WIP: Enhancing Student Understanding of Impact Dynamics Using a Jupyter-Based Simulation Tool for Injury Analysis

Mr. Nicholas J. Caccese, CBE Consultants, Inc.

Mr. Nicholas Caccese is a Technical Associate at CBE Consultants, Inc. Mr. Caccese is gaining experience applying biomechanics to a variety of real-world problems, including: automotive collisions; falls from various heights and in various orientations; impacts from falling objects; injuries resulting from the misuse of a variety of devices; and amusement ride verification. After completing an M.S. and B.S. program in Biomedical Engineering at Temple University, Mr. Caccese began his consulting career in 2019. Mr. Caccese utilizes his knowledge to assist in investigating and assessing the forces, accelerations, and motions experienced by the human body. Mr. Caccese is also developing the ability to review medical records for the purpose of assisting in the evaluation of the extent, distribution, and severity of injuries and the past medical history as it relates to the biomechanical analysis and claims, while assessing the biomechanical forces that could lead to the causation of any claimed injuries. He also has experience reviewing a variety of different imaging modalities, including Fourier Transform Infrared Imaging Spectroscopy (FTIR-IS) for evaluation of various biomedical samples and constructs, with an educational background in CT and MRI imaging. Mr. Caccese's research interests include the anthropometry of device usage, computational modeling of different bodily systems, and statistical evaluation of varying data sets.

As a consultant, Mr. Caccese applies his knowledge to assist with the analyses of injury causations and accident reconstructions for a variety of projects. He assesses whether motions, accelerations, and loads can cause injury, and his experience includes contributing to analyses and reconstructions of motor vehicle crashes; sports, and occupational injuries; and falls. He also contributes to biomechanical analyses of incidents involving consumer devices, including rolling knee walkers and hydraulic lifts, and amusement devices, including roller-coasters and water rides. He has contributed to the evaluation of biomechanical issues and injury potential associated with alternate scenarios, such as changes in design or safety equipment.

Prior to his consulting career, Mr. Caccese was employed by the research labs of Temple University's Bioengineering Department. His areas of research included: developing modules for an image tracking system to allow for computer assisted control of experiments into mechanics of animal locomotion response; culture, verification, and validation of multiple different cell lines; and design of devices to automate laboratory protocols for a research environment. In addition to his research, he operated as the assistant lab manager where he coordinated certifications, trainings, and logistical concerns for approximately 30 members across four different research groups and completed maintenance of shared laboratory equipment. He also was a founding member of the Temple University Biomedical Engineering Society (BMES) student chapter and acted as the secretary and vice president over the course of his undergraduate studies.

Dr. Robert S. Cargill II P.E., CBE Consultants, Inc.

Dr. Robert S. Cargill II is the President of CBE Consultants, Inc. Dr. Cargill applies his expertise in the principles of bioengineering to projects emphasizing the interaction between a biological system and the physical environment, particularly issues involving the biomechanics of human injury in the areas of human tolerance, occupant kinematics, and rigid body dynamics. Dr. Cargill is a seasoned testifier with testimony experience in multiple state and federal jurisdictions. His areas of specialized interest include the conceptualization, design, analysis, and evaluation of medical devices and related products, as well as in-depth forensic investigation of traumatic human injury related to machine design and failure using his specialized knowledge of industrial and construction machinery, power tools, hand tools, amusement rides, and firefighting and rescue equipment. Previously the Engineering Director at JP Research, Inc. and President of Cargill Bioengineering, LLC, and prior to that a Senior Managing Engineer with Exponent, Inc., Dr. Cargill has many years' experience evaluating forensic issues related to injury causation and product liability concerning: power tools (portable and stationary); specialized fall protection, firefighting, and rescue equipment; amusement rides and devices; industrial and construction equipment; and

automobiles and heavy trucks. In addition, he has designed and evaluated specialized products in the areas of medical devices and firefighting equipment. Dr. Cargill has also performed original research in the areas of traumatic brain injury and cell and tissue biomechanics. He has experience in cell and tissue culture techniques, research equipment design and construction, computer and physical modeling, and computer programming. Dr. Cargill has lectured in the Department of Mechanical and Aerospace Engineering at Princeton University, the Department of Mechanical Engineering and Orthopaedics at the University of British Columbia, and the Department of Mechanical Engineering at the Cooper Union. He has been an Adjunct Associate Professor at Widener University and Villanova University, a member of the academic faculty at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology, and a Research Associate and Post-Doctoral Fellow at the University of Pennsylvania. A licensed professional engineer in Alabama, New Jersey, and Pennsylvania, Dr. Cargill is also an active firefighter in New Jersey (currently Incident Safety Officer at Greenfields Volunteer Fire Company). In addition to his extensive firefighter and rescue training and experience, he previously held certification as an Emergency Medical Technician in New York and Connecticut (1986 to 1990).

Dr. Ruth Ochia P.E., Temple University

Ruth S. Ochia received her B.S. degree in biomedical engineering from The Johns Hopkins University, Baltimore, Md., in 1992 and her Ph.D. degree in bioengineering from the University of Washington, Seattle, Wash., in 2000. From 2000 to 2002, she was a Post-doctoral Fellow in the Center of Locomotion Studies, at The Pennsylvania State University, State College, Pa. From 2002 to 2006, she was a Post-doctoral Fellow and then Assistant Professor at Rush University Medical Center, Chicago, Ill. From 2006 to 2009, she was a Senior Associate with Exponent, Inc. From 2009 to 2013, she was principal of RSO Consulting, LLC, and taught as an Adjunct Professor at Widener University, Chester, Pa. Currently, she is a Professor of Instruction with the Bioengineering Department, Temple University, Philadelphia, Pa. Her research interests have included Biomechanics, primarily focusing on spine-related injuries and degeneration. Currently, her interests are in engineering education, curriculum development, and assessment.

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Introduction: Problem Based Learning (PBL) has been shown to be effective in bridging the gap between theoretical and practical engineering education.[4-6] Engineering dynamics has been specifically shown to be enhanced by using a PBL approach.[1,6] To enhance student understanding of this topic, we are using a real-world case study of potential head and neck injury due to impact from a falling piece of plaster to illustrate fundamentals of impacts and fracture mechanics in an undergraduate biomechanics course. The industrial partners developed a Jupyter Notebook (JN)-based[2] analytic model in Python[11,12] that incorporated the impact response of frangible materials and energy and momentum transfer. JN is a free and open-source tool that has seen widespread adoption in education and can be used to create dynamic and responsive visual aids to assist in the conveying of complex engineering topics,[3] which will enable students to "visualize" the effects of parametric changes and improve student learning.[7] This case formed our initial industrial-academia partnership for introducing real-world problems with the application of simulations into undergraduate curricula. The student groups were assessed on their approaches to the problem before and after exposure to the JN model.

Materials and Methods: The participants were 20 sophomore- and junior-level Bioengineering students in the second in a series of elective biomechanics courses, focused on mechanics of materials and dynamics. The students in the class were familiar with analyzing open-ended problems that required the teams to apply fundamental knowledge in a PBL setting.

The PBL Problem Statement described plaster falling from the ceiling onto a seated individual who claimed brain and neck injury. The problem was to evaluate the subject's injury potential. Information relevant to the case was provided to the students. The student teams were to determine the approach and apply their recently gained knowledge of mechanics of materials and impact dynamics to the evaluation of this biomechanics problem. This was the first time an impact problem was used as the basis for the PBL assignments in this course.

The study was divided into two sequential components: Phases 1 and 2. Phase 1 involved six teams of 3-4 students being exposed to the PBL without additional tools with the goal to do an on-paper analysis and report. The teams were provided with the scenario and were given 1 month to devise a solution and present it via a report format, which provided a structure for solving complex problems.[8] The students were frequently asked for any clarification questions, but actual review of their approaches prior to the due date was not done. Phase 2 involved the students being given the same problem statement, but with access to the JN simulation of the incident and relevant biomechanics articles. Phase 2 was conducted at the very end of the semester due to issues in setting up the JN for student use, such that students were offered to do a revision of their Phase 1 PBL as an extra credit assignment. Four teams (9 students) revised their work using the simulation.

The turnkey, JN, interface included three components: a static text description, the interface to the model and parameters, and the output of the model. The static description included: a description of the problem, a description of the model, and the model parameters available to the students for manipulation. The initial values of the parameters were those used by the industrial partners in their approach to evaluating the problem. Students could adjust each parameter via the mouse or by directly typing in values. After each change, the model output was automatically recalculated and displayed in real time. The output of the model was a simple plot of the head acceleration versus time and the neck axial load versus time. The underlying code was hidden from the students to allow them to focus on the response of the model rather than the implementation of the model or how it was coded in Python. The incident model was a one-dimensional, 4th-order, undamped mechanical system and included the impact of the plaster on the head, the bending of the plaster due to impact, and the spring-mass model of the head and neck. The incorporation of the bending of the plaster (as a plate with central contact) allowed the calculation of the maximum stress, which provided a means by which to evaluate fracture of the plaster. The objective was to illustrate to the students how the head and neck response changed if the plaster fractured.

Assessment: The PBL assignments were graded using a rubric following a multi-stepped structure for problem solving.[8] For Phase 2 of this problem, the student teams were asked to reflect specifically on the differences between their treatment of this assignment before and after the introduction of the modeling tool. The student teams' approaches to the problem were evaluated in a qualitative manner.

Results: The students' initial approach to the problem (Phase 1) was widely variable and lacking in some fundamental aspects of the problem; with some groups taking a subjective, epidemiological approach,which was completely outside the class scope. Most of the teams did not include any analysis of potential neck injury. Additionally, most of the initial solutions were based on simple impact mechanics of a point mass to the head. Some groups estimated the terminal velocity of the plaster and developed simple impact models to determine head acceleration in an effort to predict if skull fractures or concussions were possible. Two teams only calculated terminal velocity of the plaster section and then did not use this calculation further in their analyses. In addition, none of the students discussed the aspects of strength of materials related to bending and fracture of the plaster in their analyses and instead addressed the plaster as a "point" mass that contacted the top of the head.

Access to the JN in Phase 2 of the study exposed the students to another approach to the problem that differed considerably from any of the teams' initial approaches. Most of the groups evaluated the matching parameter values from their Phase 1 model with those of the JN model to investigate how ranges of data can affect outcomes. In addition, they discussed the differences between their assumptions and approaches with those of the "expert." Further, the implementation of the interaction between the head and neck in the simulations with regards to force transmission and estimating injury potential exposed the students to a novel approach to modeling the human body that had not been considered. Correspondingly, some of the students stated that their calculations were oversimplified relative to the JN model, and that they would like to see more examples of these types of models.

Discussion: The approaches taken in Phase 1 were limited, with no ability to investigate the plaster fracture as it interacted with the head. The introduction of the JN simulation demonstrated to the teams the multiple facets of the problem and how their engineering knowledge could be applied to develop possible solutions. The obvious disconnect between book equations and their application to real problems was the impetus for introducing PBL assignments into the class in the first place. The authors were aware that the model included in the JN was more complicated than what the students were anticipated to develop. However, the authors were surprised at the extent of the discrepancy between the students' approaches and calculations versus the "expert" solution. The authors had originally thought that the underlying paradigms and mechanical intuition necessary to develop a model similar to the JN model were within the capabilities of the students. The students' responses revealed that they were lacking the key insights borne generally out of experience or deep mechanical understanding.

The results of this initial study reframed the focus of the work to include the development of these engineering insights in future PBL problems. Judiciously planned and discussed homework or in-class assignments could also provide guidance to move the students' phase 1 models closer to the "expert" model found in the JN. The wide range of approaches taken by the students in the Phase 1 was revealing in that the original problem statement was potentially too broad in topic for students at this level. Including specific instructions for the students to use their engineering knowledge to evaluate the scenario for head and neck injury by observing the head energy and acceleration could potentially reign in some of the more unique analyses used by the students. Regular scaffolded assignments related to the overarching PBL scenario could also be used as a way to steer the students' approach to the analysis without explicitly laying out the analysis for them. Thus allowing the students to make these connections on their own.[9]

The student's desire to obtain more exposure to the engineering thought processes that went into the development of the model in the JN illustrates the concept of the "professional eye" versus a "student eye".[10] This discrepancy between the approach a student takes to a problem versus a professional engineer is important to consider when designing a PBL scenario. While it may seem to go without saying, it is worth remembering that topics and methods that seem trivial to a professional could not be considered by the students as they either have not been exposed to them or have not made the mental connections that a specific topic or method would be useful in approaching the PBL scenario.

There were several limitations to this study. As the JN was not available to the students until the end of the course, the time the students had to familiarize themselves with the model was limited and the final assignment was voluntary. The PBL scenario was complex, with some aspects outside of the scope of the course (e.g. modeling the plaster as a plate and including fracture in the model). This could be alleviated by reducing the complexity of the Phase 2 model while leading the teams' approaches in Phase 1 toward a more realistic model. In essence, meeting in the middle. Finally, the model itself was a black-box, not allowing the students to see how it was implemented in JN. Although the original motivation was to reduce possible confusion and complexity for the students, some students stated a willingness to create their own simulations for use in this class or others. Access to the code while minimizing distraction and overload may be accomplished in the future by exposing the students to aspects of the model through homework assignments or by utilizing a kernel (the programming language backing up the JN calculations) in a familiar programming language.

Conclusions: The use of JN simulations with PBL problems in this course revealed many opportunities and limitations. The step from textbook solutions to real world situations has been shown to be a large one. Students want to see different approaches to problems to ensure that they are going in the right direction. This is similar to the active learning technique "think-pair-share" that is commonly employed in the classroom.[8] Part of the PBL process is to show that there is "no right answer" and different solutions are a result of initial assumptions and definitions of the scenario. Therefore, it is not desirable for students to converge on a "right" answer in this context. However in light of this problem, more formative feedback on the approaches would help students stay on track and the development of simulations for each PBL could be helpful. Whether these simulations are given by the instructor or developed by the students will depend on the course learning goals, class time, and class foundational knowledge.

Further work will need to include how to present modeling/simulations in a class that is learning the basics of biomechanics.

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