RESEARCH ON LEARNING INTRODUCTORY BIOMECHANICS/MECHANICS

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Most students find mechanics and biomechanics concepts counterintuitive and difficult, and therefore have a negative perception of the subject. This paper reviews the research on learning biomechanical concepts, noting recent advances in standardized tests, identifying factors associated with learning, and strategies to increase learning. Active learning pedagogies typically double learning of mechanics and biomechanics concepts compared to traditional lecture/lab instruction. The Scholarship of Teaching and Learning (SoTL) literature in many sciences clearly supports use of active learning strategies, focusing on student engagement through personal and career interests, and emphasis on qualitative understanding of concepts. Biomechanics faculty can advance student interest in the field by continued faculty engagement and support of SoTL research.

KEY WORDS: Instruction, education, pedagogy, physics, teaching.

Teaching Newtonian mechanics in physics and an introductory biomechanics class can be difficult given that many students fear the course and often avoid it as long as possible. Biomechanics instructors in North America have tried to address these problems by organizing six teaching conferences since 1977. Over this time interest in pedagogical research or scholarship of teaching and learning (SoTL) that is specific to biomechanics, however has remained rare despite many standardized tests (Knudson, 2010). Consequently, poor student interest and traditional instruction likely means that most students do not master and apply biomechanics in professional practice, and biomechanics may not attract talented graduate into our field.

The organizers of the 34th International Conference on Biomechanics in Sports has sought to address this through an applied session on the international perspectives on teaching and learning biomechanics. There were four presentations at the 2016 conference that summarized teaching experience and SoTL on biomechanics courses of various levels. Perspectives from the Germany, Japan, Taiwan, and the USA were shared. This introductory paper for the session frames the topic by providing an overview of the research (SoTL) on learning concepts of Newtonian mechanics and biomechanics. The paper extends the work of previous reviews of research on learning biomechanical concepts (Knudson, 2010, 2013) using recent research in introductory biomechanics and physics education. Knudson (2013) provides an extensive review and bibliography of SoTL research in mechanics and biomechanics. Research on learning advanced biomechanics concepts is limited to the development of a standardized test (Knudson, 2015).

DIFFICULTY WITH NEWTONIAN MECHANICS AND BIOMECHANICS: There has been considerable interest in North American over the last 30 years on improving instruction in science/engineering/technology/math (STEM) fields. Perhaps one of the most well developed bodies of SoTL from these fields is Physics Education Research. The relatively standard concepts and laws in introductory physics, particularly mechanics has resulted in several tests including the Force Concept Inventory (Hestenes et al. 1992). Many students in introductory physics leave the course for lack of interest stimulated by the instructor (McDermott, 1991) or have difficulty learning concepts like Newton's Laws of Motion. Typical normalized learning (g) of mechanics concepts in introductory physics is only 20% (Haake, 1998). Normalized learning represents the percentage increase in concept mastery relative to the maximum possible improvement for that student based on their pre-test. This is far short of the complete mastery desired by instructors and in mind by faculty to prepare most students for success in advanced courses.

Student difficulty mastering Newtonian mechanics concepts are robust, so solving numerous numerical problems (Byun and Lee, 2014; Kim and Pack, 2002) or viewing demonstrations (Crouch et al. 2004) are generally ineffective. Considerable physics education research has focused on common misconceptions student have about motion (Halloun and Hestenes, 1985; McDermott, 1991) which are quite difficult to dispel. Transitioning students to accurate Newtonian perspectives is difficult and context dependent (Elby, 2001), so assisting students with the cognitive dissonance of new explanations of the causes of movement is important (Duit and Teagust, 2003).

Student's knowledge of biomechanics is often evaluated using instructor based tests (e.g., Bird et al. 1997; Dixon, 2005), however measuring learning requires multiple testing to determine student's change in mastery of concepts (Bird et al. 1997; Knudson 2004, 2006; Knudson et al. 2003). Recent research also indicates use of numerous tests is important to document student forgetting (Franklin et al. 2014) so that instructors can plan reinforcement activities to maintain mastery of important concept (Huston, 1999). Several studies have used the Biomechanics Concept Inventory (BCI) to document actual learning of core biomechanical concepts. Knudson (2010, 2013) reviewed these studies and a consistent result is that kinesiology/exercise science majors have similar difficulties and level of learning as typical students learning mechanics in introductory physics (Coleman, 2001). Typical instruction in introductory biomechanics in kinesiology programs in North America 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). Several retrospective studies using BCI learning scores have shown that instructor and course factors account for very little variance (2-5%) in learning (Knudson, Bauer, and Bahamonde, 2009), while student factors like GPA, interest in the subject, and perceived connection to future careers account for 14 to 40% of the variance in learning (Hsieh and Knudson, 2008; Hsieh et al. 2012).

The Knudson (2013) review reported several consistent results in the SoTL literature on mechanics and biomechanics. Despite considerable interest in computer simulation and multimedia instruction, these methods provide no unique pedagogical advantage over traditional instruction (Chandler, 2009). Most students find mastery of mechanics/biomechanics difficult, so there may be no short-cuts to the hard cognitive work of engagement with new, counterintuitive mechanical concepts. Properly designed active learning strategies, however, significantly improve student learning of these concepts beyond that of traditional instruction, even including lecture and traditional labs. The next section summarizes this research on improving learning mechanics and biomechanics.

IMPROVING LEARNING OF MECHANICS/BIOMECHANICS: Active learning or interactive engagement pedagogies are an effective approach to improving learning mechanical concepts (Hake, 1998), and these improvements in learning can scaled up for use in large classes (Beichner et al. 2007). Reviews on the effectiveness of active learning strategies in mechanics instruction in physics (Hake, 1998; Henderson and Dancy, 2009; Redish and Steinberg 1999) and other sciences are available (Freeman, et al. 2014).

The greater effectiveness of active learning strategies in biomechanics are also supported by prospective (Riskowski, 2015) and retrospective SoTL research (Knudson, Bauer, & Bahamonde, 2009). Implementing active learning strategies like the examples in Table 1 typically doubles learning compared to traditional instruction in biomechanics classes (Knudson, 2010, 2013). These more active pedagogies encourage student engagement with the material and do not have to be a complete "flipped classroom." A "flipped classroom" pedagogy requires students to read or view course content out of class and work exclusively on well-defined application projects during class (Brunsell and Horejsi,2013). Even short class preparatory quizzes before class significantly improve learning in introductory biomechanics for all students over traditional instruction (Riskowski, 2015). Riskowski also reported that qualitative pre-class activities out performed quantitative problems, this is consistent with considerable physics education research that mere quantitative problem solving does not improve learning, encouraging students to search for correct answers rather than engaging in the concepts relevant to the problems (Knudson, 2013).

Table 1. Examples of active learning strategies used to stimulate student engagement with course content and problems.

Strategy	Likely Benefits
Clicker/Questioning Systems	Track engagement & mastery
Engaged Demonstrations/Mini-Labs	Test hypotheses & reasoning
Just-in-Time Teaching (JiTT)	Student reading & guided teaching
Mini-Lecture (10 min) and Application/Case Study	Maintain attention and engagement
Small Group Projects	Engagement and link to application
Think-Pair-Share	Shared experience & learning
Two Opportunities to Practice a Day (TOPday)	Engagement, confidence & repetition
Write Test Questions & Fishbowl Review Session	Review & reinforcement

One barrier to successfully implementing active learning strategies, has been that some students resist active engagement in assigned readings and group work, adopting a passive approach to learning that assumes memorization of facts as the goal (Duncan, 2009; Duncan & Lyons, 2008; Felder and Brent, 1996). When biomechanics students are given an option to participate in active learning quizzes, students that participate more have significantly better confidence, enthusiasm, and test performance than those with lower participation (Tanck et al. 2014). Challenge-based instruction in biomechanics improves performance on more difficult questions relative to traditional instruction (Roselli and Brophy, 2006). Most advocates for active learning pedagogies, therefore, encourage faculty to gradually implement these activities to essentially train some students to take advantage of these opportunities for more meaningful engagement with course concepts and applications (Felder and Brent, 1996).

Despite the overwhelming evidence of the effectiveness of active learning pedagogies, some faculty and students remain resistant to its implementation in higher education (Miller and Metz, 2014). Biomechanics faculty are encouraged to improve the perception of the field and student learning by implementing more active learning strategies their courses. Faculty interested in active learning research on teaching mechanics are directed to the review by Fraser et al. (2014). Biomechanics scholars can also support the field by contributing to and using SoTL research specific to the field.

APPLICATION AND SUMMARY:

SoTL on learning mechanics and biomechanics concepts confirm student difficulty and poor interest in the subject. Motivating student interest to overcome misconceptions about motion is difficult. Traditional pedagogies emphasizing quantitative problem solving and multi-media technology are not as effective as active learning pedagogies. Well implemented active learning methods can double the learning of biomechanical concepts compared to traditional instruction. Biomechanics instructors are encouraged to try out these techniques. Progressive implementation of active learning in a course is suggested because some students may be resistant, preferring a passive, memorization of facts strategy. Instructors are also encouraged to contribute to or support SoTL in biomechanics. This will improve learning of biomechanics and increase the chance of students joining our field.

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