Establishing An Interdisciplinary Team of Engineering and Physical Therapy Faculty and Students to Improve Rehabilitation Technology: A Single-Site Example

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ABSTRACT

Background and Purpose: Barriers of interdisciplinary work between physical therapists and engineers persist including limitations in understanding each other's professions, time, and perceived value. The purpose of this paper is to offer a stepwise approach to establishing interdisciplinary work. **Methods:** Phase I: Physical therapy faculty and students held a roundtable discussion and simple project discussions during engineering coursework. Phase II: Year-long human-centered problem-based design in an engineering capstone course with consultation from physical therapy faculty and students. **Findings:** Positive student feedback ensured mutual value in collaboration, followed by robust problem-solving to design a clinically useful device. **Clinical Relevance:** A single site, stepwise progression in an academic setting is offered to introduce the value of physical therapy to engineers as part of an interdisciplinary team to design clinically useful devices. **Conclusion:** Physical therapists can successfully engage with engineers as part of an interdisciplinary team in developing clinically useful technologies that accurately measure the intended activity, are purposeful, and are easy to use.

Key Words: bioengineering, biomedical, multidisciplinary

INTRODUCTION

Technology is advancing at an exponential rate. Wristwatches and smartphones that tell users how many steps they take each day and collect metadata on places that people patronize are now widely available and used. As technology advances, so do the possibilities in the medical profession. Cameras, accelerometers, microchips, and miniaturized robots that can measure joint movement as well as community navigation are becoming more and more prevalent in clinical practice. In the orthopaedic setting, it is more important than ever for the engineers designing the next technological innovation to become familiar with the physical therapy profession. Physical therapists with their knowledge and expertise in human movement are well poised to assist in the development and implementation of technology. By including physical therapists in an interdisciplinary team to design new devices, the effectiveness of our ability to measure, assess, and intervene to optimize movement strategies in patients can be highly improved.

Understanding the reciprocal benefit of collaborative initiatives has led to several calls to increase interdisciplinary education and community outreach programs. Norland and colleagues demonstrated the lack of awareness of regenerative rehabilitation among physical therapists and called for physical therapy programs to establish an active approach to learning new technologies.[1] Trumbower and Wolf highlighted the importance of collaborations between physical therapy and engineering disciplines. They encouraged educational programs to support partnerships as a means to simultaneously accelerate biotechnologies and the profession of physical therapy.[2] While the Commission on Accreditation on Physical Therapy Education (CAPTE) Standards and Required Elements for Accreditation of Physical Therapy Education Programs requires interprofessional education, incorporation of engineers as an interdisciplinary team member continues to remain sparse.

Some physical therapy programs have been able to bridge the academic silos within institutions and have successfully established interdisciplinary events and projects. Faculty at the University of North Florida established a successful relationship between the School of Engineering and Physical Therapy program, designing rehabilitation technology for children with disabilities.[3] Emory University established an interdisciplinary course involving lecture and team-based design challenges to those with functional mobility limitations.[4] While these exemplars are laudable, there are limitations in the capacity to model these programs due to challenging constraints.

For an academic partnership to be viable, it is ideal that the academic physical therapy program and the academic engineering program be located in the same institution. Though physicality is a significant barrier, both partners must see value in establishing an interdisciplinary relationship.[5] If an engineering program is unfamiliar with the profession of physical therapy, willingness to collaborate may be low. Perhaps the most extensive availability of engineering students is at the undergraduate level, while physical therapy degree earners are at the post-secondary level. This educational mismatch may be a challenge to establish a mutual curriculum that offers similar levels of value for each partner. Scheduling and course rigor are barriers to successful interdisciplinary work.[6] Physical therapy students may have high levels of anxiety[7] due to an already intense curriculum and the faculty may be less likely to increase student burden by adding yet another activity or project.

While the barriers exist, academic institutions should emphasize the benefits of teamwork to both physical therapists and engineers alike. Interdisciplinary education improves perceptions of one's profession and the ability to work with others.[8] Surveys of faculty in academia, including the health sciences, have a favorable opinion of teamwork and interdisciplinary education.[6] Authors suggest that previous positive experiences,[9] and an understanding of other professions,[5] lead to optimal interdisciplinary conditions.

It is the view of the authors that physical therapists can capitalize on the academia-wide optimism by physical therapists being the first to cross the bridge to engineering. The authors of the current study feel it is essential to establish physical therapists as the provider of choice in consultation of design user interface for technology intended to assess, track, and provide feedback regarding human movement.

In this article, the authors describe a stepwise approach to collaborations between physical therapy and engineering programs. In these first two phases, the progression of physical therapy to engineers was introduced to establish a baseline of understanding of our profession. A working relationship, by demonstrating value in team-based activities was developed, using tangible human-centered problems that required interdisciplinary teams to provide solutions.

METHODS

Phase I

Interdisciplinary experiences between biomedical engineering and physical therapy students and faculty were built into an existing engineering course, Capstone Design. The course is a requirement for undergraduate students in their final year of the Biomedical Engineering Department. On two separate occasions, faculty and students from the physical therapy program participated in the engineering class sessions. Initially, physical therapy students and faculty participated in a roundtable discussion about the profession of physical therapy, the scope of practice, and physical therapists' educational training. Engineering students were encouraged to ask questions about clinical experience and the role of equipment in typical patient encounters. The roundtable session concluded with a discussion, guided by the engineering faculty, regarding device design and usability from the perspective of a physical therapist.

The physical therapy students and the faculty returned two weeks later to the Capstone Design class for the second interdisciplinary activity. Before this class period, small groups of biomedical engineering students were charged with the task of designing a simple physical ankle model, incorporating objects readily available in the home. Physical therapy faculty and students used the class period to circulate through the groups to provide feedback on each of the engineering groups' models. They provided feedback on the accuracy of the anatomic and kinesiologic properties of each ankle model. In turn, the engineering student groups communicated the limitations of materials available to produce a more accurate model. The engineering students discussed the design decisions that were made based on ranking the importance of specific ankle anatomical or kinesiologic properties while practicing communication skills necessary to work with future clients.

Both physical therapy and engineering students completed surveys on their participation in the various collaborative opportunities, lessons learned on communication, integration of suggestions into design, provision of constructive feedback, and experience with interdisciplinary collaboration. The survey was disseminated after the culmination of the class.

Phase II

The intent of Phase II was to build upon student feedback that tangible examples of design issues were helpful when collaborating with other disciplines. It was decided to continue to use the Capstone Design course in the Biomedical Engineering curriculum to achieve this while opening the opportunity to the mechanical engineering Capstone Design class as well. During this phase, faculty from the physical therapy program were invited to pitch a problem statement. The engineering students then created a product that would solve the problem statement given by the physical therapist. Four different projects from the physical therapy faculty were pitched and selected, each involving different areas of physical therapy practice ranging from orthopaedics, pediatrics, neurologic, and pain science (Figure 1).

The orthopaedic physical therapy practice problem statement was: "Accelerometery has the potential to detect those at risk for overuse running injuries such as shin splints. Feedback regarding an individual's tibial acceleration may even be a treatment to reduce the risk of shin splints. Currently, published literature and the only commercially available device measures only one leg at a time, limiting the capacity to assess what might be happening on the contralateral limb." The problem statement was available to both Biomedical Engineering and Mechanical Engineering student Senior Design courses.

Engineering students rated all submitted projects from high to low (1 to 5, respectively). Students were placed into groups based on which projects they ranked the highest. Once placed in design teams, the contact information of the faculty member that proposed the design problem statement was given to the group. Each design team scheduled monthly meetings with the faculty and any physical therapy students that are working as research assistants with the faculty. Meetings facilitated discussions regarding the clinical applicability of potential design ideas and iterations. Design teams were also encouraged to use electronic communication as needed.

FINDINGS

Phase I

Student representative quotes from engineering and physical therapy students are provided in Table 1. General themes that emerged from student feedback were: Benefits of Collaboration, Refining Communication, and Learning and Growing. When breaking down feedback related to subcomponents of Phase I, students overwhelmingly reported that large group discussions on the knowledge base and education of a physical therapist were helpful. These interactions allowed the engineering students to conceptualize clinical needs and feedback from their physical therapist partner. The engineering students felt that roundtable discussions helped generate additional human factors that might affect the design process. Small group discussions and repeated interactions between physical therapy and engineering students encouraged meta-cognition. Finally, project-based interactions provided real scenarios in which many of the previously mentioned benefits occurred.

Phase II

Biomedical engineering students chose the pediatric, neurologic, and pain-science projects. A mechanical engineering student group selected the orthopaedic project. Each of the 4 design groups consisted of 4 to 5 final year engineering students. Each group similarly scheduled regular meetings with the physical therapy faculty and students that proposed the problem statement. The mechanical engineering group is discussed as the exemplar. Key aspects of the students' design process discussed during meetings are summarized in Table 2.

The first interdisciplinary meeting between engineering and physical therapy members was to discuss the overall problem, prevalence, and impact. This open dialogue facilitated a robust discussion regarding the potential application of the device that would serve to solve the problem statement. The team identified that tibial stress fractures are among the top 5 most common running injuries with as high as a 10.6% recurrence rate.[10,11] Once a tibial stress fracture occurs, an individual will feel pain during weight-

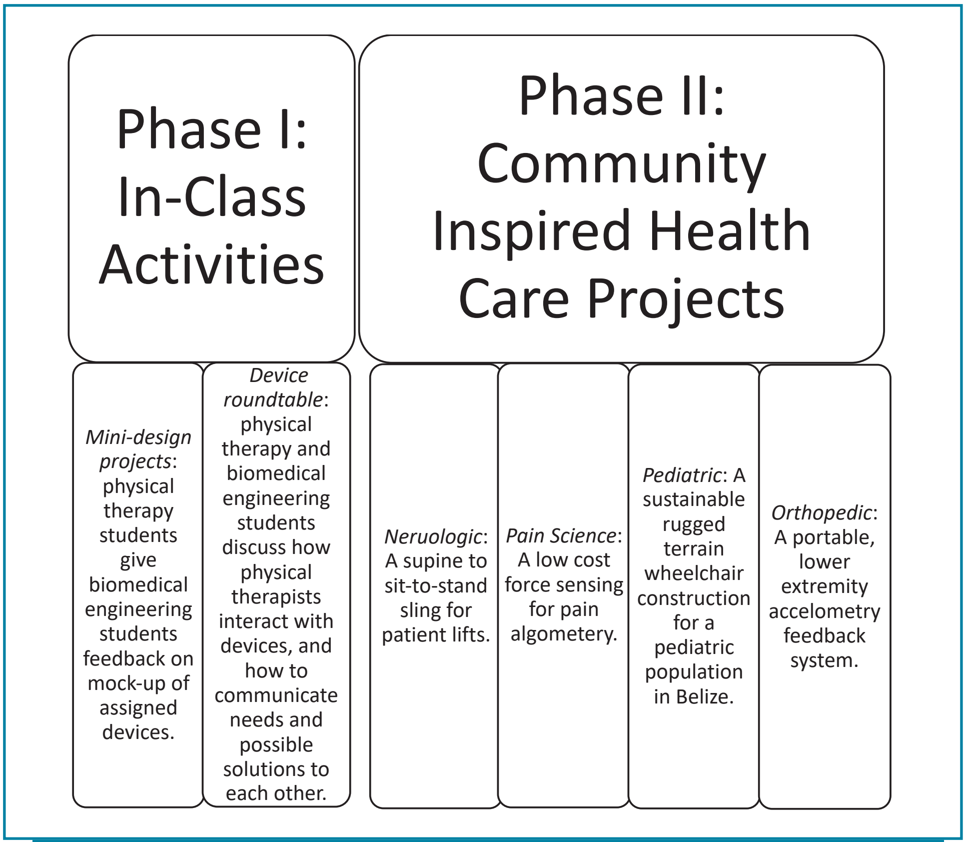

Figure 1. Description of physical therapist and faculty with engineering students and faculty in two integrative phases.

bearing activities that is relieved with rest. The rehabilitation period following a stress fracture ranges about 4 to 12 weeks.[12] During these weeks, runners are more vulnerable to creating habits of physical inactivity. Continued physical inactivity is a known risk factor for cardiovascular disease, depression, certain cancers, and high blood pressure.[13] Prevention of tibial stress fractures can help prevent athletes from slipping into a cycle of physical inactivity.

The expanded problem statement then led to the framework of a solution to the problem, incorporating principles relevant to both engineers and physical therapists. Previous research demonstrated excellent reliability and validity using wearable devices to measure tibial acceleration unilaterally.[14] Tibial acceleration data can estimate forces placed on the tibia, and in turn, monitor the risk of tibial stress fractures. The exact link between tibial acceleration and bone strain has not yet been figured out completely through research but is currently used as a proxy measurement by clinicians and researchers. Tibial acceleration is affected by similar factors that would effect bone strain, such as running technique, velocity, surface, and lower extremity stiffness.[15] A study by Milner et al[16] revealed that runners with a history of tibial stress fractures had significantly higher tibial accelerations than participants without them. Due to the current research findings, tibial acceleration can be used to monitor potential injury risk.

Even in healthy populations, asymmetries exist between lower extremities.[17] The existing literature has conflicting results regarding the significance of limb asymmetries. Potentially, asymmetries can impact lower extremity stiffness and loading rates, which relates to the risk of injuries. Furthermore, there is mixed evidence surrounding the effects of fatigue on symmetry between limbs.[17-20] The inclusion of both lower limbs while measuring tibial acceleration can potentially increase the ability to detect the risk of tibial stress fractures. The design team then made the decision that a critical feature of the new system would be to have the capacity to measure tibial acceleration of both lower extremities simultaneously.

At this stage of the design process, many different ideas started to emerge, as this device could not only be used as an assessment device for clinical analysis, but also as feedback to the user for both assessment and training purposes. The duality of purpose spurred a meaningful interdisciplinary conversation regarding the graphical user interface. Design parameters were prioritized to provide essential information for real-time feedback while other information was processed offline. Robust discussions for prioritization occurred through analysis of both motor control principles, as well as possibilities and limitations of the system components. The team continued to build off previous literature finding that runners using real-time audio feedback from a tibial accelerometer were able to significantly reduce their positive peak tibial accelerations in as little as 5 minutes. Moreover, 10 minutes of biofeedback allowed runners to maintain their gait adaptations even without the real-time feedback temporarily.[21] Likewise, runners using visual feedback were able to reduce positive peak tibial acceleration, vertical impact peak, vertical instantaneous loading rate, and vertical average loading rate. Users reported that the modifications to running gait felt natural after just a few sessions and their changes were maintained for at least one month after cessation of biofeedback.[22]

Concurrently, the team chose the accelerometer that would minimize size and mass while collecting and communicating the signal to a central processing device at sufficient speeds to maintain a meaningful signal. With each progressive decision-making step, a needs and brainstorming session occurred, followed by an assessment of device components that would improve the device. Needs ranged from the type of signal that was desired, the type of data processing that would be necessary, file storage size, method of user interaction desired, preventing reproducing an already existing system, and potential add-on uses for the system in the future to apply readily integrated new questions and needs that arise. At the final stage, the engineering team wrote an app in Java for an Android smartphone communicated with two accelerometers embedded onto a chip with Bluetooth technology. The accelerometers were individually housed in a sealed enclosure consisting of a 3-D printed flexible material in serial with a strap that was secured to the individual's distal shank. The process was iterative and an example of interdisciplinary knowledge culminating in a new device to answer a pressing clinical need. Studies will follow that investigate simultaneous lower limb kinetics to establish a symmetry index of acceleration, detect deviations, and serve as an intervention tool.

Table 1. Phase I Student Responses. Representative quotes from student feedback following phase I activities.

Categories	Representative Quotes
Benefits of Collaboration	"The experiences definitely showed the value of having multiple groups from different backgrounds collaborating to solve a common problem." (SEng) "Insightful time to integrate our professions." (SPT)
Refining Communication	"I was able to practice providing feedback to group members constructively and listening to the concerns of people with different perspectives/list of concerns." (SPT) "I think capstone in general was good for me to break this old teaching [of not questioning] and, while treating people with respect you can still elaborate on ideas." (SEng)
Learning and Growing	"It was helpful to think through all the aspects a physical therapist would be concerned with and then prioritize those ideas with what the engineers are concerned with. By comparing the two perspectives it helped me solidify my own clinical thinking for physical therapy." (SPT) "Working with individuals in the physical therapy profession really taught us to put our primary focus on [user needs] and not get so lost in the design that the needs of the users are not met." (SEng)
Community Engagement	"It opened my eyes to this idea of real world problem solving and that we have so much to learn from each-others disciplines and interests." (SEng)

Abbreviations: SPT, student physical therapist; SEng, engineering student

Table 2. Phase II Design Components. Examples of design component matched to necessary specifications and considerations for the device. Collaborations between engineering and physical therapy students and faculty drove decisions for final design components.

Design Concept	Decisions Regarding Design Specifications
System	Processor capacity necessary to collect and process data
	Sensor specifications necessary to capture and transmit wanted data
Graphical User Interface	Necessary information to be input by the user
	Essential, desirable, and nice-to-have real-time feedback to the user
	Essential, desirable, and nice-to-have delayed feedback to the user
Sensor Selection	Data streaming and storing capabilities
	Sensor size and weight
Sensor-User Interface	Sensor location
	Protection of the device in all situations of device use
	Comfort of the material and fit of interface

CLINICAL RELEVANCE

A single-site, stepwise progression in an academic setting to introduce the value of physical therapy to engineers as part of an interdisciplinary team, facilitated an understanding of the physical therapy program through roundtable discussions and a "mini-design" project. The value of the interdisciplinary partnerships increased through contributions by physical therapy faculty and students in Capstone Design projects with undergraduate final year mechanical and biomedical engineering students.

Productive collaborations between physical therapists and engineers in the literature do exist and have the opportunity to make important changes in patients' lives. For those with neurologic conditions, inertial sensing systems are being developed to monitor movement in the community.[23] Computerized methods to measure limb volume are validated for those with lymphedema due to breast cancer,[24] increasing the ease of diagnosis and monitoring the effects of treatment. Environments used in pediatric and early intervention are being enriched using robotic interactions,[25] and virtual reality environments are being used to measure and decrease fall risk in elderly patients.[26] Recent orthopaedic examples include using exercise equipment embedded with sensors to monitor home programs following joint replacement,[27] sensors that communicate with a mobile phone to measure knee movement remotely,[28] and using depth-sensing cameras to assess gait.[29] The unique needs of the orthopaedic patient population should continue to be addressed through developments in technology and design. The orthopaedic physical therapist should continue to be a part of the team that develops technology to assist in accurate diagnosis, treatment, and ongoing reassessment of their patients.

When surveyed, clinicians have identified barriers to using technology in the clinic. Barriers include a lack of time when technology takes longer than traditional methods, additive cost of devices and software, lack of standardization of measurements and methods, and poor interpretability or understanding of the results.[30] Clinicians do agree that wearable monitoring technology could enhance physical therapy assessments. Still, they feel that a single device or measuring a separate function does not meet the diverse scope of patient needs and treatments.[31] When explicitly discussing technology-driven feedback to patients undergoing orthopaedic rehabilitation, clinicians perceive the significant value to the patient but identify the technical challenges of tailoring rehabilitation to the individual.[32] Although optimism exists towards the potential of technology to improve rehabilitation, physical therapists need to directly engage with those that are developing the technologies to improve the ability to apply technologies to patients.

This study has demonstrated a successful iterative approach to engage physical therapy and engineering faculty and students in the academic setting actively. Establishing an understanding of each other's professions is an essential component of interdisciplinary work.[5,9] This was accomplished through round table discussions and a limited scope group project. Surveying students in both fields supported positive interactions and experiences. After evidence of successfully completing the first phase, a second phase of proven strategy in interdisciplinary work resulted in problem-based learning in small groups.[33] During the problem-based interactions, physical therapy proposed a clinical problem for engineering senior design students. Physical therapy faculty and students served as consultants for the project design during monthly meetings. This structure facilitated engineering students and faculty to work together to optimize the design of clinician-supported and patient-friendly technology. Further, the request to expand problem-based learning to more than one engineering discipline (biomedical and mechanical), is further evidence of the success of this iterative approach.

Future directions for these programs will include establishing a mechanism in which to allow physical therapy students to earn course credits for collaborative work with engineering design teams. Although few universities have been able to achieve this, it will enable physical therapy students, not only engineering students, to reward the invested time through course credits instead of being volunteer-based for the student physical therapists. Continued future directions would also involve a post-design year for each technology developed. Depending on the intent of the technology, this post-design year would assess the clinical or research application and encourage quality improvement and redevelopment processes critical to ensuring the optimal usability for patients and clinicians.

CONCLUSIONS

This is an academic example of a stepwise approach to engage engineers by first establishing a baseline understanding of each other's professions and then engaging in meaningful problem-based cases. Physical therapists must continue to strive to engage with engineers as part of the interdisciplinary team in developing clinically useful technologies that are accurate, purposeful, and easy to use.

ACKNOWLEDGEMENTS

Initial pilot funding provided by the GW Honey W. Nashman Center for Civic Engagement and Public Service.

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