SHARE: Free-Body Diagram Yoga for Introductory Biomechanics Courses

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Dr. Pim Oomen is an Assistant Professor in Biomedical Engineering at the University of California, Irvine. He received his BS, MS, and PhD in the department of Biomedical Engineering at the Eindhoven University of Technology, focusing on growth and remodeling of native and engineering cardiovascular tissues. He completed his postdoctoral training in the department of Biomedical Engineering at the University of Virginia before joining the department Cardiovascular Medicine as a Senior Scientist, focusing on translating bioengineering approaches to clinical care. His lab at UC Irvine develops inclusive multiscale computational and experimental tools with the goal of advancing our knowledge of cardiac remodeling, improve and design cardiovascular therapies, and to train a new, diverse generation of biomedical engineers. He teaches biomechanics and finite element modeling to undergraduate Biomedical Engineering students, and gets to combine his passion for music and science in teaching undergraduate engineering students to build novel musical instruments.

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Motivation:

In biomechanics courses for undergraduate biomedical engineering programs, free-body diagrams (FBDs) are a fundamental skill for analyzing forces and moments that act on a physical body [1-5]. During learning modules for FBDs, students often find it difficult to understand static and dynamic principles due to the involvement of mechanical concepts of motion, their causes, and the mathematical principles behind them [6]. Prior literature on biomechanics course learning modules have shown that active learning instruction can improve learning outcomes and conceptual understanding of these principles [6, 7]. For example, Singh 2017 [7] developed an active learning module that utilized project-based unmet need identification and innovation in a nursing simulation clinic to improve student learning of applied statics and dynamics. It was found that the active and project-based learning modules were able to improve their technical knowledge of biomechanics as well as their lifelong learning skills through exposure to adaptive learning and innovation. Similarly, Mutto et. al [8] found that the use of problem-based learning methodologies aimed at applying anatomical foundations and physics related to the human body to real cases improved student context-based competencies, spatial understanding, and clinical reasoning. Given the benefits of active learning principles on fostering technical knowledge, particularly in physics-based concepts [6-8], instructors of an introductory biomechanics course at the University of California Irvine developed an active learning module in which students applied their contextual knowledge of physics and human anatomy to novel biomechanics problems of their choosing, entitled “Free Body Diagram Yoga”.

Learning Objectives:

The “Free Body Diagram Yoga” learning module was implemented in an introductory biomechanics course that focuses on statics and dynamics principles applied to the human body, including topics on rigid bodies, analysis of structures, forces in beams, moments of inertia, friction, kinetics, work and energy. The learning module assessed the following learning objectives: 1) apply models of rigid bodies and equivalent systems of forces to solve engineering problems, 2) evaluate the equilibrium of rigid bodies, 3) understand distributed forces and how to determine centroids and centers of gravity, and 4) analyze structures. Learning objectives (1) and (2) focus on ABET’s Student Outcome 1: an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics [9]. The learning module was also designed to assess the “create” level of Bloom’s taxonomy by composing a unique problem and solution for the underlying static or dynamic forces [10].

Implementation:

Students were first given introductory lectures on concepts underlying biomechanics principles such as statics, of particles, forces, moments, couples, centroids and centers of gravity, and analysis of structures. They were then asked to apply their knowledge to these concepts to an image that they created performing any yoga or unique pose of their choice (see Appendix A for the sample assignment provided, rubric, and example student submissions). Students developed a FBD of either the static or dynamic pose (e.g. Figure 1), and analyzed the underlying internal and external forces and torques. To provide more inclusivity for the assignment for those who did not want to perform a pose, they were allowed to analyze forces acting on an outside object, person, or animal that agreed to a photo (e.g. friend, family member, internet image, objects on tables, or pets, see Appendix B). Lastly, in addition to lectures, literature on anthropometric data of human body segments [11-13] and support model types for different parts of the body [14] were also provided to the students.

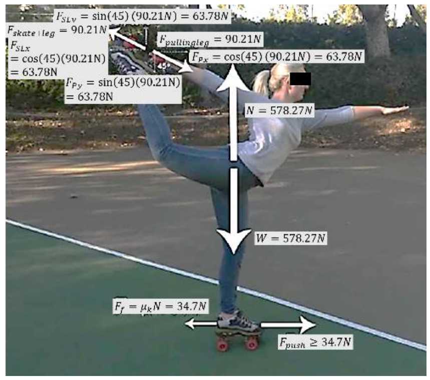

Figure 1: Sample FBD student submission given their interest in figure skating.

Situational Factors:

The learning module was implemented both in remote (2020 and 2021 course offerings) and in-person classroom environments across two instructors over the course of 6 years. It was first introduced in the 2020 course offering to 130 biomedical engineering students, and then utilized in the 2021 (N = 144), 2022 (N = 114), 2023 (N = 139), 2024 (N = 159), and 2025 (N = 180) course offerings. Each course offering had two teaching assistants (TAs) and one instructor, with the exception of 2025 in which three TAs were assigned. The module was able to assess students' abilities to apply, analyze, and evaluate the learning outcomes of a created biomechanics problem using a very low-level of resources required. Qualitative course evaluations indicated that students appreciated the module's creative engagement and real-world application, even though some found the open-ended nature of the assignment challenging, particularly with reaction forces and moments. The module allowed students to learn biomechanics principles to fields that are of interest to them beyond the suggestion of yoga, such as figure skating, rock climbing, weightlifting, archery, and veterinary medicine. Instructors and TAs were able to grade the assignments using a standardized rubric that assessed students' assumptions, equations, and solving of their created problem (Appendix A), and the use of groupwork reduced the grading workload. Furthermore, students learned how to utilize peer-reviewed literature sources to perform biomechanical analyses to solve real-world problems, and understand how static and dynamic principles are used in biomechanics research. For example, one student noted that "*I found the course intellectually stimulating when doing practice problems that had research implications and when working on the Create Your Own Free Body Diagram Problem.*". Instructors were able to assess higher cognitive levels of understanding [10], as students had to create a unique problem and solve it given their knowledge of physics and anatomy beyond problems provided in a textbook. In the future, it can be applied to other biomechanics courses at other institutions across disciplines that require knowledge of biomechanics, which may lead to an improved module that can enhance student engagement and acquisition of learning outcomes.

Human Subjects and Ethics Approval Statement: This work was approved under the University of California Irvine Institutional Review Board as exempt under IRB Protocol No. 0216.

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Appendices:

Appendix A:

Sample Assignment:

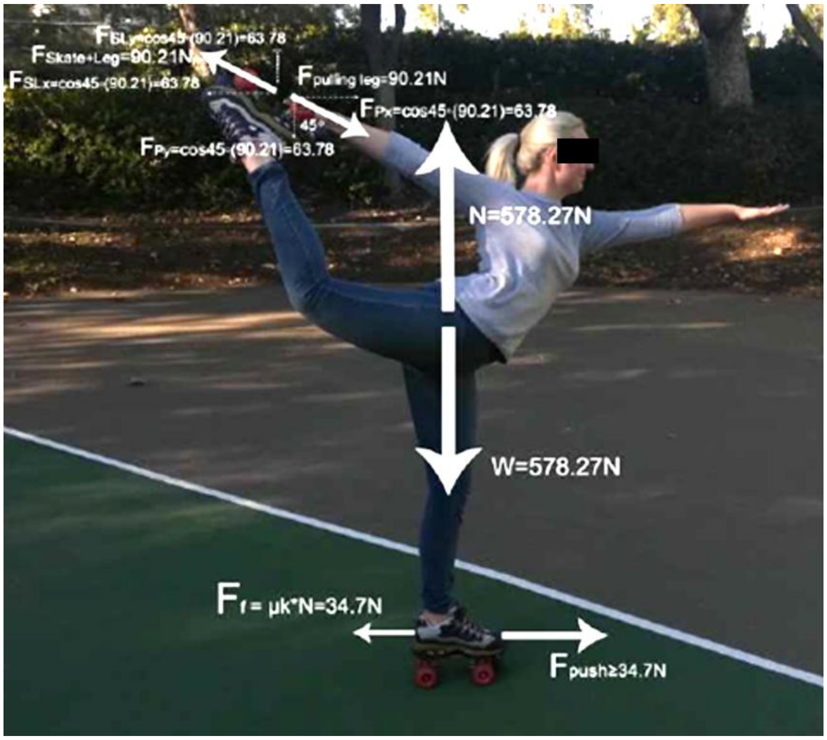
With a partner or yourself, take a picture in a unique position and draw a free body diagram of the internal and external forces. Then, given your weights and measured distances (you can lie about your weight if you want :)), calculate the forces acting on your rigid body. Below are some examples of some fun free body diagrams developed by past students.

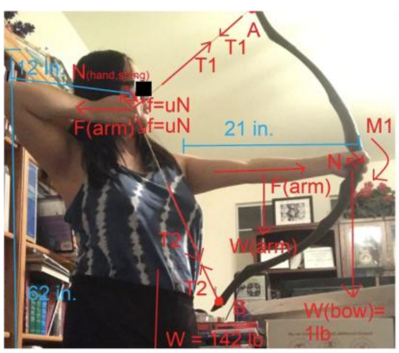
Rubric:

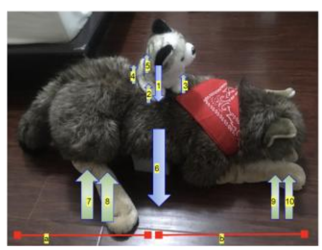
Free Body Diagram	Governing Equations	Correct Solution	**Total**
Total: 60	Total: 30	Total: 10	**100**
-10: overly simplified FBD	-5: missing assumptions for equations	-5: incorrect solution due to incorrect equations	
-5: missing or incorrect internal reaction forces or friction forces	-5: missing references for how to derive forces or weights	-5: incorrection solution for centroid locations	
-5: missing distributed loads or moments	-5: incorrect dimensions	-10: did not solve for any unknowns	

Appendix B:

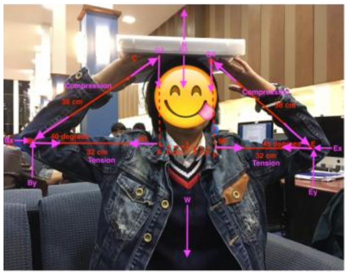
Sample Student Submissions of their Free Body Diagram Image Only:

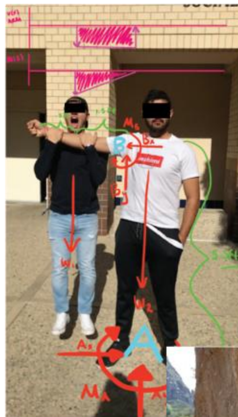


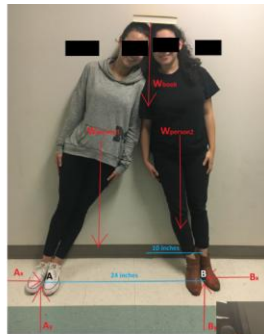


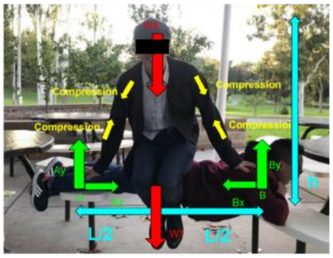


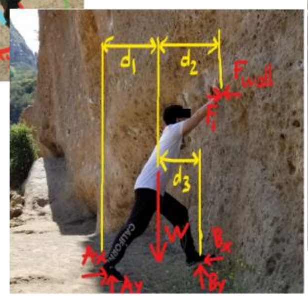
My mom is trying to get me to stop watching Netflix during quarantine. She tries to push me off of the couch, where I permanently reside. Assume that my mom is static and rigid and the vertical component of the push force has a magnitude of 10 N directed downwards. My mom weighs 55 kg, while I weigh 45 kg. The coefficient of static friction between my skin and the couch leather is 0.8. With what horizontal force directed to the right will I begin moving? Will I slide or tip? What are the magnitudes of the other forces acting within/on my mom?

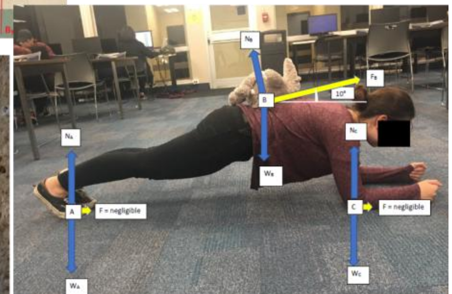


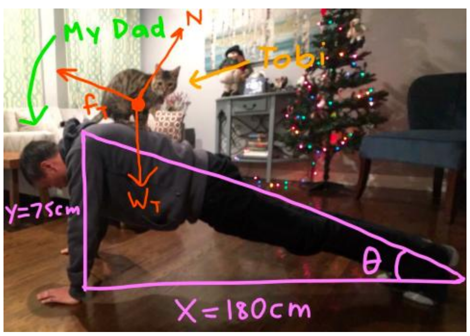




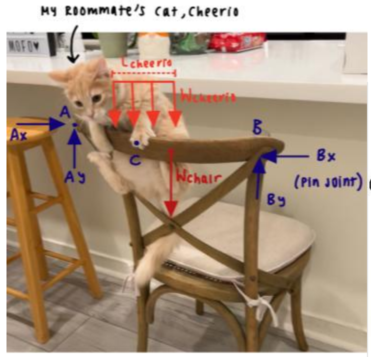








My Roommate's Cat, Cheerio



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