroom instruction are allocated for completion of this module.

Finally, the Joint Biomechanics module introduces various kinematical principles related to joint movement, such as instant centers of joint rotation and sliding versus rolling at human diarthrodial joints. The human knee joint is used to illustrate these various concepts. Thus far, only one challenge has been designed: "Can a voluntary contraction of the leg muscles rupture the anterior cruciate ligament?" The learning outcomes for this challenge are (a) to be able to define and calculate an instant center of joint rotation; (b) to be able to calculate the angular velocity of a body; and (c) to be able to formulate and solve static equilibrium problems related to the mechanical state of a human articulating joint. The challenge has been designed to occupy two weeks of classroom instruction.

Assessment and Evaluation

In part, the new HPL-based undergraduate course on biomechanics was motivated by our previous experiences with the design, delivery, and assessment of the Jumping Jack module. In Fall 2001, we performed a comprehensive assessment of the first challenge of the jumping module using students in a senior-level undergraduate biomechanics course taught in the Mechanical Engineering Department at The University of Texas. This study occupied just one week of course instruction. The assessment was based on a Two Group Design[3], in which the class was randomly divided into two groups, a control group and an experimental (HPL) group. The control group received traditional instruction comprised of lectures and example problems solved in class. The HPL group received the innovation, specifically Challenge 1 of Jumping Jack. Pre-test and post-test questions were designed to measure changes in conceptual understanding (i.e., how well students grasped the underlying principles of the material being taught) as well as transfer (i.e., how well students were able to extend their knowledge to novel situations). Analyses of these results showed some differences between the HPL and control groups; most importantly, that the HPL group scored significantly better on the questions designed to test transfer.

In Spring 2002, we performed a follow-up assessment that involved the first two challenges of the jumping module. This study occupied two weeks of course instruction and was conducted in an undergraduate class titled "BME 342: Computational Biomechanics" taught by in the Department of Biomedical Engineering at UT Austin. Once again, a Two Group Design[3] was used, with the class divided randomly into an experimental (HPL) group and a control group. Pre-test and post-test questions were designed to measure changes in factual knowledge, conceptual understanding, and transfer. Results obtained from this study also showed a significant increase in students' ability to transfer post-HPL.

While the aforementioned studies revealed some interesting findings, they were limited in two respects. First, it is difficult to draw any compelling conclusions based on interventions that involve only one or two challenges from a single module. Second, it is difficult to say anything meaningful about how the HPL model affects the development of cognitive skills when the interventions span just 1-2 weeks of classroom instruction. Thus, the new undergraduate course on biomechanics was developed to enable a more rigorous evaluation of the HPL model in relation to bioengineering engineering education.

Assessment materials for the course were designed to test the general hypothesis that "the HPL approach accelerates the novice's ability to develop expertise in biomechanics of human movement". In particular, we formulated a metric to evaluate the development of expertise in biomechanics over the course of a full semester (12 weeks of instruction). This metric is rooted in three different facets of adaptive expertise: (1) *factual knowledge*, which measures students' knowledge of biomechanics and tests their quantitative skills (i.e., their ability to arrive at the correct numerical answer); (2) *conceptual understanding*, which tests the learner's grasp of the underlying core principles; and (3) *transfer*, which measures the learner's ability to extend his or her knowledge to new contexts. Development of adaptive expertise in biomechanics of human movement is quantified by means of the following equation:

$$Biomechanics\ Expertise = w_1 F + w_2 C + w_3 A, \qquad (1)$$

where $F = Factual\ knowledge$, $C = Conceptual\ \ understanding$, $A = Adaptive\ expertise$, and $w_1,\ w_2,\ w_3$ are weighting factors (constants). Selecting the values of the weighting factors is somewhat arbitrary. As a first pass, we propose that factual knowledge should be roughly half as important as either conceptual understanding or adaptive expertise, in which case: $w_1 = 0.2;\ w_2 = 0.4;\ w_3 = 0.4$.

Our current plan is to conduct the assessment and evaluation using a Two Group Design[3]. The control group will comprise students in the undergraduate biomechanics course offered in the Department of Mechanical Engineering at UT Austin; the experimental (HPL) group will comprise students in the new undergraduate biomechanics course taught in the Biomedical Engineering Department. Changes in factual knowledge, conceptual understanding, and transfer are measured using Pre-test and Post-test questions given to both groups over the course of a semester. The assessment materials are designed to tease out student performance in each of the three facets of adaptive expertise represented in our metric defined by equation (1). This metric will be used to compute development of adaptive expertise in biomechanics of human movement for the HPL and control groups.

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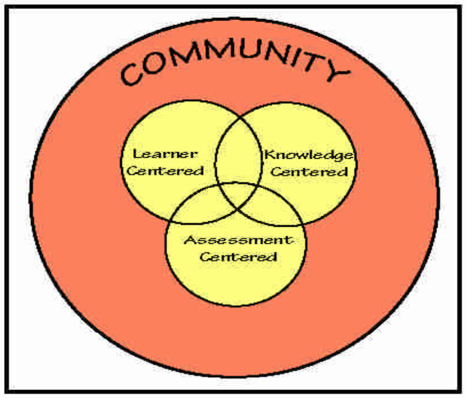

Figure 1: How People Learn (HPL) framework for integrating four types of learning environments: learner, knowledge, assessment, and community centeredness (From Bransford et al., 1999).

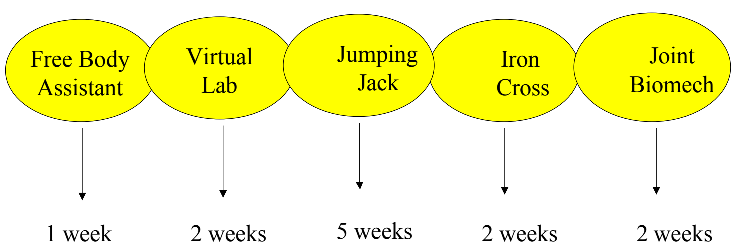

Figure 2: Electronic learning modules used in the new HPL-based course on biomechanics. The number of weeks of instruction is indicated below each module. See text for details.