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PRACTICAL EXPERIENTIAL LEARNING: A METHODOLOGY APPROACH FOR TEACHING UNDERGRADUATE BIOMECHANICS

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Bagesteiro, L. B. Biomechanics is the field of study that examines different physical characteristics of the human body combined with the principles of Newtonian mechanics. This discipline requires competency in algebra, trigonometry, and physics, which is particularly challenging for many students pursuing an undergraduate degree in kinesiology. This paper presents the development and implementation of a biomechanics instructional approach for kinesiology undergraduate students using active-experimental learning sections. Focused on integrating acquired knowledge and applied real-life examples via hands-on experiences, the students work in small groups to complete five lab activities and a final project. Lab activities are designed to match concepts in the lectures as well as advance students' skills in data collection, processing, and analysis. These active and experimental learning approaches offer students the opportunity to gain occupational experience by collecting data and estimating kinematic and kinetic parameters. Students also critically interpret data and gain a solid understanding of methods used to improve the performer's movements. Throughout the semester, students demonstrate improvements in their critical thinking abilities and proficiency in using dedicated biomechanical software and hardware through a series of increasingly challenging lab activities. They also apply the learned skills in their final project, where they choose and analyze a unique movement for injury prevention and/or performance improvement. In conclusion, the progressive arrangement of these activities successfully guides students to practice and apply their data collection and analytical skills to human movement analysis.

Key Words: biomechanics, education, experiential, undergraduate laboratory

INTRODUCTION

One goal of biomechanics is to analyze human movement and apply basic mechanical concepts to physical activity and sports to prevent injury and/or improve performance (Flanagan, 2019). "Biomechanics is the study of the structure and function of biological systems by means of the methods of mechanics" (p. 189) as proposed by Hatze (1974).

At the undergraduate level, biomechanics courses are most often offered to students within the engineering (e.g., mechanical and biomedical engineering - Munro, 2012; Singh et al., 2018) and health science (e.g., Kinesiology and Sports Medicine - Hamill, 2007; Riskowski, 2015) programs. Frequently, it is an introductory course that applies mechanical principles to analyze human movement, providing a foundational level for understanding the interaction of mover and physical environment, efficiency in daily living tasks, work settings, sports, and exercise. For example, students learn how kinematic measurements apply to a performer's movements (Flanagan, 2019; Liu et al., 2017). To accomplish this, they are required to apply and integrate anatomical and biomechanical concepts to a wide variety of activities across performers of varied age, skill, acute injury, chronic disability, and fitness levels (McLester & St. Pierre, 2020).

While traditional lecture-based courses follow information presented in textbooks or other resources specified for the course (e.g., theoretical case studies), studies have reported that this approach makes it difficult for students to learn important concepts and fundamental principles as well as provide sufficient ability to apply their knowledge in different settings (Baeten et al., 2013; Bransford et al., 2000; Harris et al., 2002). Additionally, their long-term retention is frequently lower than expected, making it hard for students to connect the presented information to real-life examples. Fortunately, the effectiveness of active learning strategies has been supported by various studies (Baeten et al., 2013; Clough, 2005; Prince & Felder, 2006; Schwartz et al., 2005). This method has been shown to successfully (1) engage engineering students who work with real-world cases (applied examples, problem solving, project-based, etc.) (Harris et al., 2002; Martin et al., 2007; Roselli, & Brophy, 2003; Shultz, et al., 2019; Singh, 2017; Singh et al., 2018), (2) increase student motivation and understanding of the relationship between their in-class experiences and their future work, and (3) results in positive learning attitudes that significantly increase students' knowledge and enhance their critical thinking and communication skills, while exposing them to the components of creativity and life-long learning skills (Martin et al., 2007; Terezini, et al., 2001). While these important skill sets are needed in future movement scientists in the field of Kinesiology, limited research has specifically focused on kinesiology programs (Knudson et al., 2009). This study determined that emphasis should be given to conceptual understanding rather than quantitative problem-solving, increase laboratory activities to account for greater normalized learning and explore whether contact hours or the nature of laboratory learning experiences contribute to interactive engagement pedagogy.

Although traditional lecture-based teaching styles are often selected as the instructional approach in many science courses, the multifaceted and collaborative study of biomechanics is typically seen by learners as complicated, difficult to deal with, and less than exciting. Because it involves a different aspect of classical mechanics, motor control, and anatomy, it calls for unique student-centered teaching methods to make learning memorable (i.e., experiential learning). The hands-on aspects of a laboratory component allow personalized class examples, student generated data sets, and an opportunity for more effective active learning that students generally view positively (Catena & Carbonneau, 2018; Griff, 2016). The laboratory is an interactive environment, facilitating instructor communication in many ways (e.g., communication between instructor and students regarding course material issues, observing each student's perception in experimental practice, and one-on-one instructor-student interaction) (Singh, 2017). Furthermore, experiential learning increases motivation and engages students in real-world applications while building connections between their in-class practices and prospective professional careers (Singh et al., 2018).

KIN485 (Biomechanics) is a 3-credit upper division course required for students in the exercise and movement sciences concentration within the Department of Kinesiology at San Francisco State University (K-SFSU). It is part of the CSU Affordable Learning Solutions initiative, which provides students with Zero-Cost instructional materials. San Francisco State is an ethnically diverse university, with students coming from different backgrounds and cultures, with 39% being underrepresented minorities (URM) and 29% First Generation attending college (CSU Student Dashboard, 2020). KIN485 is generally a large class (up to 105 students) with a wide range of student math competency and math anxiety. Pre-requisites include Physics (conceptual or general), Anatomical Kinesiology, and Research Methods in Kinesiology. Biomechanics is a required course for most kinesiology majors within the CSU system.

Biomechanics is a particular challenge for many K-SFSU students because it requires competency in Algebra, Trigonometry, and Physics in order for students to successfully analyze the biomechanics of human movement. Assessment of student's baseline competencies in Algebra and Trigonometry (short quiz with multiple choice questions on Math and Mechanics) showed that out of the 181 students (Fall 2018 – Fall 2019) tested, only 31% passed the quiz, with 28% of the students falling well below basic competency levels. Additionally, almost 60% of the students scored lower than 60% for algebra and trigonometry while 80% of the students scored lower than 60% for mechanics. Thus, to target these specific K-SFSU students and facilitate learning and understanding of concepts, KIN485 has a hands-on approach in which applied hardware and software are used to help calculate and analyze biomechanical properties.

Math anxiety is another challenge among students enrolled in KIN485. Recently (Fall 2018), a total of 84 students in the course filled out the Math Anxiety Scale – Revised (MAS-R) (Bai et al., 2009). This measure has been shown to correlate with math performance in college students (Hopko et al., 2003). MAS-R scores showed that 27% had high negative affect and 38% had low positive affect scores on the bi-dimensional measure of math anxiety; those who have low positive affect and high negative affect perform worse (i.e., those with low positive and high negative scored 1 or 2 out of 5 math related questions, and less than 5 in mechanics (out of 10); whereas the high positive and low negative performed with 4-5 (math) and 7-9 in mechanics) than those with high positive affect and low negative affect. To minimize these anxieties, KIN485 assessments are structured in small, low-stake assignments and quizzes, group assessments, and projects (Warwick, 2017). This gives students lower-stress processes combined with an opportunity to demonstrate their knowledge without having to worry as much about performance.

This paper aims to describe and discuss lab activities designed for an introductory biomechanics course (KIN485) tailored to undergraduate kinesiology students by focusing on student engagement and improving comprehension of complex concepts.

HANDS-ON ACTIVE LEARNING EXPERIENCES

Students taking KIN485 meet three days a week: a large 50-min lecture section twice a week, and one lab session (2h45min – up to 35 students/section). Laboratory sessions comprise over 60% of weekly instructor contact time and thus are an essential component of this course. Students in the lecture enroll in one of three lab sessions. This combination of relatively short lectured-based and long laboratory-based teaching exposes students to the wide-ranging interdisciplinary field of biomechanics. Topics covered include: Linear and Angular Kinematics, Inertia and Momentum, Anthropometry, Equilibrium and Human Movement, Linear and Angular Kinetics, and Applied Biomechanical Examples (Occupational and Sports Biomechanics).

Over the course of a semester, students work in self-selected groups of three or four to complete five lab activities and one final group project. Groups remain the same for the entire semester. The laboratory sections are an essential component of the course as they match lecture content and help students understand and apply those concepts. With kinesiology and biomechanics studying human movement, strengthening students' skills in data collection, processing, and analysis with experiments that involve human participants is a fundamental task in biomechanics. Therefore, the final group project incorporates all lecture and lab experience, allowing students to creatively apply acquired competencies and skills while analyzing a specific movement of their choice. They are encouraged to select a task/motion that is meaningful, interesting, and relates to their own experience, making the assignment more fun and interactive to explore.

Lab Activities

Each lab is conducted over a period of two weeks. The first week is directed to familiarize students with the lab topic and provide sample data (collected from previous research) to process and analyze for practice. During the second week, they collect their own data based on the specific lab procedure. All group members are encouraged to wear appropriate clothing and shoes and participate in data collection. Every student must be an active subject (i.e., they must participate in the lab activity by performing one of the many required tasks involved in the experiment) The instructor observes their level of participation which is a factor in the instructor's graded assessment of their lab performance. The five labs are: (1) Gait Analysis (Linear Kinematics), (2) Walking Analysis (Video based), (3) Arm Reaching Analysis (Angular Kinematics), (4) Anthropometry (Inertial Properties), and (5) Ground Reaction Force Measurements (Linear Kinetics) – see Table 1. Lab sequencing is based on lecture-lessons order presentation. Throughout the five lab activities, students gain knowledge and practice using different software (e.g., Excel, Tracker, LoggerPro) and hardware (e.g., camera, electro-goniometer, force platform) and solve practical problems as they arise.

Table 1

Lab Activities Outline

Lab	Concepts	Activity	Key Terms	Equipment	Analysis
1	Linear kinematics (1D)	Walking and running	Time, position, displacement, step length, step rate, speed, velocity, and acceleration	Stopwatch, measuring tape, calculator	Spatial-temporal gait parameters, time normalization
2	Linear kinematics (2D)	Gait cycle	Time, position, gait cycle, camera speed (frequency), calibration, marker, stride length, stride time	2D motion analysis software (Tracker), cell phone camera	Planar motion, gait cycle events, center of mass displacement
3	Angular kinematics	Arm reaching	Time series, angular position, linear displacement, planar reaching, normalization, right and left differences	Tracker (motion analysis), electronic goniometer (Vernier), LoggerPro software	Angular displacement and velocity. Linear and angular relations
4	Anthropometry	Body measures	Center of mass location, body segment inertial properties, segment mass, segment length	Flexible measuring tape, 50-cm ruler, calculator, scale	Body segments inertial properties
5	Linear kinetics	Standing and balance	Time, ground reaction force components, walking force profiles, peak values, balance, 1-leg standing	Force platform (Vernier), LoggerPro software	Ground reaction forces, body-weight normalization

Lab handouts and all additional readings are posted in an online learning management system (i.e., iLearn) and required to be read prior to each lab. Lab handouts include key-terms, learning outcomes, a brief introduction, materials, experimental procedure, specific tables and graphs (data processing), and thinking points (data analysis). Students are trained to use the lab equipment in the same session they use the equipment. This is also explained in the lab handout (step-by-step instructions, similar to a brief manual). After students finish each lab activity, they are given two weeks to write up a lab report including an extended abstract and summary of results that build skills in experimental and technical-scientific writing. The extended abstract section of the lab report should provide the highlights of the experiment by answering four basic questions: (1) Why the experiment was necessary (purposes and aims); (2) What was done (background information); (3) How was it performed (materials used and experimental procedure employed to investigate the problem; (4) What was found (outcomes and implications of the work). The summary section of the lab report should also include their quantitative results (e.g., means, standard deviation, peak values) in the form of graphs and tables that address questions and purposes, as suggested in the respective laboratory handout. This section is organized around tables and figures that are sequenced to present the key findings in a logical order.

Lab Activity 1

For Lab 1 students use a universal activity to study linear kinematics: human locomotion (i.e., walking and running). Their first task is to work with Olympic running records sample data (100 m sprint event, 10-meter intervals (split times)). They are given one set of variables (i.e., displacement and time) to derive another set (i.e., velocity and acceleration). The week after, each student performs walking trials over a 15-meter distance at three speeds. The time to walk through the test zone is measured and the number of steps taken in the zone is counted. Learning outcomes for this lab are to apply the basic concepts of linear kinematics and quantitative analysis for human linear motion assessment and to use computer programs (e.g., MS Excel) for data processing and analysis. The lab goal is to verify the relationship of gait spatial-temporal parameters and different walking speeds. Specific outcomes are: apply the basic concepts of linear kinematics and quantitative analysis for human linear motion assessment and use computer programs (e.g., MS Excel) for data processing and analysis (i.e., sprinters' position, velocity, and acceleration curves). Depending on certain conditions (e.g., weather, track availability, etc.), a variation of this lab consists of collecting and reproducing 100-m amateur running data at the track, with three different sport background volunteers.

Lab Activity 2

Lab 2 introduces the use of an open-source video analysis software – Tracker (Brown, 2018) – to perform 2D walking analysis (gait cycle) an important daily activity. In the first week of Lab 2, students are given video files of four different participants pre-recorded from both right and left sides. In the following week, they videotape two groupmate walking trials and perform the same analysis. By the end of this session, they are able to collect, analyze and quantify a gait cycle using Tracker (Brown, 2018) for motion analysis (see Figure 1). Lab 2 aims to compare, contrast, and evaluate specific gait events and parameters (e.g., step length, support time, stance phase and swing time) among different participants with regard to age, gender and body side. They also learn to express displacement and time variables, as a function of (%) body height and gait cycle, respectively.

Lab Activity 3

In Lab 3, students continue using Tracker to investigate angular motion of the upper extremities during an essential daily activity, i.e., planar reaching (see Figure 2). They first work with pre-recorded reaching videos. These videos show two participants performing fast targeted reaching with right and left arms. The purpose of this lab is to examine and describe elbow angular motion and hand linear displacement when comparing the two participants and differences and/or similarities between the hands. In the succeeding week they are provided with an electronic goniometer (Vernier, 2013) to measure the elbow extension (angular displacement) when performing right and left planar arm reaching movements of one group member. The focus of this section of the lab is the elbow joint movement measurement, description, and comparison once movements are time normalized (% of movement time).

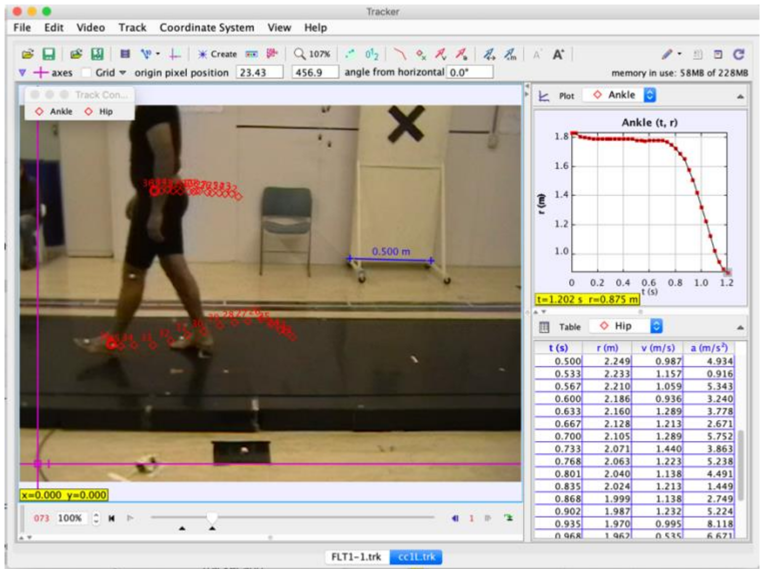

Figure 1. Screen shot of video analysis tool (Tracker) with sample processed analysis of gait cycle (Lab 2) video.

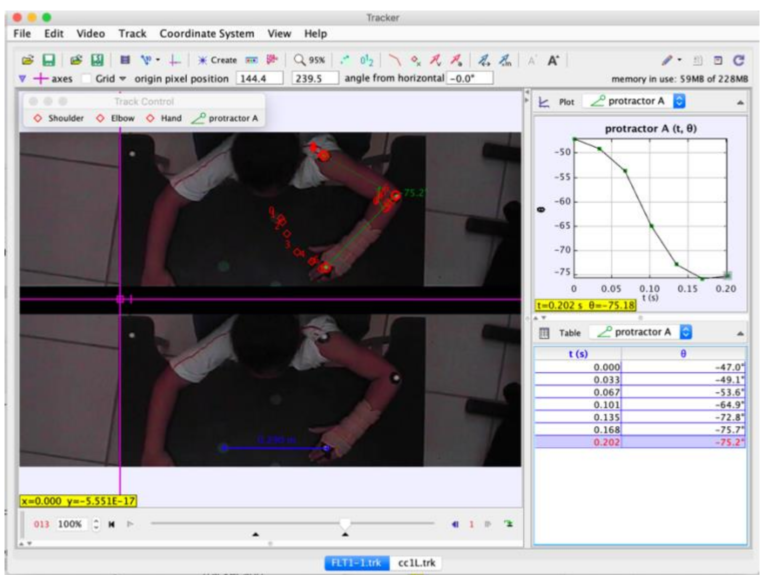

Figure 2. Screen shot of video analysis tool (Tracker) with sample processed analysis of reaching task (Lab 3) video.

Lab Activity 4

Easily accessible materials are used in Lab 4; however, calculations and analysis are increasingly complex because body segments inertial properties estimation require extensive use of equations. Two students from each group volunteer to have their body segments measured. Following anthropometric models' diagrams, specific body measurements are taken as well as participants' body mass and standing height. Students are reminded that accurate measurements are critical to obtain a good estimation, and thus, they are to carry out the measurements in the most precise way possible. This lab's purpose is to take specific measurements of two student bodies and estimate their segmental masses and locations of segments' center of mass. The expected outcome is to accurately calculate body parameters using direct and indirect methods and compare their results.

Lab Activity 5

Lab 5 introduces students to ground reaction force (GRF) components analysis. Students are first presented with force platform (FP) files representing 3D GRF components. These are force vs. time profiles from two participants walking and running at comfortable speeds. They manipulate and process force and time data series to examine and interpret GRF profiles for walking and running. In order to make comparisons they normalize averaged profiles to body weight (BW) and % of movement time (see Figure 3). Their analysis focuses on differences and/or similarities in the vertical and horizontal force data in terms of peak values and time to reach these values. Subsequently, they measure the GRF developed during standing. They then examine and interpret GRF profiles during two- and one-leg balance, as well as compare vertical GRF means and standard deviations for different conditions.

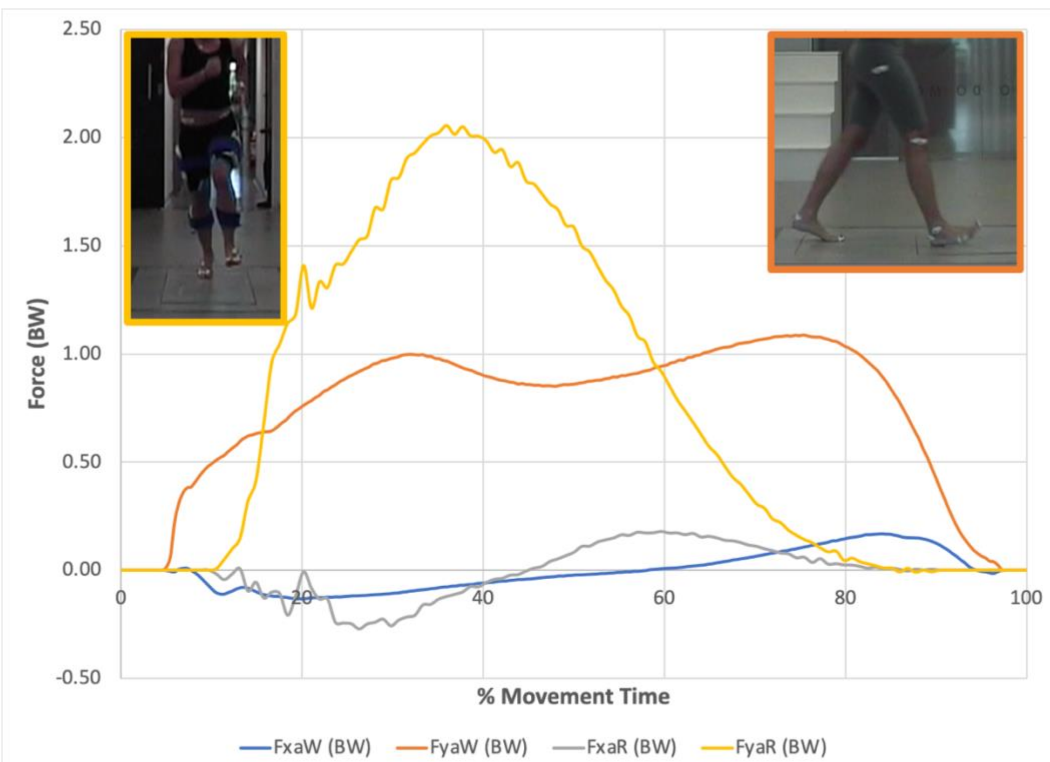

Figure 3. Lab 5: Normalized GRF profiles, walking (W) and running (R) comparison. The insets depict sample screen shots of participants' walking (orange border – sagittal view) and running (yellow border – frontal view) on the force platform.

Final Project

The final group assignment is a semester-long project where students work on the design, data acquisition and analysis, and draw conclusions. The group members remain the same for the entire semester. Student groups are encouraged to choose a unique movement that they are interested in analyzing biomechanically and conduct a kinematic video-based analysis on their activity (e.g., walking upstairs, taekwondo push-kick, overhead soccer throw, volleyball jump serve, swim starting block jump). With access to all of the equipment used in previous labs, students analyze their movement for the purpose of improving performance and/or preventing injury.

Group work creates opportunities for professional development skills such us diverse critical thinking, collaborative and co-operative learning and achievement. It also challenges students' abilities to communicate effectively, work efficiently and manage personality conflicts. To enhance some of these factors the project is assessed in two parts. Around midterm, students do a 3-5-minute presentation as a checkpoint, where they receive feedback from the audience (i.e., instructor, graduate teaching assistant, and peers). Frequently, while developing the final project during our lab sessions a practical question for students at this time is to choose the required body-markers for their specific purposes. This often provides lively interactions, leading up to comprehension and understanding of this key point of the analysis. At the end of the semester, these projects culminate with a 5-min video presentation by students showing their experiment protocol (e.g., number of trials, number of participants, handedness, etc.), results interpretation (i.e., data processing through graphs and tables, followed by data analysis to determine findings and draw conclusions), and concrete functional plan to improve movement performance or prevent performer's injury (e.g., weekly routine exercise schedule and/or rehabilitation protocol).

FINAL REMARKS AND FUTURE WORK

This paper has summarized biomechanics lab activities designed to promote students' learning in a low-cost undergraduate kinesiology course. Description of each lab, its learning objectives, and outcomes were discussed. It is well established that biomechanics is a crucial discipline within a kinesiology degree. As such, it is important to introduce and expose learners to all fields that they will encounter while pursuing their careers in kinesiology. As described here, a possible course delivery method includes lectures and lab arrangements specifically planned to integrate students' everyday real-world applications with the extensive and comprehensive field of biomechanics.

Students' qualitative comments express appreciation towards the hands-on experience, stating that they are enjoyable, helpful, and realistic. More specifically, they stated that the course structure helped them improve their data analytical and graphical illustration skills, which reflects their appreciation of making connections that further their understanding of movement-related sciences and practitioners. Furthermore, students' performance seemed quite favorable to the active learning method. Their positive response could be a result of the dynamically motivated learning environment, which includes working collaboratively in engaging and relevant lab experiences that provide timely learning progress feedback.

Previous studies (Clough, 2005; Martin et al., 2007; Prince & Felder, 2006; Riskowski, 2015; Schwartz et al., 2005; Warwick, 2017) have indicated that the active and experiential learning approach fostered students' technical knowledge and life-long learning skills while exposing them to the components of adaptive learning and innovation. Moreover, such experiences have resulted in significantly higher learning gains and better conceptual understanding.

The course setting described here models how biomechanics can be taught to increase student engagement through effective hands-on learning (Shultz et al., 2019), which may also play a vital role in students' confidence and perception to ensure understanding of advanced concepts. Also important is the classroom environment (Catena & Carbonneau, 2018). By applying small group assignments and incremental learning, students build a supportive community of learners that decreases the fear of making mistakes and stimulates questioning as a positive experience. This is enhanced by extensive time spent in a laboratory environment (i.e., reduced formal lecture time), which offers more time for student-instructor and student-student interactions (e.g., problem-solving sessions and open discussions). As a consequence, lab activities are design to complement lectures and be a focal point to foster students' critical thinking skills and probe experimental investigation. As the course progresses, it exposes students to human movement applications associated with their future careers in sports and/or rehabilitation (Bye et al., 2019; Roselli & Brophy, 2003).

In summary, the hands-on opportunities in KIN485 presented here provide practice with biomechanical concepts, which appear to achieve the primary purpose of comprehending major topics of human movement and analysis. Throughout the semester, students experience different methods of data collection and draw conclusions from it, which successfully address the secondary purpose of this project to enhance students' skills in data collection, processing, and analysis. Some potential future directions to explore are: (a) number of students in class - it seems beneficial to reduce class size to improve students' learning experience; (b) peer mentorship - it can help students learn from each other's experience and thrive together; (c) guest speakers and/or field trips - to enhance biomechanics relevancy/applicability in students' view as well as prospective networking opportunities; (d) public engagement, to promote commitment and a two-way process of interaction and listening with a mutual goal. These can be implemented in a future controlled quantitative study and should include student survey data, student learning outcomes and assessments through reviewers and instructor scores, and peer evaluations. Such study can focus on evaluating the efficacy of an interactive engagement pedagogy to increase student learning and performance in biomechanics specifically focused on kinesiology programs as reported in science classes (Harris et al., 2002; Riskowski, 2015; Roselli & Brophy, 2003; Singh et al., 2018).

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REFERENCES

Baeten, M., Dochy, F., & Struyven, K. (2013). The effects of different learning environments on students' motivation for learning and their achievement. The British Journal of Educational Psychology, 83(Pt 3), 484–501. https://doi.org/10.1111/j.2044-8279.2012.02076.x

Bai, H., Wang, L., Pan, W., Mary, F. (2009). Measuring mathematics anxiety: Psychometric analysis of a bidimensional affective scale. Journal of Instructional Psychology. 36(3), 185-193.

Bransford, J. D., Brown, A. L., Cocking, R.R., Donovan, M.S., & Pellegrino, J. W. (Eds.). (2000). How people learn: Mind, brain, experience, and school. Washington, DC: National Academy Press.

Brown, D., (2018). Tracker. Java video analysis and modeling [Computer software]. https://physlets.org/tracker/

Bye, T. K., Carter, K. R., Carrier, D. R., & Elmer, S. J. (2019). An outside-the-box activity to demonstrate how humans and animals turn. Advances in Physiology Education, 43(3), 282–287. https://doi.org/10.1152/advan.00159.2018

Catena, R. D., & Carbonneau, K. J. (2018). Guided hands-on activities can improve student learning in a lecture-based qualitative biomechanics course. Anatomical Sciences Education, 12(5), 485–493. https://doi.org/10.1002/ase.1832

Clough, G. (2005). Educating the engineer of 2020: Adapting engineering education to the new century. National Academy of Engineering. Washington, DC: National Academy Press.

CSU – The California State University. CSU Student Success Dashboard - Who Are My Students? (2020, August 12). https://csusuccess.dashboards.calstate.edu/public/csu-by-the-numbers/student-populations

Flanagan, S. P. (2019). Lesson 1 Introduction. In Biomechanics: A case-based approach (pp. 1-9). Burlington, MA: Jones & Bartlett Learning.

Griff, E. R. (2016). Changing undergraduate human anatomy and physiology laboratories: Perspectives from a large-enrollment course. Advances in Physiology Education, 40(3), 388–392. https://doi.org/10.1152/advan.00057.2016

Hamill, J. (2007). Biomechanics curriculum: Its content and relevance to movement sciences. Quest, 59(1), 25–33. https://doi.org/10.1080/00336297.2007.10483533

Harris, T. R., Bransford, J. D., & Brophy, S. P. (2002). Roles for learning sciences and learning technologies in biomedical engineering education: A review of recent advances. Annual Review of Biomedical Engineering, 4, 29–48. https://doi.org/10.1146/annurev.bioeng.4.091701.125502

Hatze, H. (1974). The meaning of the term biomechanics. Journal of Biomechanics, 7(2), 189–190.

Hopko, D. R., Mahadevan, R., Bare, R. L., & Hunt, M. K. (2003). The abbreviated math anxiety scale (AMAS): Construction, validity, and reliability. Assessment, 10(2), 178–182. https://doi.org/10.1177/1073191103010002008

Knudson, D., Bauer, J., & Bahamonde, R. (2009). Correlates of learning in introductory biomechanics. Perceptual and Motor Skills, 108(2), 499–504. https://doi.org/10.2466/PMS.108.2.499-504

Liu, W. Y., Spruit, M. A., Delbressine, J. M., Willems, P. J., Franssen, F., Wouters, E., & Meijer, K. (2017). Spatiotemporal gait characteristics in patients with COPD during the gait real-time analysis interactive lab-based 6-minute walk test. PloS one, 12(12), e0190099. https://doi.org/10.1371/journal.pone.0190099

Martin, T., Rivale, S. D., & Diller, K. R. (2007). Comparison of student learning in challenge-based and traditional instruction in biomedical engineering. Annals of Biomedical Engineering, 35(8), 1312–1323. https://doi.org/10.1007/s10439-007-9297-7

McLester, J., & St. Pierre, P. (2020). Chapter 1: Biomechanics and related movement disciplines. In Applied biomechanics: Concepts and connections (pp. 1-5). Burlington, MA: Jones & Bartlett Learning.

Munro, D. (2012). Work in progress: Hands-on biomechanics lab for undergraduate universities. Proceedings - Frontiers in Education Conference. 1-6. DOI: 10.1109/FIE.2012.6462235.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. Journal of Engineering Education, 95(2), 123–138. https://doi.org/10.1002/j.2168-9830.2006.tb00884.x

Riskowski, J. L. (2015) Teaching undergraduate biomechanics with Just-in-Time Teaching, Sports Biomechanics, 14(2), 168 –179. https://doi.org/10.1080/14763141.2015.1030686

Roselli, R. J., & Brophy, S. P. (2003). Redesigning a biomechanics course using challenge-based instruction. IEEE Engineering in Medicine and Biology Magazine: The Quarterly Magazine of the Engineering in Medicine & Biology Society, 22(4), 66–70. https://doi.org/10.1109/memb.2003.1237504

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. In J. Mestre (Ed.), In Transfer of learning from a modern multidisciplinary perspective (pp. 1-51). Greenwich, CT: Information Age Publishing.

Shultz, S. P., Millar, S. K., Fink, P., Hébert-Losier, K., Handsfield, G., Sheerin, K., Wells, D., & Clarke, J. (2019). Improving engagement with biomechanics: Student perspectives and a professional development initiative. Journal of Biomechanical Engineering, (87)18, 202–205, https://doi.org/10.1016/j.jbiomech.2019.03.006

Singh, A. (2017). A new approach to teaching biomechanics through active, adaptive, and experiential learning. Journal of Biomechanical Engineering, 139(7), 071001–071007. https://doi.org/10.1115/1.4036604.

Singh, A., Ferry, D., & Mills, S. (2018). Improving biomedical engineering education through continuity in adaptive, experiential, and interdisciplinary learning environments. Journal of Biomechanical Engineering, 140(8), 081009–081016. https://doi.org/10.1115/1.4040359

Terezini, P. T., Cabrera, A. F., Colbeck, C. L., & Bjorklund, S. A. (2001). Collaborative learning vs. lecture/discussion: Students' reported learning gains. Journal of Engineering Education, 90(1), 123–129. https://doi.org/10.1002/j.2168-9830.2001.tb00579.x

Vernier. (2013). Goniometer (GNM-BTA) [Apparatus and software] https://www.vernier.com/product/goniometer/

Warwick, J. (2017). Dealing with mathematical anxiety: Should one size fit all? The Mathematics Enthusiast, 14(1-3), 161–174.

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