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BOARD # 36: Work-In-Progress: Enhancing Biomedical Engineering Education through Collaboration with Physical Therapy

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Work in Progress: Enhancing Biomedical Engineering Education through Collaboration with Physical Therapy

INTRODUCTION

Physical therapy is growing with the increased aging population and focus on preventative medicine to promote health and wellness [1]. The market for wearables (e.g. smart watches, VR headsets) is expected to grow from $28.2 billion in 2021 to $66.9 billion in 2030 [2]. The wearables industry includes technology aimed at facilitating physical therapy exercises at home. Patients who completed their physical therapy prescription at home have better outcomes related to health, mobility, and pain compared to their non-compliant counterparts [3]. The growing industry is poised to incorporate cutting-edge technology if properly supported by engineering, particularly biomedical engineering. Biomedical engineers are uniquely equipped to develop creative solutions at the intersection of science and medicine. To properly train biomedical engineers to tackle these complex problems, it is pivotal that they have opportunities to hone their skills during their undergraduate biomedical engineering education.

The goal of this paper is to showcase a newly developed a three-course medical device design series (Course 1, Course 2, & Course 3). In this course sequence, biomedical engineering students are taught how to develop medical devices through progressively more complex projects related to unmet needs in physical therapy.

COURSE SEQUENCE STRUCTURE

When developing these three courses the educational concept of scaffolding was implemented (Appendix 1) [4]. The idea was to provide the most guidance to students in the Course 1 course and gradually transfer responsibility to the student as the student progresses through Course 2 and Course 3. **The goal of this research is to determine the effectiveness of project-based learning taught using scaffolding, particularly with projects related to physical therapy and rehabilitation devices.**

Scaffolding particularly the one-on-one scaffolding in engineering education, has been shown to improve learning and student outcomes [5]. Scaffolding can take many forms but in engineering education it is often in the form of solving authentic problems while supported by instructors through feedback and guidance. Providing students with authentic problems and giving students the opportunity to iterate on various design aspects and solutions does not ensure they learn how to effectively iterate [6, 7]. Lewis developed a novel teaching approach which led to students engaging in more high-level iterative practices compared to more traditional problem-based learning coaching [8]. We hypothesize that by completing nine engineering design projects the students will not only improve the quality of their engineered solutions as measured by graded projects and user feedback but also gain confidence in solving ill-structured problems similar to real engineering problems.

Course 1: Medical Device Design: The Fundamentals

Course 1 is a junior level course which introduces the medical device design process. The lectures, homework, and labs are prescriptive and aimed at breaking down the design process into simpler tasks and more manageable objectives. As the students progress through this course, they need to take on more responsibility for a successful outcome. There are four projects in BME 3710 (Appendix 2) starting with a 90 minute "Crash Course in Design Thinking" adapted from d.school at Stanford University [9] and culminating in a final eight-week project to develop and fabricate a prototype for a client with a recent surgery to repair an ulnar collateral ligament (UCL) tear of the right metacarpophalangeal thumb joint. The projects within the course focus on physical rehabilitation science and assistive devices. The students receive feedback and guidance from experts in physical therapy to optimize their solutions.

Course 2: Medical Device Design Studio
Course 2 is the intermediate medical device design course geared towards electro-mechanical design and development. In this course, students focus on advanced prototyping skills including solid modeling, proper electrical component selection, integrating electrical components with hardware design, and testing electro-mechanical device against industry standards. The students complete three projects in this course (Appendix 2). The first project is to replicate and improve a musculoskeletal joint (wrist, elbow, knee, or ankle) using reverse engineering techniques. The goals of this project were to 1) help the biomedical engineering students learn and understand the anatomy and kinematics of a joint, 2) provide BME students and opportunity to learn foundational knowledge prior to applying it to their final project, and 3) give physical therapy students these musculoskeletal joint models to help them learn joint kinematics. The physical therapy students provided videos to the BME students to introduce the anatomy, joint range of motion, and common pathologies. The second project builds on the first project and the students were tasked with adding motion to their joint by incorporating a computer(microcontroller) and a motor. For the final project the students are asked to identify and define a problem related to their assigned musculoskeletal joint and then prototype a solution. All projects included a presentation, demonstration of prototype, and written report.

Course 3: Advanced Medical Device Design Studio
Course 3 is the final course in the medical device design course sequence and focuses on advanced prototyping and manufacturing techniques for mechanical and electromechanical medical devices. Students also implement design controls and complete documentation required of a proper quality management system. All projects are tested for safety and efficacy against related industry standards. In BME5715, the students complete two projects, one individually and one as part of a team (Appendix 2). Project A is completed collaboratively as part of a team and following interviews of physical therapists, clinicians, and patients, the students were assigned to one of the following projects: 1) develop a solution for ambulatory multiple sclerosis individuals with difficulty initiating gait due to hip flexor weakness, 2) develop a solution for C6 spinal cord injury individuals to initiate wrist flexion and utilize tenodesis to have a functional grip, or 3) develop a solution for ambulatory Parkinson's disease individuals to aid/prevent/reduce gait freezing. Project A concludes with a presentation, demonstration of prototype, and written report. For Project B, students are asked to perform a feasibility study and determine if it is feasibility to design and develop a device/software/solution for one of the listed problems: home oxygen tube management, pediatric pelvic floor dysfunction, pediatric wheelchair attachment to keep clothes and hands clean, adaptive tools to help those with dementia remain in home, adaptive tools to help those recovering from stroke, or a custom project with instructor approval. The deliverables for Project B include a written report and initial design of the solution.

ASSESSMENTS OF EFFECTIVENESS

The students will be surveyed before, during, and after each course. We are currently finalizing the assessments and surveys which will be distributed to the students with one exception. We have surveyed one group of students who have completed Course 2, the second course in the medical device course sequence. The survey is included in Appendix 3. We have data from this group because we measured the effect of novel teaching techniques as part of a different study. To complete this data collection the survey was submitted to the University of Iowa Institutional Review Board (IRB) and deemed to exempt from further review (IRB ID# 202308190).

PRELIMINARY RESULTS

Preliminary results are limited to Project 1 and the Final Project in Course 2 with data collected from 15 BME students (Appendix 4). Overall, the students had positive responses when asked about the projects and supporting material. When asked if the educational video and material produced by the physical therapy students impacted their knowledge, 87% of BME students reported high positive impact or moderate positive impact. When asked about the value of Project 1, 100% of BME students responded positively with high positive value, moderate positive value, or small positive value (See Appendix for specific question). When asked about the value of the final project, 67% of the BME students responded with high positive value and the other 33% responded with moderate positive value(See Appendix for specific question).

We have kept in touch with many of the students who have completed the medical device design course sequence, and they report that the courses prepared them to make immediate contributions to projects and provide valuable information critical to success in the medical device industry. It will be interesting to determine if and how these anecdotal stories can be supported by data collected from current biomedical engineering students.

FUTURE WORK

As mentioned in a previous section, the authors are currently optimizing and finalizing surveys and other methods of quantification to measure the effectiveness of scaffolding in this setting. We are working with the Center of Teaching and Learning at our institution to ensure that our research methods are sound and future research activities will be able to answer our primary research question. We are also reviewing the current scaffolding techniques incorporated into each course, the best way to measure the impact, and communicate those results.

CONCLUSIONS

This research was designed to determine the effectiveness of project-based learning supported by the educational concept of scaffolding. The projects were completed in collaboration with physical therapy as students tend to flourish when solving real problems. Although limited data has been collected and analyzed at this time, the preliminary findings are encouraging. They support both scaffolding to teach engineering medical device design and the usefulness of strong collaboration with clinicians in rehabilitation settings and in medicine.

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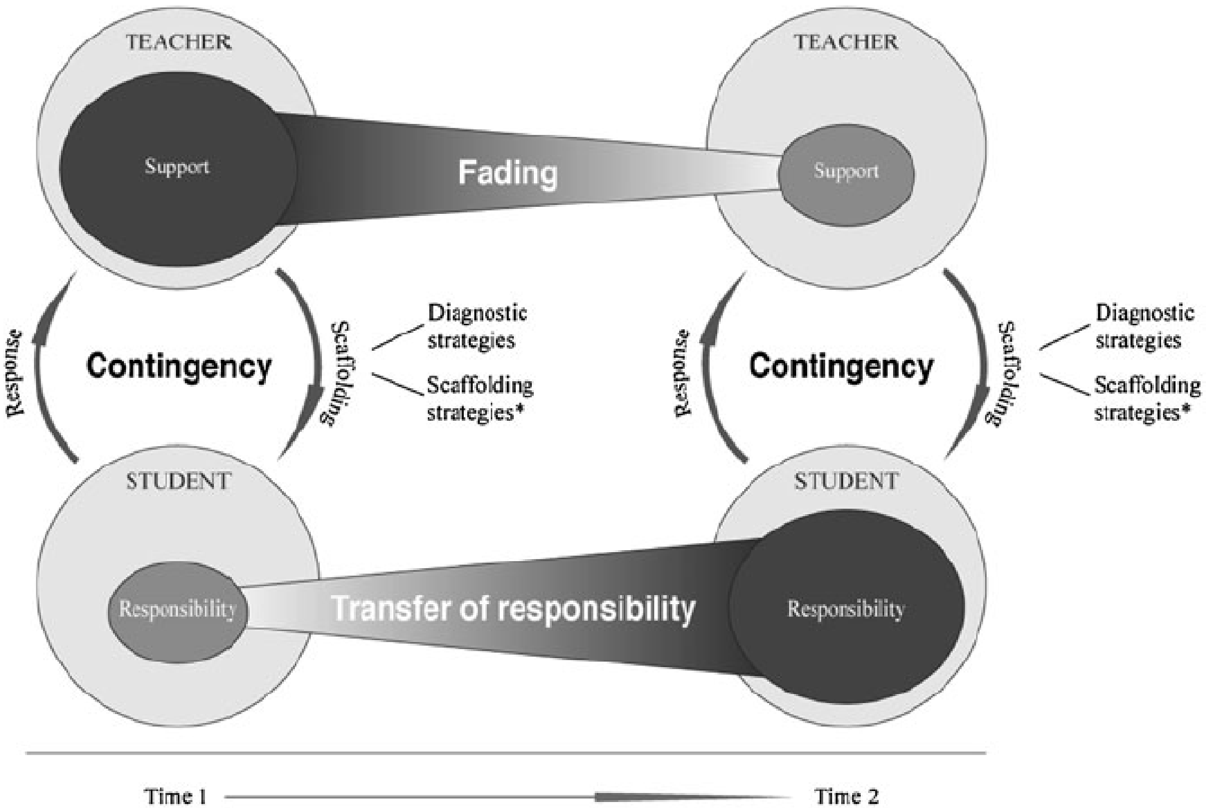
APPENDICES

APPENDIX 1: Conceptual Model of Scaffolding from van de Pol 2010 [4]



APPENDIX 2: Medical Device Design Course Sequence

Course	BME3710	BME4710	BME5715
Projects (Duration): Description	Crash Course in Design Thinking (90 min): Redesign the gift giving experience	Project 1 (4 weeks): Replicate and improve a musculoskeletal joint (wrist, elbow, knee, or ankle) using reverse engineering techniques (static model)	Project A (15 weeks): The students were assigned one of the following based on interest (completed as a team)
	Quarter Project (2 weeks): Re-design and prototype a mobility aid or other assistive device, provide a mathematical model of current design and the re-design, create solid model of the current design and the improved model, and provide a list of design specifications that will be fulfilled by this device.	Project 2 (4 weeks): Add motion to the joint produced in Project 1 by incorporating a computer(microcontroller) and a motor (dynamic model)	1) Design and develop a solution for ambulatory multiple sclerosis individuals with difficulty initiating gait due to hip flexor weakness 2) Design and develop a solution for C6 spinal cord injury individuals to initiate wrist flexion and utilize tenodesis to have a functional grip 3) Design and develop a solution for ambulatory Parkinson's disease individuals to aid/prevent/reduce gait freezing.
	Midterm Project (4 weeks): Prototype and test the device suggested in your Quarter Project and write standard operating procedure to produce the improved device.	Final Project (6 weeks): Identify and define a problem related to their assigned musculoskeletal joint and prototype a solution	Project B (15 weeks): Perform a feasibility study and determine if it is feasibility to design and develop a device/software/solution for one of the listed problems (completed individually)
	Final Project (8 weeks): Develop and fabricate a prototype for a client with a recent surgery to repair an ulnar collateral ligament (UCL) tear of the right metacarpophalangeal thumb joint and include all written delieverables outlined in the project description		1) Home oxygen tube management 2) Pediatric pelvic floor dysfunction 3) Pediatric wheelchair attachment to keep clothes and hands clean 4) Adaptive tools to help those with dementia remain in home 5) Adaptive tools to help those recovering from stroke 6) Custom project
Course Learning Objectives	To identify appropriate theory and equations needed to theoretically define a problem.	To apply reverse engineering to fabricate and assemble a replica of a musculoskeletal joint.	To perform background research and interviews to define a problem and relevant user needs.
	To clearly sketch and create a three-dimensional, solid model of a novel medical device.	To design and create an amplifier and filter to collect, analyze, and display EMG.	To create virtual and physical prototypes using various prototyping and fabrication techniques.
	To create virtual and physical prototypes using various prototyping and fabrication techniques.	To select proper electrical components and configure an electrical system for a medical device prototype.	To apply design controls for medical devices and understand quality management systems.
	To understand medical device classification	To integrate electrical components into the hardware design to solve a novel healthcare need.	To effectively communicate within a team, new ideas, evaluate current designs, and suggest improvements for future iterations.
	To effectively communicate within a team, new ideas, evaluate current designs, and suggest improvements for future iterations.	To apply design controls for medical devices and understand quality management systems.	To design, manufacture, and assemble a medical device and defend design using sound engineering concepts.
	To design, manufacture, and assemble a medical device and defend design using sound engineering concepts.	To effectively communicate within a team, new ideas, evaluate current designs, and suggest improvements for future iterations.	To perform a feasibility study to determine the viability of a medical device product
		To design, manufacture, and assemble a medical device and defend design using sound engineering concepts.	To provide correct and complete documentation required as part of a quality management system.

APPENDIX 3: Survey of BME:4710 students

Q1 How did watching the video and reviewing the material made by the physical therapy students impact your knowledge of your assigned joint?

- High positive impact
- Moderate positive impact
- Small positive impact
- No impact
- Small negative impact
- Moderate negative impact
- High negative impact

Q2 Your models and models like yours will be used in a class to teach physical therapy students musculoskeletal movements, anatomy, kinetics, and kinematics to treat patients with musculoskeletal injuries or disorders. How does that make you feel?

- Dislike a great deal
- Dislike somewhat
- Neither like nor dislike
- Like somewhat
- Like a great deal

Q3 What was the value of replicating or reverse engineering your assigned joint(Project 1)?

- ◯ High positive value
- ◯ Moderate positive value
- ◯ Small positive value
- ◯ No value
- ◯ Small negative value
- ◯ Moderate negative value
- ◯ High negative value

Q4 What did you learn by replicating or reverse engineering your assigned joint(Project 1)?

____

Q5 Please provide any other feedback for Project 1 here (if any).

____

Q6 For the final project, you and your team was asked to first identify a problem to solve common to a musculoskeletal joint. How did the video and material developed by the physical therapy students impact your decision?

- High positive impact
- Moderate positive impact
- Small positive impact
- No impact
- Small negative impact
- Moderate negative impact
- High negative impact

Q7 What was the value completing the Final Project?

- High positive value
- Moderate positive value
- Small positive value
- No value
- Small negative value
- Moderate negative value
- High negative value

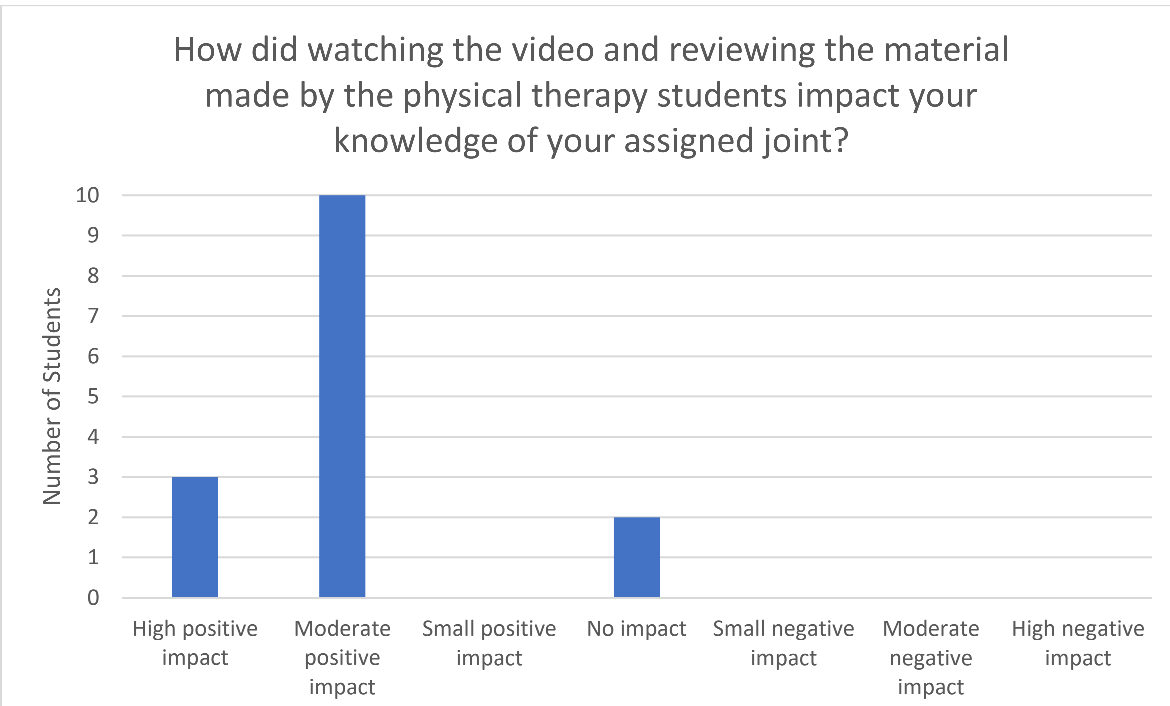
Q8 What did you learn by completing your Final Project?

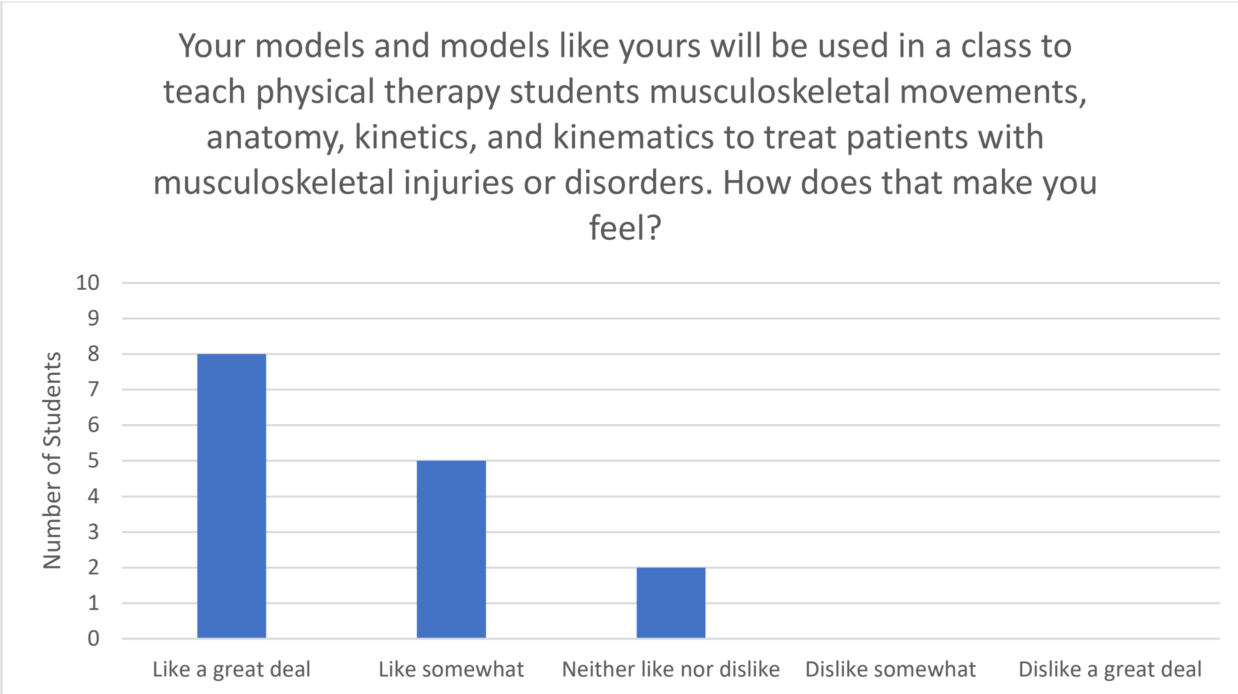
____

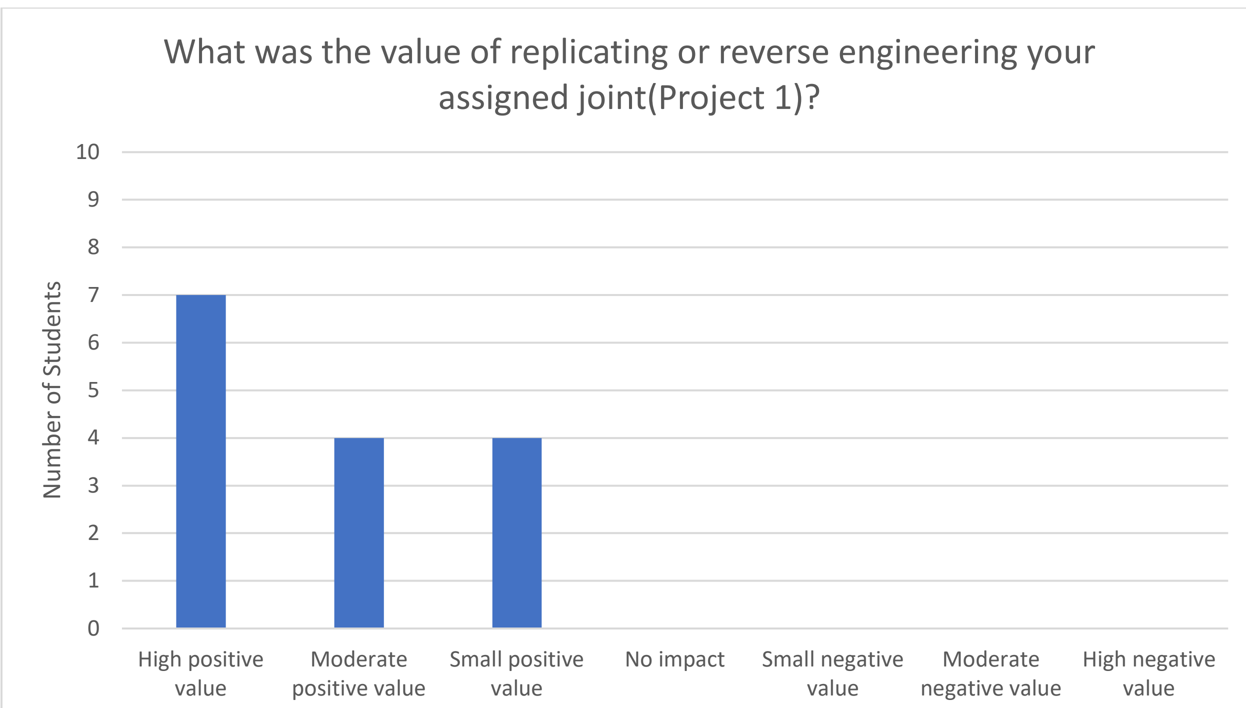
Q9 Please provide any other feedback for Final Project here (if any).

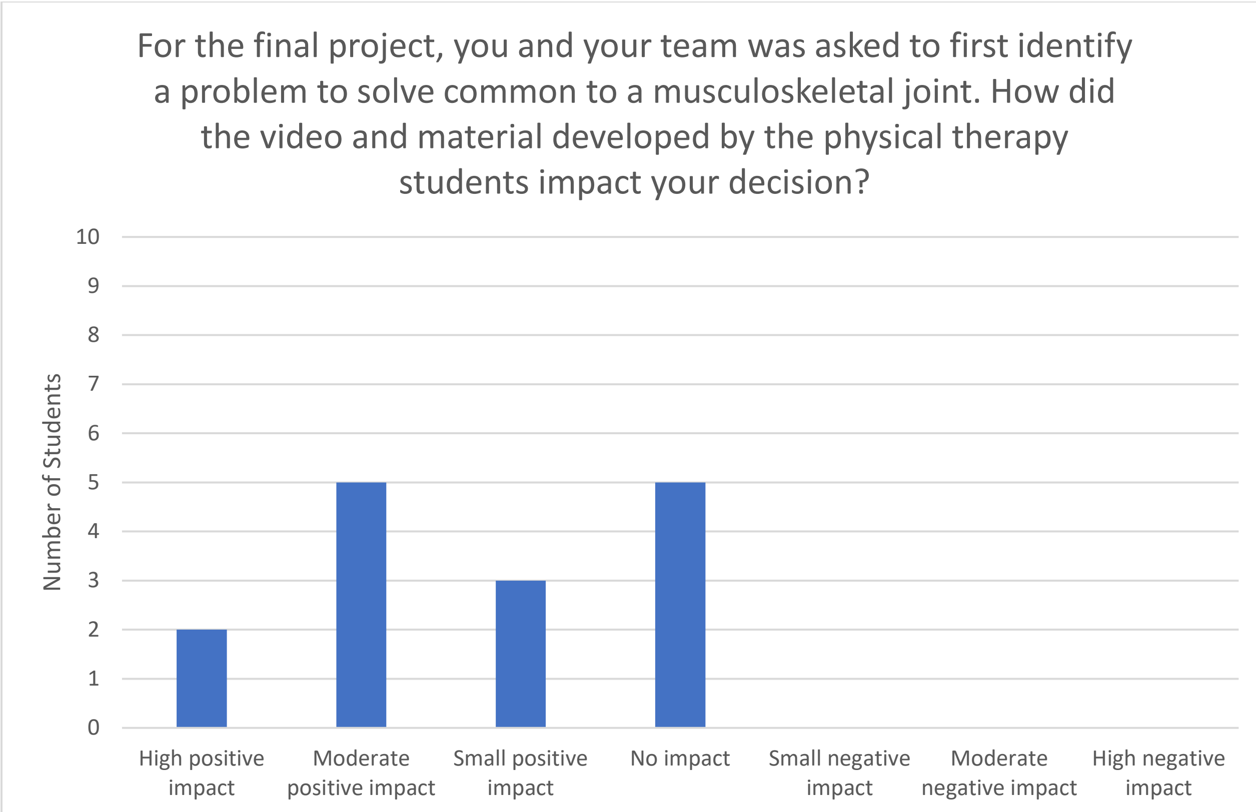
____

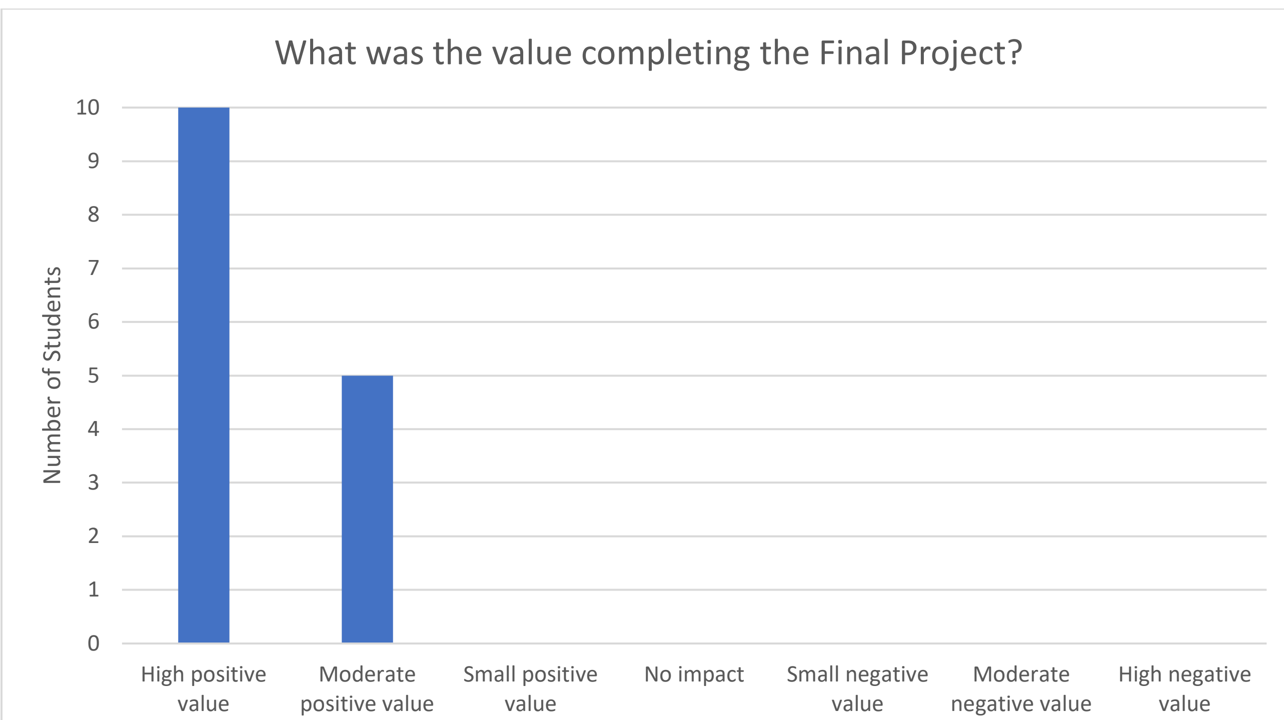
APPENDIX 4: Preliminary Results from Project 1 and Final Project in BME:4710




Your models and models like yours will be used in a class to teach physical therapy students musculoskeletal movements, anatomy, kinetics, and kinematics to treat patients with musculoskeletal injuries or disorders. How does that make you feel?
Number of Students
10
9
8
7
6
5
4
3
2
1
0
Like a great deal
Like somewhat
Neither like nor dislike
Dislike somewhat
Dislike a great deal


What was the value of replicating or reverse engineering your assigned joint(Project 1)?
Number of Students
10
9
8
7
6
5
4
3
2
1
0
High positive value
Moderate positive value
Small positive value
No impact
Small negative value
Moderate negative value
High negative value


For the final project, you and your team was asked to first identify a problem to solve common to a musculoskeletal joint. How did the video and material developed by the physical therapy students impact your decision?
Number of Students
0
1
2
3
4
5
6
7
8
9
10
High positive impact
Moderate positive impact
Small positive impact
No impact
Small negative impact
Moderate negative impact
High negative impact


What was the value completing the Final Project?
Number of Students
0
1
2
3
4
5
6
7
8
9
10
High positive value
Moderate positive value
Small positive value
No impact
Small negative value
Moderate negative value
High negative value