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Work in Progress: Haptic Robotics in Biomedical Education

Dr. Anne Schmitz, Gannon University

I got my Mechanical Engineering undergraduate degree from the University of Wisconsin-Madison. During my schooling, I explored many opportunities to apply my engineering degree. I was involved with the Formula One Racecar Team, did a semester long co-op working on fume hoods, did a summer internship at Kimberly Clark designing a HVAC system, and did another summer internship at General Electric designing anesthesia equipment. As a senior, I got involved in research doing finite element analyses of a prosthetic foot. This immediately got me hooked on applying engineering to medical applications.

I obtained my Biomedical Engineering PhD at the University of Wisconsin-Madison. My work focused on computational biomechanics. More specifically, developing musculoskeletal models of the body to simulate movement and see how surgery and soft tissue injury affects movement. During my graduate work, I was also a teaching assistant for Introduction to Biomechanics where I developed a love for teaching. I then did postdoctoral research at the University of Kentucky where I experimentally measured movements (e.g running form), which provides data that can be used to validate the models I build. Here at Gannon University, I will continue building computational models with a focus on the knee to optimize surgical techniques (e.g. ACL reconstruction) to restore normal function after injury. When I'm not doing research, I enjoy going swimming and playing my violin.

Dr. Karinna M. Vernaza, Gannon University

Dr. Karinna Vernaza joined Gannon University in 2003, and she is currently a Professor in the Mechanical Engineering Department and Associate Dean of the College of Engineering and Business. She earned her Ph.D. and M.S. in mechanical engineering from the University of Notre Dame. Her B.S. is in Marine Systems Engineering from the U.S. Merchant Marine Academy. Her primary teaching responsibilities are in the solid mechanics and materials areas, including biomaterials. She was awarded the 2012 ASEE NCS Outstanding Teacher Award, 2013 Gannon University Distinguished Faculty Award and 2013-2014 Gannon University Faculty Award for Excellence in Service-Learning. Vernaza does research in the area of alternative fuels (biodiesel), engineering education (active learning techniques), and high-strain deformation of materials. She is currently the PI of an NSF S-STEM and ADVANCE-PAID grants.

Dr. Davide Piovesan, Gannon University

Davide Piovesan was born in Venice, Italy on October 10 , 1978. He is currently Assistant Professor in the Mechanical Engineering department at Gannon University and the director of the Biomedical Engineering Program. He received his M.S.M.E in 2003 and D.Eng in Mechanical Measurement in 2007 at the University of Padova, Italy. His dissertation presented a set of experimental and analytical validation techniques for human upper limb models. From 2004 to 2008 he was a visiting scholar and post-doctoral fellow at the Ashton Graybiel Spatial Orientation Lab at Brandeis University. There, he worked on the mechanics of movement adaptation in non inertial environments as part of a NASA extramural funding program. He joined Northwestern University in 2008, working as a post-doc fellow at the Rehabilitation Institute of Chicago until 2013 in the field of rehabilitation robotics. Davide's main research interest is to gain insights on the role of biomechanics in the neural control of movements, with applications to rehabilitation engineering.

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1. Introduction

Biomedical engineering is a broad field that ranges in scale from design of orthopedic implants to the design of nanoparticles for diagnosing disease. All of these areas have one major content area in common: biology. In fact, one of the ABET Inc. program specific outcomes is for students to "apply an in depth knowledge of biology". In the last accreditation cycle, a rubric was defined to identify the most pertinent components of biology for biomedical engineering. Specifically, the rubric contains five dimensions: 1) ability to identify anatomical structures; 2) ability to identify the function of each component; 3) understand the process taking place within the biological system; 4) understand interactions within the components of the organism; and 5) understand interactions of the organism with the environment. The rubric defines the different levels of proficiency (e.g. a score of 1 through 4) through action verbs that correlate with the different levels of Bloom's Taxonomy of intellectual behavior [1, 2]. This carefully crafted rubric has been used to assess assignments covering application of biology to engineering.

One important engineering tool that can be used to assess if students are able to apply concepts of biology is computational modeling. Musculoskeletal models typically contain representations of bones, muscles, ligaments, and joints. Hence, these models can be used to explore anatomy and perform what-if simulations to probe the function of various structures [3-5]. Haptic robotics, a newly emerging technology, is another tool that can be incorporated in the curriculum to assess the application of biology as haptics allows for kinesthetic feedback. This feedback allows the user to physically interact with a simulated biological system, which is lacking in the computational modeling tool. Few universities have haptic robotics available for teaching; therefore, it is unclear if this technology is effective for assessing an in depth knowledge of biology. The goal of this study is to compare how computational modelling and haptic robotics experiments could be used to assess a student's ability to apply an in depth knowledge of biology.

2. Methods

Two experiments, a computer simulation lab and a haptic robotic lab, were performed in BME 440 Bioengineering Lab at Gannon University. This course is required and typically taken by students in their senior year. Therefore, these students have already had basic biology, anatomy, and physiology coursework.

A previously developed computer simulation of the upper limb movements required for eating was performed by students [6]. In summary, a muscle-actuated forward dynamics simulation of the arm bringing food to the mouth was performed. An optimization algorithm implemented in OpenSim [7] was used to calculate the muscle forces needed to match the model marker trajectories of the upper and lower arm to those measured experimentally. The students were asked to produce a lab report in the form of a journal article. In the discussion they were asked to address specific questions of anatomy and physiology of the movement under study which could be directly assessed using a rubric.

A separate experiment on a different student cohort tested if the same knowledge could be acquired using haptic feedback. Students completed a pre-laboratory assignment in which they wrote a custom Matlab (MathWorksInc.,Natick,MA) code for post-processing of the data. Second, a robotic manipulator was utilized to measure sensorimotor function during a guided reaching task. To measure sensorimotor function, students used a Kinarm robot to move a handle from a central point to more distal points as they lit up on a virtual reality screen. The robotic device measured the trajectory of the hand as it moved from the central point to the indicated distal point. This test was done for each hand of each student. Then, students used the custom code from the pre-laboratory assignment to calculate the total length of the path the hand traveled. Finally, each student wrote a laboratory report in a journal article type format to present and interpret the findings of the experiment.

3. Results

The scores of the two lab experiences, computer simulation and haptic robot labs, for two students were compared. The scores were compared for each dimension of the rubric, rather than the overall scores. This was done to gain a deeper understanding of the effect of these labs on the students' ability to apply knowledge of biology. Compared to the haptic robot experiment, the computer simulation lab showed higher scores for anatomy (4 vs 3.5), physiology (4 vs 3.5), and ecology (4 vs 3.5). However, the haptic robot experience was higher for process (3.5 vs 3) and interaction (3.5 vs 3).

4. Discussion and Conclusion

The computer simulation lab showed higher scores for anatomy (4 vs 3.5), physiology (4 vs 3.5), and ecology (4 vs 3.5), as compared to the haptic robotic lab experience. In the simulation lab reports, students were able to "categorize": structure of different biological systems and their elements (anatomy), the function of these elements (physiology), and how these elements interact with environment (ecology). All of these play to the strengths of computational models where muscles and bones are included as components in the model. In the computer simulation lab, students interacted with the model to get a more detailed view of anatomy. The students also performed simulations of movements required for eating to determine the function of these components by visualizing which muscles are needed to perform elbow flexion and extension, as well as simulations to investigate how these components interact with the environment. While the elements of anatomy, physiology, and ecology are all present in the haptic robotic experiment, there is no direct visualization of the human anatomy. This is likely why the computer simulation experiment showed higher scores for these three areas.

The haptic robot experience provided higher scores for process recognition analysis and synthesis (3.5 vs 3), as well as for the characterization of the interaction among different components of the system (3.5 vs 3). Indeed, during haptic interactions between the student and the robot, the movement process is actually experienced through tactile and proprioceptive sensations. The students can therefore use these additional senses to understand how the movement process takes place and perceive on themselves how different components of the biological system (i.e. muscles, bones, sensory-motor system) interact with one another to reach the goal.

While it is recognized that the number of subjects is low and cannot give enough statistical power, this is a common problem for new programs which only have a limited amount of graduates and seek accreditation. It is important to emphasize that this data is part of a continuous improvement process where assessment data are acquired and evaluated to improve the educational experience of the student. While methods like "chalk and talk" worked for hundreds of years, society has experienced huge technological leaps in the last decades. The work environment has become interactive and technologically advanced. It is the role of academic institutions to incorporate these changes in their curriculum in order to prepare their graduates to enter the work force with a higher technological proficiency.

In conclusion, Gannon University is one of the few academic institutions in the United States to develop a laboratory experience utilizing haptic robotics for biomedical engineering undergraduate students. It is evident that computer simulations and haptic robotics complement each other. The combination of these two experiments enhances the learning experience of students majoring in biomedical engineering and they provide the venue for assessing their ability to "apply and in depth knowledge of biology."

5. References

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