Making it Relevant: Using Research Articles to Teach Biomechanics

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An important learning goal of an undergraduate Biomechanics class is to have students see human movement through the lens of physics; but students often get lost in the math and forget to reconnect theory with the physical world. By supplementing weekly lessons in the course with a related research article, the physics principles are tied to meaningful applications. Assigned guiding questions help students pull out important elements of the article, while calculations drawn from the published results help them apply what they are learning in class. A secondary outcome is that students are introduced to literature in Biomechanics, preparing those who are headed to graduate school for research. For those entering the workforce, the articles show the value of findings coming from academia and give them a way to remain at the forefront of scientific knowledge during their careers. Feedback from both the stronger and weaker students has been positive and the above stated goal for the class is being better achieved. The following paper provides guiding principles used to incorporate research articles into lesson plans and specific examples of article choices with the assigned questions. Techniques presented can be applied to a number of different engineering courses.

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Background

"I don't see how biomechanics is relevant." I had been teaching biomechanics for four years when a kinesiology major in the Pre-Occupational Therapy track told her advisor that she preferred not to take the advanced biomechanics elective. During those four years, I had been focused on meeting the students were they were at academically. This student pointed out that I had not done enough to focus on where the students want to end up professionally. I had not made biomechanics relevant.

Academically, the required junior-level biomechanics course attempts to balance the quantitative treatment of biomechanics and a qualitative understanding of human movement. As an engineer, I enjoy exploring the order of the physical world through mathematical expressions; as a kinesiology professor it is important that I tie the mathematics to a descriptive explanation of their physical meaning. On a very basic level, the course content revisits the mechanics topics taught in introductory physics while applying those topics to human movement. While the students are accustomed to memorizing a known set of facts about the human body in their other major classes, this course attempts to show them how to use mathematics and physics to understand the mechanisms behind movement, even if they have never seen the particular movement before. In other words, the goal of the course is for students to look at the body through the quantitative lens of physics.

Professionally, most of the students in the course are headed into careers in the health professions or athletic training. *Biomechanics of Human Movement* is attended every fall semester by 10-20 kinesiology majors and the occasional physics major. Since many biomechanics books[1-4] and videos[5-8] draw examples from sports, the required introductory course traditionally focused on the biomechanics of sport, while the advanced biomechanics elective dealt with clinical applications. When I heard pre-health profession students were opting out of the advanced class because biomechanics was "irrelevant," I knew something had to change.

The solution to the problem turned out to be a tool that not only balances the quantitative with the qualitative treatment of biomechanics beautifully, but also allows flexibility to choose examples that are relevant to each class of students based on their interests. It can be tailored to relate to both kinesiology and engineering undergraduate students at all levels of biomechanics. This tool is *research articles*. The following sections of this paper will describe in more detail some guiding principles and specific examples of how to integrated the research articles into the structure of a biomechanics course (Fig. 1). The principles presented can be applied in almost any undergraduate engineering course.

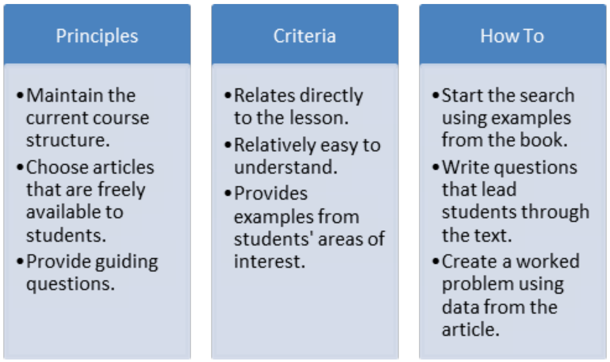

Figure 1. Principles for integrating research articles into a course, criteria for choosing articles, and simple how-to steps.

Formulation

Principles

To those interested in integrating research articles into an undergraduate course, this section begin with a few principles (Fig. 1). First, it is not recommended that the instructor significantly change the course structure when adding research articles to the curriculum. The main topics and textbook readings should remain largely the same from the previous semester. The research articles are assigned as weekly assignments that compliment the course topics, so only small portions of class and exam time will need to be altered to support the new material. The research articles are a tool, not a new teaching paradigm. Thus, the articles should be able to fit within most teaching paradigms, whether they be traditional lectures, flipped classrooms or project based. When making this tool work best in a class, it is important to take small steps.

Second, one should chose research articles that are accessible to the students either because they are open-source online or through a subscription of the college library. Rather than publishing a course reader, one can simply provide links to the online source or to the college's library catalog. Beyond the obvious benefit of convenience to the professor and savings to the students in not having to pay for copyright access, sending students to the source has additional benefits. The action of going to the source to get the material, if even by simply following a link, is the students' first step towards performing literature searches of their own. And seeing the article on either the journal's or the author's website introduces them to the web presence of the Biomechanics community.

Finally, guiding questions should be written that both help the student process the article and tie it to the class material. Reading research articles in a new scientific area is a daunting task. The guiding questions serve as a roadmap for the students, showing them which portions of the article are important and helping them explore concepts that may be difficult to grasp. When writing a question that is related to the textbook content, provide a reference to the section of the textbook to make the connection doubly clear and to give students more contexts in which to answer the question (see Supplemental Materials).

Implementation

The 14-week *Biomechanics of Human Movement* course at Gordon College is broken up into three units: Kinematics, Linear Kinetics, and Angular Kinetics (Fig. 2). Each unit is composed of 4 lessons (approximately one lesson per week), with one week reserved for review and exam. The class meets together for one full hour on Monday, Wednesday and Friday, and divided into two lab sections on Tuesday. Assigned reading from the textbook and questions that assess a basic level understanding of the material, must be completed prior to class on Monday. The reading from the research articles, assessed through guiding questions, is due in class on Friday after the students have the opportunity to ask questions and quickly edit their responses as needed.

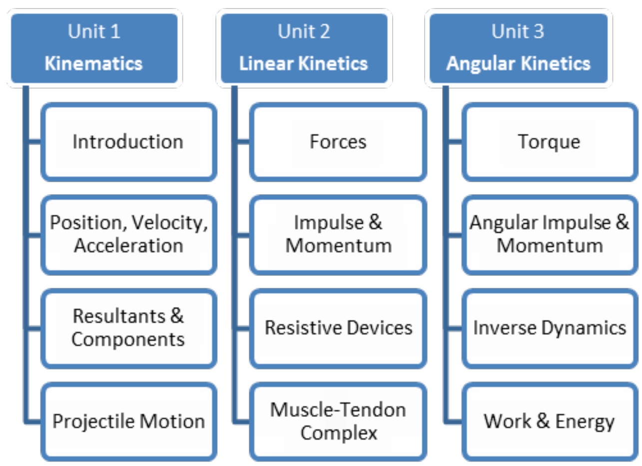

Figure 2. Course schedule, divided into three units of four topics.

The course loosely follows the lessons in the textbook, *Biomechanics: A Case-Based Approach*,[9] as detailed in the Supplemental Materials. One of the strengths of this book is the 'Applied Research' boxed features that accompany most lessons with examples from cited literature. These features "are helpful in illustrating biomechanical concepts and present evidence of the practical value of biomechanics (p. xiii)." When searching for a research article to assign for the week, one should start with examples already provided in the book. This allows continuity of thought, giving students more detail about particular topics rather than inundating them with a large number of applications. In this course, the 'Applied Research' features from the students' textbook reading assignment are the ideal places to start from in searching for research articles. While many of good biomechanics articles are not freely available to students, author and reference lists from those articles can lead to an article that is.

There are three main criteria for choosing an article (Fig. 1). The first criterion: How well the article relates to the topic of the current lesson. Ideally, the research topic of the article will be mentioned in the textbook as an example of how the biomechanics principles can be applied. More importantly, the methods section of the article presents equations that use the physics the students are learning. While oftentimes equations presented in research articles are too complex for biomechanics students to grasp on their own, a short explanation in class can show them how in the most basic form the authors apply the same principles that the students are learning. One should avoid review articles or others that are more qualitative in nature because the research articles should show how experimental measures are gathered and how the calculations students are learning can lead to helpful information about human movement.

The second criterion: how easily students will be able to understand the article when provided with some help. While the task of reading research articles will certainly not be easy for the undergraduate student, they should be able to understand the majority of the article when guided through it. For this reason, one should avoid methods papers and may choose to advise students to skip portions of the articles that will confuse them (see Supplemental Materials: Angular Impulse & Momentum).

The third criterion: the article's ability to provide an example from a new area within the class' interests. While research articles that meet the first two criteria will show students how important biomechanics is as a tool to answer important questions, the third criterion makes biomechanics relevant to them personally. It helps if the instructor knows many of the students enrolled in the class, so that before the first day of class she already has a sampling of their interests. This allows the instructor time to choose articles for the first unit. Once the semester begins, the instructor should get to know the students and their interests (career, sports, and recreational activities). This will inform the instructor in which direction to move when choosing articles for future units.

The Questions

It is important that guiding questions accompany the assigned research articles. Before attempting to write the questions, first read the section of the textbook assigned to the students for the week. Then read the article, highlighting points of interest and making notes of questions that one could ask or additional information that one could provide to the students. Some of these questions and information can be reserved for class when the instructor reviews the article with the students, the rest should be used to construct short answer questions for the students. Whenever a topic presented in the article is a good example of points from the textbook reading, cite the textbook's lesson number along with a question that asks students to apply that concept in their analysis of the article. Finally, conclude the reading questions by asking the students to summarize the research findings and their importance (see Supplemental Materials).

When possible, include quantitative questions requiring calculations together with the short answer questions. The calculations should require the use of equations from the textbook and data from the methods or results sections of the research article (see questions beginning with * in the Supplemental Materials). While an important outcome is that students get practice applying the physics they are learning to the specific biomechanics example, this exercise helps them understand the data better. I have found this tool to be very valuable and plan to write more worked problems into future reading responses.

Analysis

While no formal method for analyzing the effectiveness of the research articles was constructed, students provided both verbal and written feedback. The last question on the final exam asked, *What is a something you learned this semester about biomechanics or its practice that is particularly important or interesting to you?* The following responses show the impact of the research articles:

> "The journal about wheelchair propulsion was great for application – I help a man with a C4-C5 spinal injury and this helped me understand the mechanics of wheelchairs better."
>
> "I really enjoyed reading articles about prosthetics and the research that has been done. I was able to apply physics I had learned this summer to scenarios that I would be working with someday in the physical therapy field."
>
> "I learned how to make physics relevant to life, and more the angular component. In Physics class I saw how linear was relevant but in Biomechanics I was able to see how the angular component has a much greater role in the human body and how that can be calculated to become better performers and clinicians."

"I really like learning about torque and how to model and measure it in order to decrease injury. I think it's important because it could really be helpful in preventing injuries in athletes, especially if the athletes were to be taught exactly what's going on in their bodies when they make certain movements."

In the course evaluation administered by the college, some students responded about the reading assignments when asked general questions about the class:

"I really like how Dr. Ventura had us read current and related articles of research that is going on today. It helped to see how the concepts were related to actual real life stuff."

"I liked learning how the concepts related to current science situations."

"The homework readings and lab have been extremely helpful and thought provoking."

According to my own assessment, research articles had unexpected outcomes in addition to meeting the goals of (a) making biomechanics relevant to the students and (b) combining a qualitative understanding of biomechanics with its quantitative aspects. One such outcome is that the research articles provide an additional level of inquiry for advanced students. While attempting to make biomechanics accessible to the struggling students, it is equally important to challenge the advanced students. The guiding questions provide accessibility for all students, but those who can handle the material can find more information by delving into the article on their own. In addition, the research articles assigned in class came up during a discussion with a student researcher as we designed an experiment in the Biomechanics Laboratory. As soon as the following semester, students were using the articles for research, an excellent preparation for graduate school.

Conclusions

Learning to look at the world through a new lens is difficult. Research articles can be used as a tool to show students examples of how it is done. Guiding questions tie the articles to the topics presented in class and readings from the textbooks. Worked problems using data from the articles give students more practice using physics to analyze human movement. Students respond positively to these assignments, especially when they cover topics that the students find relevant.

References

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8. Sean P. Flanagan. *Biomechanics: A Case-Based Approach.* Jones & Bartlett Learning, (2013).

Supplemental Materials: Reading Assignments

Lessons are assigned from Sean P. Flanagan. *Biomechanics: A Case-Based Approach.* Jones & Bartlett Learning, 2013.

Unit 1 Kinematics

Linear and Angular Kinematics (Lessons 2 and 4)

Aron J. Murphy, Robert G. Lockie and Aaron J. Coutts. "Kinematic determinants of early acceleration in field sport athletes." *Journal of Sports Science and Medicine* (2003) 2, 144-150.

A. 2.1.1 Read the methods section of the paper and describe the body being analyzed, the point used to represent the body, and the frame of reference used to assess velocity.
B. 2.3 What is defined as a step in this study? What events defined the first and second steps? What start and end points were used to measure stride?
C. Box 3.1 Based on the description of the markers in the methods section, how do you expect the hip and knee angles were calculated? Write out equations you would use to calculate each of the two angles and make sure to define your variables based on the marker names.
D. 4.1.1 Which rigid bodies are defined in this study? How is defining these bodies as rigid only an approximation?
E. 4.1.2-3 Describe the axes of rotation used in the analyses, what is defined as the origin (an angle of zero), and what direction of rotation is defined as a positive angle.
F. 4.1.4-5 Describe the angular displacement that was of interest in the study and how angular velocity was calculated
G. Which measures were found significantly different? Using your own words, describe in two paragraphs how the authors explain these findings.

Resultants & Components (Lessons 3.1-3)

Pedro E. Alcaraz, et al. "Effects of three types of resisted sprint training devices on the kinematics of sprinting at maximum velocity." *Journal of Strength and Conditioning Research* (2008) 22(2):1-8.

A. What were the four conditions tested in this study? Which was the control? Using your own words, describe how the authors chose the resistances used for this study.
B. *3.1-3 Assuming the tension in the cord towing the sled (its resultant force) was 16% body weight, calculate the components in the horizontal and vertical directions (in % body weights) acting on the sprinter when the cord was at an angle of 12.5 degrees and when the cord was at an angle of 15.5 degrees.
    a. Is it safe to assume that the tension in the cord matches the weight of the sled? Why or why not?
    b. What could the researchers have controlled in the procedures so that the cord angle was the same for all runners regardless of height?
    c. Compare the vertical force that you calculated to be exerted by the sled with the vertical force of the weighted belt. Is it the same, greater or lesser? What would you expect to be the training implications?
C. 2.3 What three events were of interest in the study and how were they defined?
D. 4.1.1 Which rigid bodies are analyzed in this study? How were their angular positions defined? Which measures had significant differences from unloaded sprinting and under what conditions (gender, load and event)?
E. 4.1.5 The angular velocities of which joints were analyzed in this study? Which measures had significant differences from unloaded sprinting and under what conditions (gender, load and event)?
F. Using your own words, describe the authors' recommendations with respect to resistance training for sprinting.

Projectile Motion (Lesson 3.4)

Mont Hubbard. *Safer ski jump landing surface design limits normal impact velocity*." *J ASTM Intl*, (2008) 6 (1): 1-9.

A. 2.1.1, 3.1 Which axes define the plane for this study? What is the origin? What point is used to represent the skier?
B. How is the skier able to takeoff at a different angle than the ski ramp angle? How did the author account for this?
C. Which causes greater injuries? Greater perpendicular (normal) landing velocities or greater tangential landing velocities? Explain in your own words how this affects the design goal of ski jump landing slopes.
D. In your own words, explain equivalent fall height. How is EFH for a ski slope calculated? What does an EFH approaching zero mean physically?
E. What factors other than safety come into play when choosing a landing slope?
F. *3.4 Calculate the landing location and the slope angle that gives a minimum EFH for the parameters (takeoff angle: 25 deg; in-run velocity: 31.5mph; flight time: 2.3s), using the provided steps:
    a. Calculate the vertical and horizontal components of velocity at takeoff
    b. Calculate the vertical and horizontal position at landing time (landing location)
    c. Calculate the vertical and horizontal components of velocity at landing time
    d. Calculate the resultant angle of velocity at landing time (slope angle). Is this angle within the suggested range for a slope angle?

Unit 2 Linear Kinetics

Forces (Lesson 6.1-3)

Martyn Shorten, Bret Hudson, and Jennifer Himmelsbach, "Shoe-Surface traction of conventional and in-filled synthetic turf football surfaces." *XIX International Congress on Biomechanics* (2003).

A. 6.1 What outside forces act on a football player to change his or her velocity? In what ways?
B. Use equation 6.2 to explain why defensemen are often massive and running backs often less massive in football.
C. 6.2 Would you characterize the Traction Force as a Propulsive force or Braking force or both? why?
D. 6.2.3 What is the Effective Force of the Applied, Traction and Normal Forces?
E. 6.3 Is the Traction Force a Contact force or a Reaction force? why? How about the Normal Force and the Applied Force?
F. 6.3.1 Explain in your own words the difference between traction (as described in the article) and friction.
G. "For each trial, the instantaneous traction requirement was calculated as the ratio of the normal reaction force component to the magnitude of the horizontal reaction force vector." What does a traction requirement over 1.0 tell you physically about the motion? A traction requirement under 1.0?
H. Why do you think the variability in traction requirements increased for increased cutting angles although the average traction requirement stayed the same?

Impulse and Momentum (Lesson 5.1-2 and 6.4)
Jeff G. Seegmiller and Steven T. McCaw. "Ground reaction forces among gymnasts and recreational athletes in drop landings." *Journal of Athletic Training* 2003; 38(4):311–314
A. 5.2 Which group had a greater average mass, the gymnasts or the recreational athletes? How were differences in mass accounted for when making force and impulse comparisons between the groups?
B. *6.4 The authors report the averaged peak force, time to peak force, and impulse for each of the two landing peaks of the gymnasts and the recreational users. Using the data from Tables 1 and 2 for a height of 90cm ($F1_{gymnasts}$=32.84N/kg; $F1_{rec}$=24.0N/kg),
    a. Estimate the group averages of Rate of Force Development to F1 for the gymnasts and recreational users. (Table 1)
    b. Estimate the group averages of Average Force from landing to F1 for the gymnasts and recreational users. (Table 2)
    c. Explain why these are just estimates and not actually the group averages
C. What were the significant results from this study? What were the implications?

Muscle-Tendon Complex (Lessons 11 and 12.4)
Susan L. Rozzi et al. "Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players." *The American Journal of Sports Medicine* (1999) 27:312-319.
A. 11.1 Describe in your own words how a muscle can act like a (a) motor, (b) brake, (c) spring, (d) strut. Use more detail than summarized in the "Section Question Answer" box. What are the hamstrings acting as during a single-legged standing test?
B. The methods section describes in detail 5 separate tests done on each subject. For each test:
    a. Give the name provided in the heading,
    b. Write a short description of the procedure,
    c. Use Tables 2 and 3 to determine which measurement(s) were compared for each test, including units of measurement, and
    d. Report statistically significant findings.
C. What results were found (and subsequent conclusions were drawn) regarding female knee joint laxity and neuromuscular activity?
D. Explain how this study's findings regarding kinesthesia were supported by some studies but not necessarily others. How did the authors explain it?

Unit 3 Angular Kinetics

Torque (Lessons 7.1-2 and 17.2.4)
L.A. Rozendaal, H.E.J. Veeger, L.H.V. van der Woude. "The push force pattern in manual wheelchair propulsion as a balance between cost and effect." *Journal of Biomechanics* (2003) 36: 239–247.
A. Explain in your own words the paradox of efficiency in wheelchair propulsion.
B. The following statement is imperative to understanding the R-contours: "If the propulsion force is applied in the direction from the elbow to hand it does not require an elbow moment; if applied in the direction from shoulder to hand, it does not require a shoulder moment."
    a. What do the e, s, and t vectors stand for in Figure 1?
    b. If the propulsion force is applied in the direction from the elbow to hand in the positions (A), (B), and (C) in Figure 1, which e vector (↑ or ↓) would propel the wheel forward? Would the anterior or posterior shoulder muscles contribute to that force? (answer for each position)
    c. If the propulsion force is applied in the direction from the shoulder to hand, which s vector (↑ or ↓) would propel the wheel forward? Would the elbow flexors or extensors contribute to that force? (answer for each position)
C. Figure 6(B) shows θR (the optimal angle), θT (the angle tangent to the wheel) and θF (the experimental angle of the force applied by wheelchair users). What are three things that this data tells you about the forces usually applied by wheelchair users?
D. Based off the experimental methods and the results displayed in Figure 7, how comfortable would you be in generalizing these findings across different users and conditions?

Angular Impulse & Momentum (Lessons 5.3-4 and 7.3-5)
A.K. Silverman and R.R. Neptune. "Differences in whole-body angular momentum between below-knee amputees and non-amputees across walking speeds." *Journal of Biomechanics* (2011) 44: 379–385.
(Note: The Results section of this paper is particularly heavy, but the figures provided are extremely helpful. Feel free to skip the text in that section and refer back to it as needed while you are reading the Discussion section.)
A. For each of the 3 planes, identify the moment arm (X, Y, or Z) that is paired with each GRF and whether you expect the moment arm to vary a little or a lot, and why:
B. Angular Momentum is equivalent to the body's moment of inertia (I_{BODY}) about the body's Center-of-Mass (COM_{BODY}) multiplied by the body's angular velocity (ω_{BODY}) about the COM_{BODY}. Assuming I_{BODY} only changes minimally, study Figure 1 and Figure 2 Non-Amputees and describe what is happening in terms of ω_{BODY} (the body's sway) during the gait cycle for each of the three planes.
Tip: Divide the Gait Cycle into phases (0-10%: Weight Acceptance; 10-50% Single-Leg Support; 50-60% Push-off; 60-100% Swing). Note the symmetry between the first and second halves of the gait cycle.
C. Again using Figures 1 and 2, point out differences between the amputees and non-amputees for the frontal and sagittal planes as relates to ω_{BODY}.
D. What did the authors of this study say about the contribution of prosthetic feet and arms to whole-body angular momentum of amputees?

Inverse Dynamics (Lesson 13 and Supplemental Reading)
Brandon D. Rooney, Timothy Derrick. "Joint contact loading in forefoot and rearfoot strike patterns during running." *Journal of Biomechanics* (2013) 46: 2201-2206.

A. "While GRFs reach magnitudes of approximately 2.5 times body weight during running, the joint contact forces are estimated to reach 8-15 body weights." Explain in your own words why this is true.
B. Examine the Sagittal Moments in Figure 1 and discuss what is happening during the first 20% of stance (Weight Acceptance) for the Rearfoot Strikers versus the Forefoot strikers. Explain in terms of muscle function (extensors/flexors or plantar/dorsiflexors).
C. In Figure 2, the estimated muscle forces were compared with EMG (muscle excitations) from another publication. Based on your knowledge of muscle force production, explain in what ways this is a good comparison and in what ways it fails.
D. Look at the differences in Axial Contact Forces between Rearfoot Strikers and Forefoot strikers as presented in Figure 3. Compare with the differences in muscle forces in Figure 2 and explain how the muscles are likely contributing to the differences in the axial forces.
E. What are the findings and the importance of this study?

Work- Energy during Gait (Lessons 8 and 17.2.7)
Arie Rotstein et al. "Preferred Transition Speed between Walking and Running: Effects of Training Status." *American College of Sports Medicine* (2005) 1864-1869.

A. In your own words, explain how kinetic and potential energies are out-of-phase during walking and what impact this has on metabolic energy expenditure.
B. In your own words, explain how kinetic and potential energies are in-phase during running and what impact this has on metabolic energy expenditure
C. What biomechanical variables have been tested in the search of a consistent way to predict the Preferred Transition Speed (PTS) between walking and running for a given person?
D. Based on their methods of determining the PTS, how do the researchers define PTS? Why is this definition so important? (see Discussion)
E. Based on the findings of this study, doe metabolic energy expenditure likely determine PTS? Does the rate of perceived exertion? Does heart rate?