PHYSICS AND BIOMECHANICS EDUCATION RESEARCH: IMPROVING LEARNING OF BIOMECHANICAL CONCEPTS

Duane Knudson

Texas State University, San Marcos, TX, USA

Many students find mechanical concepts counterintuitive, difficult, and often have a negative perception of physics and biomechanics classes. This paper reviews the research on learning mechanical concepts from the physics and biomechanics literature. Substantial progress has been made in standardized tests of biomechanical concepts and identifying factors that are associated with learning these concepts. Active learning pedagogies double learning of physics and biomechanics concepts compared to traditional lecture/lab instruction. Biomechanics instructors should consider using research-based instructional strategies, participate in and support the scholarship of teaching and learning of biomechanical concepts.

KEY WORDS: Instruction, mechanics, pedagogy, teaching.

Teaching introductory biomechanics is a challenging task. Many exercise science/kinesiology majors have negative perceptions about physics and the introductory biomechanics course, often avoiding them for as long as possible. Teaching biomechanics is also challenging because two difficult bodies of knowledge must be integrated: the complexity of human anatomy and counter intuitive nature of Newtonian mechanics.

Biomechanics faculty in North America have noticed these problems and tried to address them by organizing six teaching conferences to discuss these issues since 1977. Knudson (2010) reviewed the research on teaching and learning biomechanics published in the first five conference proceedings and peer-reviewed journals. This paper extends this review of biomechanics and physics education research on learning mechanical concepts. The review is organized around the increased interest in the scholarship of teaching and learning in higher education, physics education research, research on learning biomechanical concepts, and the application of this research to improve learning of biomechanical concepts.

INTEREST IN SCHOLARSHIP OF TEACHING AND LEARNING (STL): Considerable interest has developed in studying the pedagogy and learning of knowledge from numerous academic disciplines since Boyer (1990) called for greater acceptance of STL in higher education. STL is usually considered systematic scholarship that presents data on student learning that is ultimately peer-reviewed and presented to an external audience. There are now over 400 journals devoted to STL in various disciplines. While there is general interest in pedagogical research in most disciplines, there is great interest specifically in learning science concepts and scientific thinking. It is widely believed in North America that there is a need for improved instruction in science/engineering/technology/math (STEM).

PHYSICS EDUCATION RESEARCH: Fortunately for biomechanics faculty, the parent discipline of physics has a long history of STL, particularly in the area of Newtonian mechanics. Several standardized tests of physics concepts have been developed. The most famous may be the Force Concept Inventory which measures mastery of concepts of force and Newton’s Laws of Motion (Hestenes et al. 1992). Typical students in introductory physics have difficulty learning these concepts with normalized learning scores (g) of 20% (Haake, 1998). These difficulties persist despite students solving numerous external quantitative problems (Kim and Pak, 2002) or observing demonstrations (Crouch et al. 2004).

Much of these difficulties results from interference from incorrect and persistent, preconceptions of the causes of motion (Halloun and Hestenes, 1985; McDermott, 1991). Considerable research has explored conceptual change of beliefs about the causes of motion and noted that new conceptual models are unstable and context dependent (Elby, 2001), as well as several strategies that can be used to help students with the difficulty and discomfort in transitioning to new conceptual understandings (Duit and Teagust, 2003). One effective pedagogy has been active learning or interactive engagement. Numerous physics education research studies have reported that active learning effectively doubles the learning of mechanical concepts (Hake, 1998), and these improvements in learning can be implemented in large classes with minor changes in facilities and faculty training (Beichner et al. 2007). Good reviews of these active learning strategies in physics have been published (Hake, 1998; Henderson and Dancy, 2009; Redish and Steinberg 1999). My co-presenters in this applied session will go into detail on how active learning pedagogies can be effective in helping students learn new and difficult biomechanical concepts.

RESEARCH ON LEARNING BIOMECHANICAL CONCEPTS: While biomechanics faculty had organized two teaching conferences, it was not until the 3rd national conference in 1991 that actual data on student learning biomechanical concepts (STL) was presented (Knudson, Morrison, and Reeve, 1991). Over the first five teaching conferences STL on biomechanical concepts represented a small minority (0-18%) of papers published in the conference proceedings (Knudson, 2010). The majority of the education papers published in the teaching conference proceedings and journals since 1980 tended to report course concepts, activities, or technologies without explicit data on learning (Knudson, 2010).

There have been some studies of learning in biomechanics and over the years four benchmarks have emerged for documenting learning biomechanics concepts: instructor tests based on their own (Dixon, 200) or NASPE (2003) standards (e.g. Bird et al. 1997); the Force Concept Inventory (e.g. Coleman, 2001), and the Biomechanics Concept Inventory (Knudson 2004, 2006; Knudson et al. 2003).

Bird et al. (1997) reported that a typical biomechanics course could improve mastery of the NASPE standards from 18 to 74%. Similarly, Coleman (2001) reported the introductory biomechanics course at the University of Edinburgh improved mastery of Newton's Laws of motion from about 30% to 70% using the Force Concept Inventory. Several studies using the Biomechanics Concept Inventory (BCI) have reported results consistent with physics education research. Traditional introductory biomechanics course instruction results in improvement from pre to post-test of 25 and 40%, which is equivalent a g score of 20% (Knudson 2004, 2006; Knudson et al. 2003). This is far short of maximum possible improvement or mastery of the national course objectives desired by most faculty for their students.

Several descriptive studies have used the BCI to identify variables that are associated learning biomechanical concepts. Typical course and instructor variables commonly assumed to be good instructional practice, account for much smaller variance (2-5%) in learning (Knudson et al. 2009) than student characteristics and behaviors (14 – 40%) do (Hsieh and Knudson, 2008; Hsieh et al. 2010). Consistent with physics research, the student characteristics that were significantly related to learning biomechanics concepts were grade point average, and student's perception of career relevance, and their interest in the subject (Hsieh and Knudson, 2008; Hsieh et al. 2010). One important observation was that increasing course credit hours from 3 to 4, essentially a 66% increase in contact hours because of a required laboratory more than doubled learning (Knudson et al. 2009). The universities with labs in this study used conceptually-focused, active learning experiences emphasizing what students could see, feel, and think about course concepts over calculations and word problems. Figure 1 illustrates this and typical learning scores from traditional and active learning instruction in introductory physics.

Knudson et al. (2009) also reported a weak inverse association ($r = -0.18$) between average spending on labs and learning. This small effect was interpreted as a possible distraction effect of technology that has also been reported in hypermedia and visualization research (Chandler, 2009). Published research reports on teaching biomechanics with computer simulation instructional technology mirror these results with learning about equal to traditional instruction (Duncan and Lyons, 2008; McPherson and Guthrie, 1991; Pandy et al. 2004; Roselli and Brophy, 2006; Washington et al. 1999). Students tend to interact superficially with interactive physics simulations, unless specifically trained to use these new learning tools (Yeo et al. 2004). These effects could explain why dramatic improvements in software and computing power, as well as numerous papers proposing interactive, multimedia and computer instructional programs (e.g. Carlton et al. 1999; Chow et al. 2000; Kirtley and Smith, 2001; Nicol and Liebscher, 1983) that have not been tested with pedagogical research or adopted based on anecdotal evidence of improved learning. It is likely that computers and multimedia provide no unique pedagogical advantage to the hard cognitive work of engagement with new, counterintuitive mechanical concepts over other pedagogies for most students.

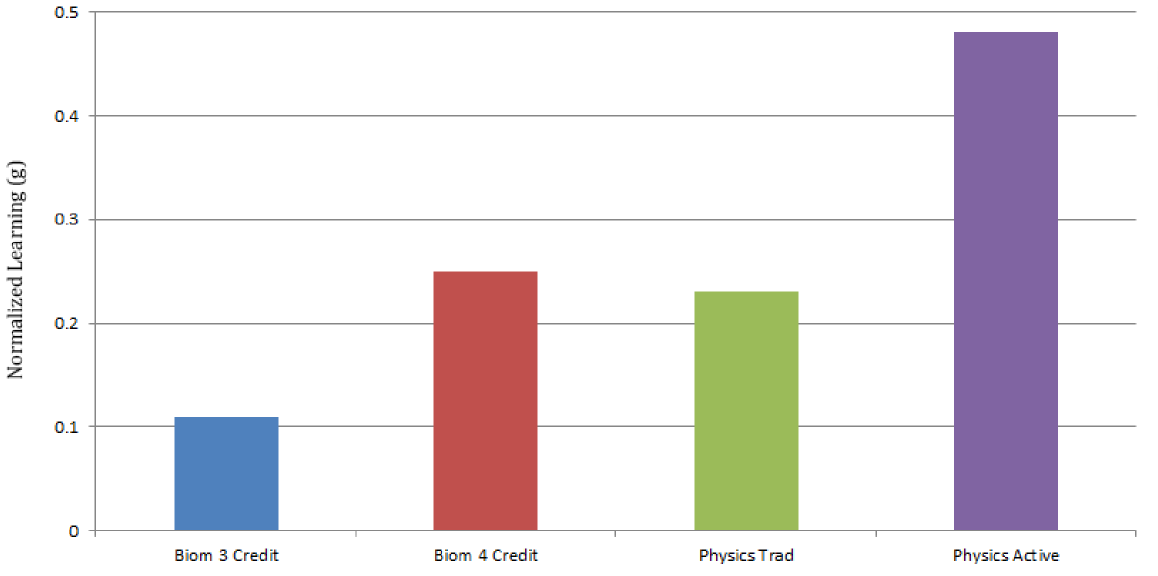

Figure 1. Mean learning in introductory biomechanics courses with 3 credit hours and 4 credit hours (required laboratory) measured with the BCI (Knudson et al. 2009) and mechanics in university physics measured with the force concept inventory (Hake, 1998).

APPLICATION AND SUMMARY:

STL in physics and biomechanics confirm that learning mechanical concepts is difficult for most students. Helping student change these incorrect conceptions about motion is difficult and not easily resolved by quantification and interactive multimedia technology. Considerable research in these areas supports the following recommendations for improving learning in introductory biomechanics classes. Instructors should learn about active learning strategies, like breaking up lectures with several questions and active learning activities. Second, listen and attend to student interest and experience in learning and career aspirations. Third, design active, often qualitative laboratory experiences that align with student interest and professional applications. Fourth, faculty should support the STL in biomechanics to improve instruction and recruit future scholars/teachers to the field. Future research should focus on measures of student learning of biomechanics concepts and prospectively explore active learning strategies that have been shown to be more effective in learning mechanical concepts than traditional instruction.

REFERENCES:

Beichner, R.J., Saul, J.M., Abbott, D.S. et al., (2007). The student-centered activities for large enrollment programs (SCALE-UP) project. *Reviews in Physics Education Research*, 1, Available: http://www.per-central.org/document/ServiceFile.cfm?ID=4517

Bird, M., Balas, C., & Lantz, C. (1997). Using pre-post assessment in biomechanics courses. In J. Wilkerson, K. Ludwig, & M. Butcher (Eds.), *Proceedings of the fourth national symposium on teaching biomechanics* (pp. 145-153). Denton, TX: Texas Woman's University.

Boyer, E.L. (1990). *Scholarship reconsidered: priorities of the professoriate*. Princeton, NJ: Carnegie Foundation for the Advancement of Teaching.

Chandler, P. (2009). Dynamic visualizations and hypermedia: beyond the "wow" factor. *Computers in Human Behavior*, 25, 389-392.

Carlton, L.G., Chow, J.W., Ekkekakis, P., Shim, J., Ichiyama, R., & Carlton, M.J. (1999). A web-based digitized video image system for the study of locomotion. *Behavior Research Methods, Instruments, & Computers*, 31, 57-62.

Coleman, S.G.S. (2001). Misunderstanding of Newtonian mechanics—a problem for biomechanics teaching? In J. Blackwell & D. Knudson, D. (Eds.), *Proceedings: fifth national symposium on teaching biomechanics in sports* (pp. 49-52). San Francisco: University of San Francisco.

Chow, J.W., Carlton, L.G., Ekkekakis, P., & Hay, J.G. (2000). A web-based video digitizing system for the study of projectile motion. *Physics Teacher*, 38, 37-40.

Crouch, C.H., Fagen, A.P., Callan, J.P., & Mazur, E. (2004). Classroom demonstrations: learning tools or entertainment? *American Journal of Physics*, 72, 835-838.

Dixon, S.J. (2005). Diagnostic assessment of preparedness of level one sports science students for biomechanics modules. *International Journal of Mathematical Education in Science and Technology*, 36, 49-63.

Duit, R., & Treagust, D.F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25, 671-688.

Duncan, M.J., & Lyons, M. (2008). Using enquiry based learning in sports and exercise sciences: a case study from exercise biomechanics. *Practice and Evidence of Scholarship of Teaching and Learning in Higher Education*, 3, 43-56.

Elby, A. (2001). Helping physics students learn how to learn. *American Journal of Physics*, 69, S54-S65.

Garceau, L.R., Ebben, W.M., & Knudson, D. (2012). Teaching practices of the undergraduate introductory biomechanics faculty: A North American survey. *Sports Biomechanics*, 11, 542-558.

Garceau, L., Knudson, D., & Ebben, W. (2011). Fourth North American survey of undergraduate biomechanics instruction in kinesiology/exercise science. In J.P. Villas-Boras, L. Machado, W. Kim, & A.P. Veloso (Eds.) *Biomechanics in Sports 29*, *Portuguese Journal of Sport Science*, 11(Suppl. 2), 951-954.

Halloun, I.A., & Henestes, D. (1985). The initial state of college physics students. *American Journal of Physics*, 53, 1043-1055.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: a six thousand student survey of mechanics test data for introductory physics. *American Journal of Physics*, 66, 64-74.

Henderson, C. & Dancy, M.H. (2009). Impact of physics education research on the teaching of introductory quantitative physics in the United States. *Physical Review Special Topics – Physics Education Research*, 5, 020109. DOI: 10.1103/PhysRevSTPER.5.020107

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *Physics Teacher*, 30, 141-158.

Hsieh, C., & Knudson, D. (2008). Student factors related to learning in biomechanics. *Sports Biomechanics*, 7(3), 398-402.

Hsieh, C., Smith, J.D., Bohne, M., & Knudson, D. (2012). Factors related to students' learning of biomechanical concepts. *Journal of College Science Teaching*, 41(4), 83-89.

Kim, E., & Pack, S. (2002). Students to not overcome conceptual difficulties after solving 1000 traditional problems. *American Journal of Physics*, 70, 759-765.

Kirtley, C., & Smith, R. (2001). Application of multimedia to the study of human movement. *Multimedia Tools and Applications*, 14, 259-268.

Knudson, D. (2004). Biomechanics concept inventory: version two. In M. Lamontagne, D.G.E. Robertson, & H. Sveistrup (Eds.) *Proceedings of XXIInd international symposium on biomechanics in sports* (pp. 378-380). Ottawa: University of Ottawa.

Knudson, D. (2006). Biomechanics concept inventory. *Perceptual and Motor Skills*,

103, 81-82.

Knudson, D. (2010). What have we learned from teaching conferences and research on learning in biomechanics? In R. Jensen, W. Ebben, E. Petushek, C. Richter, & K. Roemer (Eds.) *Scientific Proceedings of the 28thConference of the International Society of Biomechanics in Sports* (pp. 678-681). Marquette, MI: Northern Michigan University.

Knudson, D., Bauer, J., & Bahamonde, R. (2009). Correlates of learning in introductory biomechanics. *Perceptual and Motor Skills*, 108, .499-504.

Knudson, D., Morrison, C., & Reeve, J. (1991). Effect of undergraduate kinesiology courses on qualitative analysis ability. In J.D. Wilkerson, E. Kreighbaum, & C. Tant (Eds.), *Teaching Kinesiology and Biomechanics in Sports* (pp. 17-20). Ames, IA: NASPE Kinesiology Academy.

Knudson, D., Noffal, G., Bauer, J., McGinnis, P., Bird, M., Chow, J., Bahamonde, R., Blackwell, J., Strohmeyer, S., & Abendroth-Smith, J. (2003). Development and evaluation of a biomechanics concept inventory. *Sports Biomechanics*, 2, 267-277.

McDermott, L.C. (1991). Millikan lecture1990: what we teach and what is learned—closing the gap. *American Journal of Physics*, 59, 301-315.

McPherson, M.N., & Guthrie, B.M. (1991). The implementation and evaluation of a computer assisted learning program in undergraduate biomechanics. In J.D. Wilkerson, E. Kreighbaum, & C. Tant (Eds.), *Teaching kinesiology and biomechanics in sports* (pp. 73-76). Ames, IA: NASPE Kinesiology Academy.

NASPE (2003). *Guidelines for undergraduate biomechanics*. Reston, VA: author. Available: http://www.aahperd.org/naspe/publications/teachingTools/upload/Guidelines-for-Undergraduate-Biomechanics-2003.pdf

Nicol, K., & Liebscher, F.F. (1983). An integrated system for biomechanics designed for small working groups and for teaching. *Journal of Human Movement Studies*, 9, 135-144.

Pandy, M.G., Petrosino, A.J., Austin, B.A., & Barr, R.E. (2004). Assessing adaptive expertise in undergraduate biomechanics. *Journal of Engineering Education*, 93, 211-222.

Redish, E.F., & Steinberg, R.N. (1999). Teaching physics: figuring out what works. *Physics Today*, 52, 24-30

Roselli, R.J., & Brophy, S.P. (2006). Effectiveness of challenge-based instruction in biomechanics. *Journal of Engineering Education*, 95, 311-324.

Washington, N., Parnianpour, M., & Fraser, J.M. (1999). Evaluation and assessment of a biomechanics computer-assisted instruction. *Computers & Education*, 32, 207-220.