**Supplemental Information: Challenge Based Instruction Cultivates Transferable Skill and Confidence in Biomedical Problem Solving**

## Representative Survey Problem: Biomechanics

In Ethiopia, 76 percent of the population (77 million people) lack access to water. Therefore, in order to get water for families to drink, prepare food, or bathe, individuals must fill containers with water at the nearest source and carry it to their home or village. In Ethiopia, the average individual needs four gallons of water per day. Each gallon of water weighs 8 lbs (approximately 3.6 kg). This act of carrying water often falls on women and children in the village, who have the time during the day to make the round trip to the water source. To put in perspective, these loads of water are typically no less than 20% and no more than 35% of their body weight.

The average Ethiopian family lives 6 kilometers (round trip) from the nearest water source. Therefore, women must load jugs and buckets with water and carry each of them for a length of three miles, mostly along gravel or dirt paths. To complete this task, they rely on back carrying (using jugs, which are strapped to the back), or head carrying. Head carrying dates back to ancient times, and involves walking to one's destination while balancing a significant load on top of the skull.

In 1985, a team of researchers from South Africa and Scotland studied a group of six women from the Luo and Kikuyu tribes and, interestingly, discovered that the women could carry a load of up to 20% of their body weight on their head without expending any more energy than they would in an unencumbered walk (no water). Aspects of the gait that these women had developed included, but were not limited to, increased bone density in the spinal cord, and the strengthening of specific muscle groups.

In 2010, a team of researchers at Cape Peninsula University of Technology in South Africa disputed the experimental design of the 1985 study, and conducted their own controlled experiment of head carrying. They found that experience with head carrying (10 years, on average) provided no benefit to women, in terms of energy expenditure. Additionally, they found head carrying and back carrying to be equally effective, in terms of energy expenditure.

You have been called as an engineering consultant by the authors of the original study (1985). They have extensive experience studying African tribes, but they have no significant knowledge in the area of biomechanics. They want you to develop a biomechanical model of head carrying that could reinforce or dispute the findings of their original work.

Your challenge here is two-fold. First, to develop a model for head carrying. Relevant free body diagrams will be especially important here. Second, to make a recommendation to the researchers as to whether their original conclusion, which was that loads of up to 20% could be carried without additional energy expenditure, was likely legitimate or the result of an experimental design error.

***Figure S1:*** *A representative challenge problem from interview settings (biomechanics content, for assessment of GIM-confidence transfer) is given above. Students were given either this challenge, or one of two others of similar scope and difficulty. By the end of the class, each student was given each challenge exactly one time. Similar biomechanics challenges were given to students in interview settings, to assess transfer of the GIM framework.*

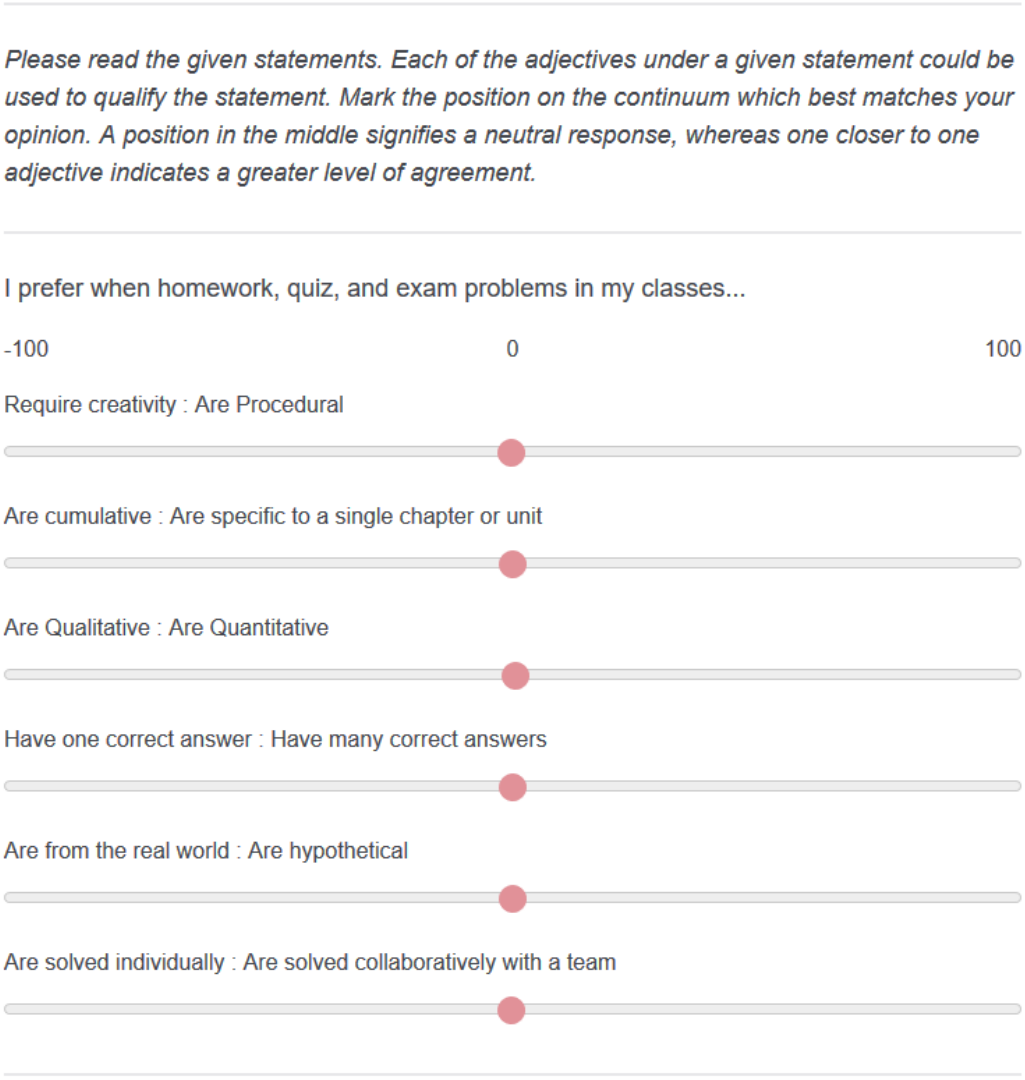


***Figure S2:*** *Semantic differential question(s) regarding class preferences. Responses given in Figure S8.*

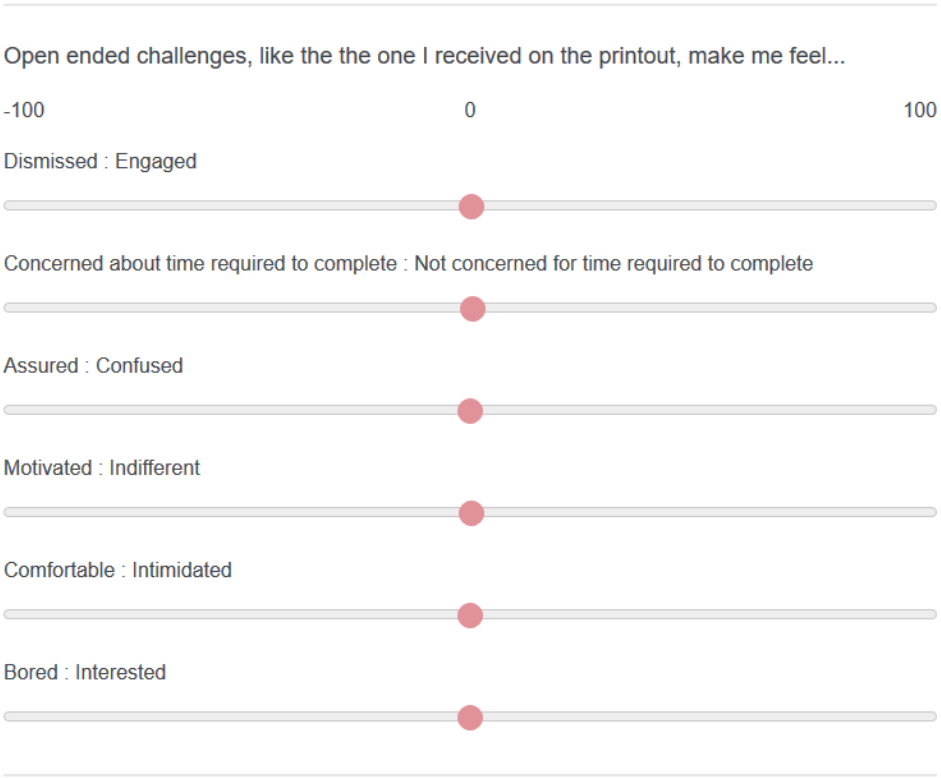


***Figure S3:*** *Semantic differential question(s) regarding students' attitudes and opinions toward open- ended challenges. Responses are given in Figure 5.*

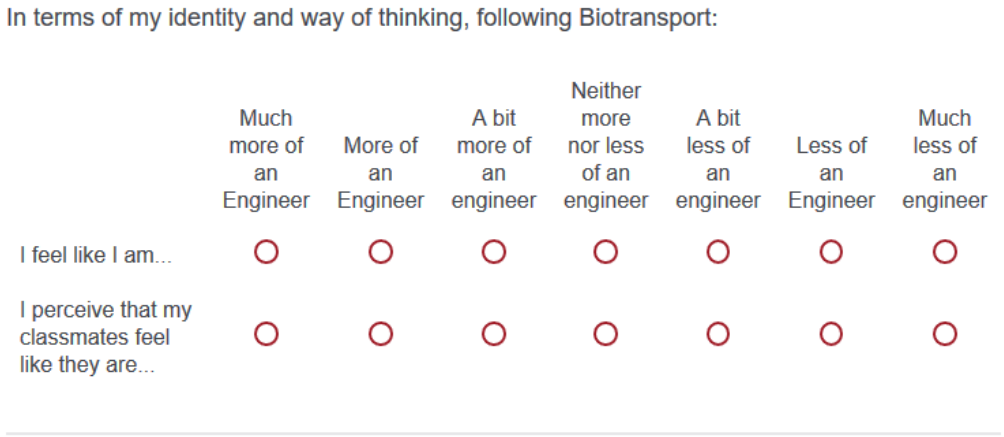


***Figure S4:*** *7-point Likert-scale questions probing students' degree of identification as a practitioner of engineering. Results given in Figure 6.*

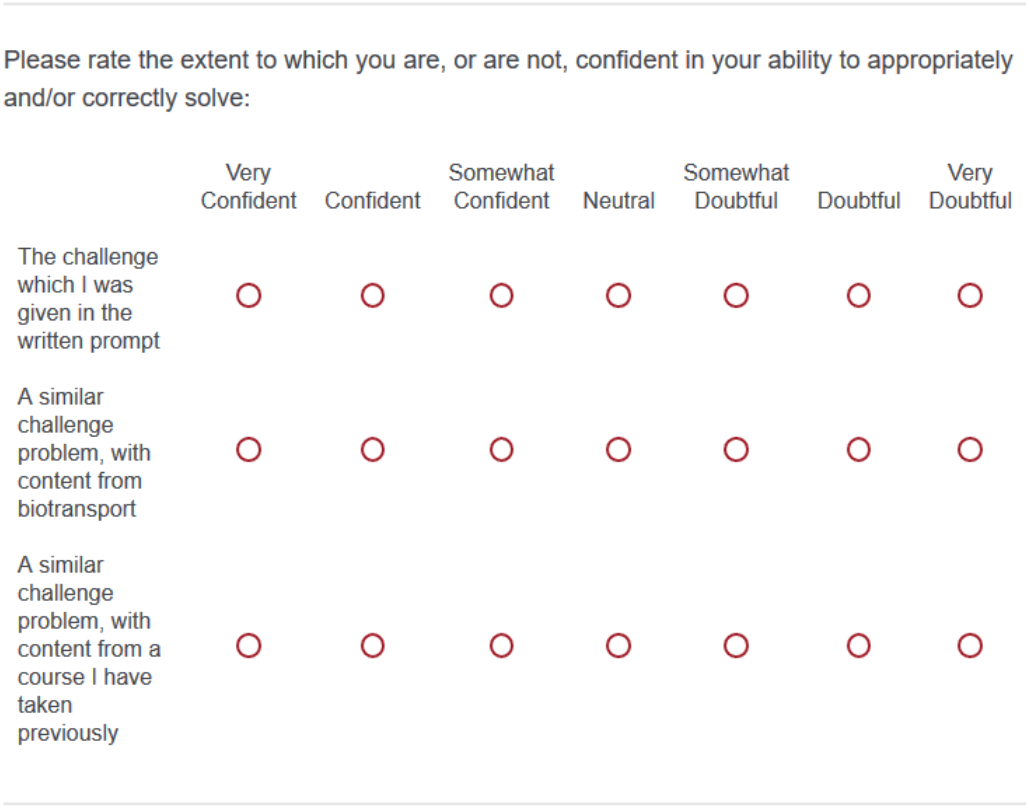


***Figure S5:*** *Students' confidence toward solving open-ended challenges, in various content domains, was assessed using a 7-point Likert scale. The challenge that students were given in the prompt was derived from biomechanics content (See Figure S1). All students in the class had taken biomechanics previously at their home institution.*

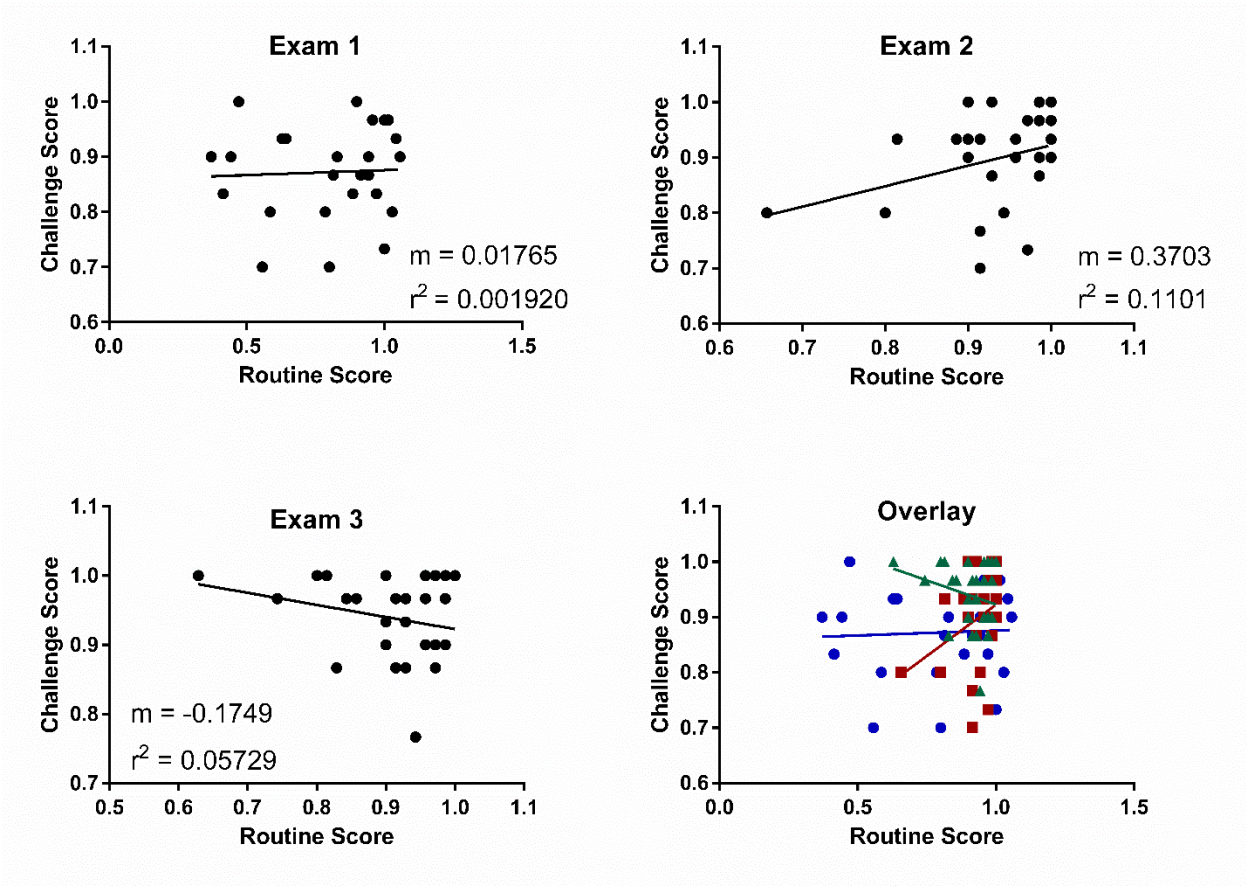


***Figure S6:*** *Routine-Challenge predictive power and regression analysis, separated by exam. Slope and goodness-of-fit values are given for each regression. n=29. Exam 1 covered system analysis and fluid mechanics, exam 2 focused on bioheat transfer, and exam 3 was a cumulative final exam. Cumulative regression analysis of all exams is given in Figure 3c.*

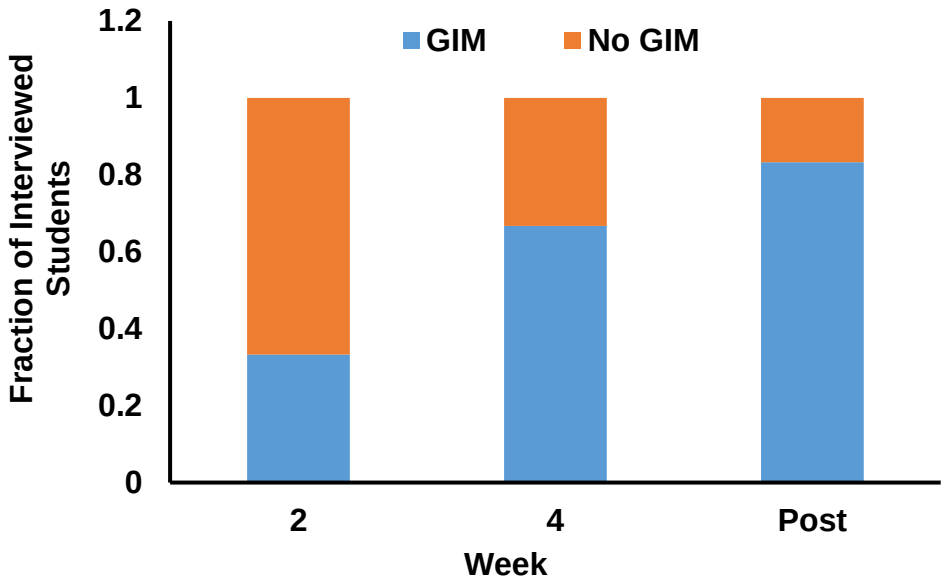


***Figure S7:*** *Graphical depiction of the evolution of students' frameworks for solving open-ended biomechanics challenges. The proportion of interviewed students (6) that employed a modified-GIM framework for solving the challenge is given for each interview iteration. The post-class interviews occurred more than two months after course completion.*

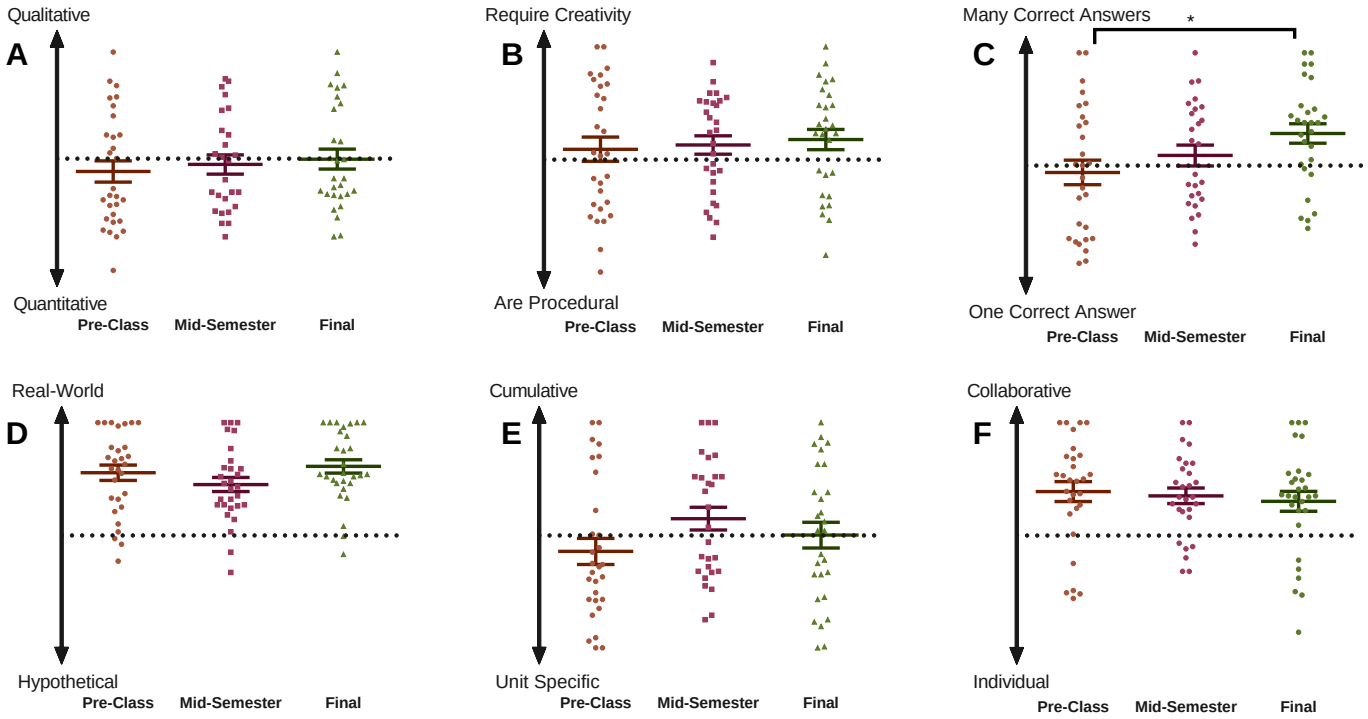


***Figure S8:*** *Students' preferences for the nature of homework, quiz, and exam problems in their classes. For the duration of the class, students preferred problems that were derived from the real world, that required creativity, and were solved collaboratively within teams. Over time, students' preferences trended toward problems that were more qualitative, more creative, more correct answers, and more cumulative. These results can inform the selection of homework, quiz and exam problems by instructors in engineering courses. In general, the challenge-based instruction format employed in the present study required a blend of qualitative/quantitative analysis, in a creative and cumulative manner. Problems had multiple correct solutions, were derived from the real world, and were solved collaboratively within four-member teams.*