Improving Biomedical Engineering Education Through Continuity in Adaptive, Experiential, and Interdisciplinary Learning Environments

Anita Singh[1]
Biomedical Engineering,
School of Engineering,
Widener University,
Chester, PA 19013
e-mail: asingh2@widener.edu

Dawn Ferry
School of Nursing,
Widener University,
Chester, PA 19013

Susan Mills
School of Nursing,
Widener University,
Chester, PA 19013

This study reports our experience of developing a series of biomedical engineering (BME) courses having active and experiential learning components in an interdisciplinary learning environment. In the first course, BME465: biomechanics, students were immersed in a simulation laboratory setting involving mannequins that are currently used for teaching in the School of Nursing. Each team identified possible technological challenges directly related to the biomechanics of the mannequin and presented an improvement overcoming the challenge. This approach of exposing engineering students to a problem in a clinical learning environment enhanced the adaptive and experiential learning capabilities of the course. In the following semester, through BME448: medical devices, engineering students were partnered with nursing students and exposed to simulation scenarios and real-world clinical settings. They were required to identify three unmet needs in the real-world clinical settings and propose a viable engineering solution. This approach helped BME students to understand and employ real-world applications of engineering principles in problem solving while being exposed to an interdisciplinary collaborative environment. A final step was for engineering students to execute their proposed solution from either BME465 or BME448 courses by undertaking it as their capstone senior design project (ENGR401-402). Overall, the inclusion of clinical immersions in interdisciplinary teams in a series of courses not only allowed the integration of active and experiential learning in continuity but also offered engineers more practice of their profession, adaptive expertise, and an understanding of roles and expertise of other professionals involved in enhancement of healthcare and patient safety.
[DOI: 10.1115/1.4040359]

Keywords: biomedical, education, adaptive, experiential, interdisciplinary

Introduction

For medical technology innovation to successfully address the healthcare needs at minimum costs it is imperative that the new generation of engineers be trained differently. The current training environment for these innovators is very different from the scenarios in which the medical device industry emerges [1]. A realistic working environment, in this case a clinical setting and a team working together on these innovations is not replicated in the current academic setting. Most engineering education happens in a classroom and laboratory setting where the focus is on acquiring knowledge and its application [2]. Very rarely is the goal to understand real-world market needs, the associated costs, and others factors, including the stakeholders that can significantly help bridge the gap between innovations and the demands of the healthcare industry.

To overcome these limitations, it is important to integrate new approaches to biomedical engineering (BME) education such that the graduates of biomedical engineering programs are not only well trained to be problem solvers but are also trained in the skills and perspectives needed to better understand the healthcare settings and their needs. The graduates should be able to create practical solutions within socio-economic constraints [3], while working with all the key stakeholders critical to developing medical technology solutions, including clinicians, other healthcare providers, regulatory experts, investors, industry insiders, and patients [4,5]. This is only possible through the inclusion of adaptive and experiential learning environments within the curriculum [6,7] and not just in one course but in a series of courses. It is also important that interdisciplinary courses be offered where key participants of healthcare industry such as clinicians and nurses are brought together with engineers while getting trained in problem solving strategies. Through their interactions, these students will gain a better understanding of other team members' expertise, the possibilities of their contributions, and outcomes of successful professional collaborations [8–10].

Another important gap in engineering education is the ability of engineers to identify a problem that is worthy of solving [11]. Engineering problem solving courses, which are introduced as early as in the first semester of engineering education, are often driven by the instructor and include well-defined problems for which students are trained to obtain solutions using fundamentals of engineering, their technical proficiencies, and problem-solving skills [12]. The steps involved are as follows: understanding the problem, generating some concepts, selecting a concept, prototyping the selected concept, followed by validation [13]. While these

[1]Corresponding author.
Manuscript received April 4, 2018; final manuscript received May 17, 2018; published online June 7, 2018. Assoc. Editor: Kristen Billiar.

steps are to be employed in the real world, very rarely are the problems well defined with known wants, needs, and constraints. Training engineers to seek problems for which they can define a well thought-out problem statement is crucial for the next generation's technological advancements. To accomplish this goal, a series of courses are required that can introduce elements of problem identification in an adaptive and experiential learning environment while offering a better understanding of the needs, wants, and constraints. Training in problem identification then needs to be followed by a course that can help execution of the proposed solution through the traditional steps of engineering design.

Through this study, we report our experience of developing a series of BME courses geared toward training biomedical engineers to better understand the needs of the healthcare industry through active and experiential learning and offer engineering solutions while working in an interdisciplinary team setting (Fig. 1).

Methods

Courses and Participants. A team consisting of one BME faculty, one Nursing faculty and a Nursing Simulation Laboratory Director worked collaboratively to create a series of BME/NURS courses that included the adaptive and experiential learning environment in an interdisciplinary setting.

Course 1: In the first course, BME465: Biomechanics, the BME faculty and Nursing Simulation Laboratory Director worked collaboratively with the last three cohorts in the past three years. Participants in this course were biomedical ($n = 43$) and mechanical engineering ($n = 10$) senior students. These students were exposed to the simulation laboratory located in the School of Nursing. Each team, consisting of at least one mechanical and two to three biomedical engineering students, was required to develop an understanding of the role of the mannequin in creating simulation scenarios and its limitations in meeting the goals of nursing education while continuously interacting with the Nursing Simulation Laboratory Director. The biofidelity of these mannequins drives their application in creating simulations and enhancing the biofidelity that directly relates to enhancing its application in teaching. Using principles learned in the Biomechanics course (course content detailed in Singh [14] and aligned with Accreditation Board for Engineering and Technology student outcomes a, c, g, h, j, l, and m), engineering students worked together to identify three unmet needs and offer an engineering solution to one of the three needs. In this phase of training, emphasis was placed on adaptive learning through the application of engineering principles to enhance the biofidelity of the mannequin. Additionally, immersion in the simulation laboratory and project-based training offered students the experiential learning component of teaching.

Course 2: In the second series of courses, BME448: Medical Device (aligned with Accreditation Board for Engineering and Technology student outcomes g, h, i, and j), engineering students ($n = 26$) were teamed with nursing students who were enrolled in a NURS338-Evidence-based practice course ($n = 24$). The BME and Nursing faculty worked collaboratively to create an interdisciplinary environment by bringing the engineering and nursing students together in one classroom setting during the previous two offerings of the course in the last two years. Students from these two disciplines were teamed together and were introduced to the

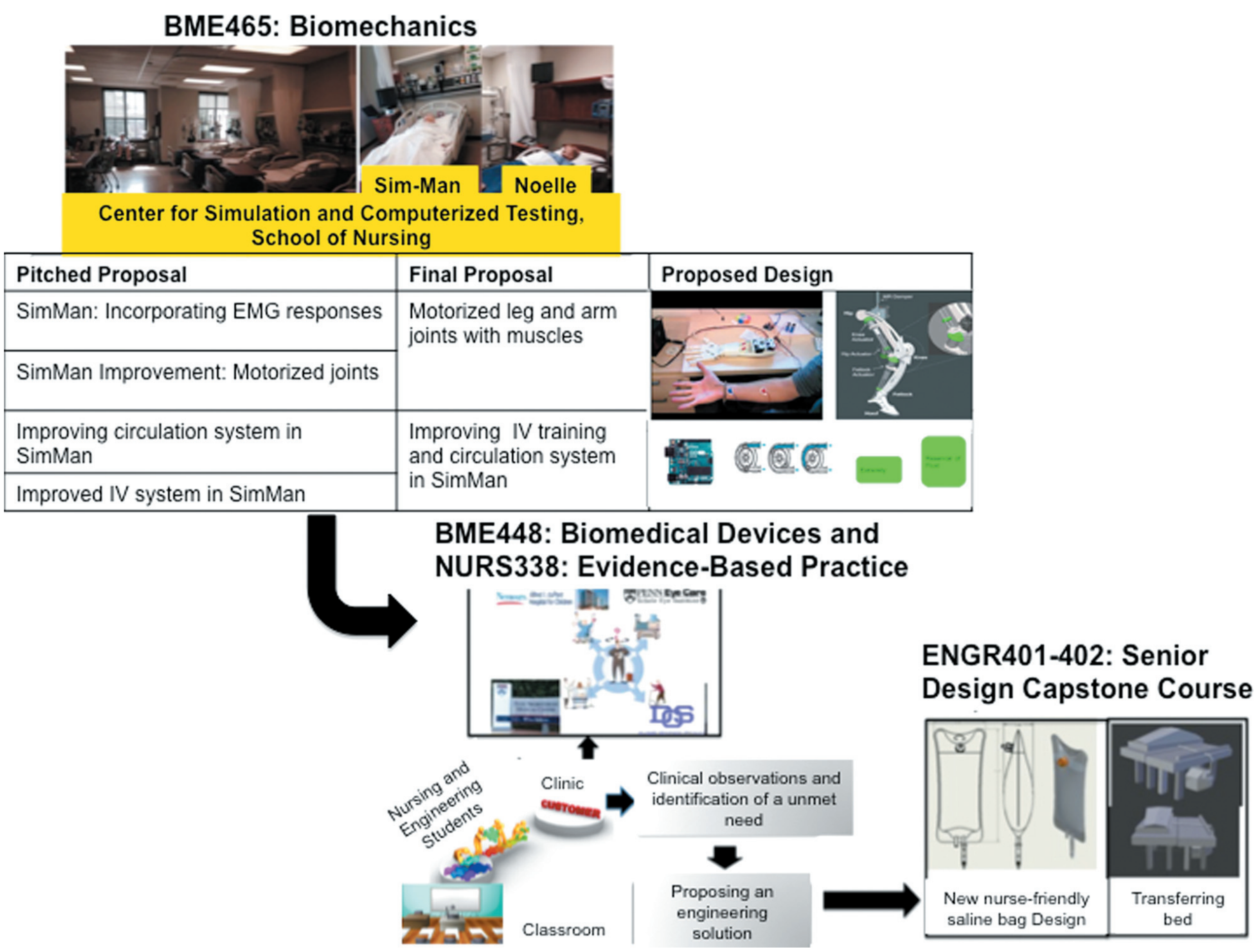

Fig. 1 Series of courses (BME465: Biomechanics, BME448: Medical Devices, ENGR401-402: Senior Design Capstone Courses) in the BME Curriculum with adaptive and experiential learning environment in an interdisciplinary setting

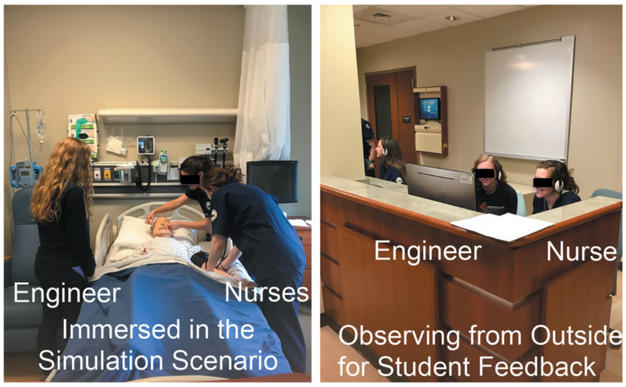

Fig. 2 Students immersed in simulation scenarios: left, engineering and nursing student teams working together to diagnose the problem in a simulated setting; right, team observing from outside to provide student feedback during debriefing

Biodesign [15] process. Through powerpoint slides, interactive in-class activities, and online readings, all the teams created their team's mission, outlined their strengths and weaknesses, and an acceptance criteria for their strategic focus. To further enhance their collaborations and their communication skills, the teams were exposed to two different clinical settings: simulation-based and real-world. Before visiting these settings, the teams were required to understand the disease state fundamentals, anatomy, physiology, pathophysiology, and current treatment options and roles of various stakeholders in these settings. Additional lecture topics included responsible conduct of research, intellectual property and patenting, Food and Drug Administration and regulatory path, and market analysis.

Simulation-based clinical settings: Two simulation classes (75 min long and accounting for 7% of the total course contact hours), including three scenarios that prompted collaboration and communication among students from these two disciplines, were offered. Student learning was further fostered by orienting them to the environment, debriefing them about the scenarios, and making

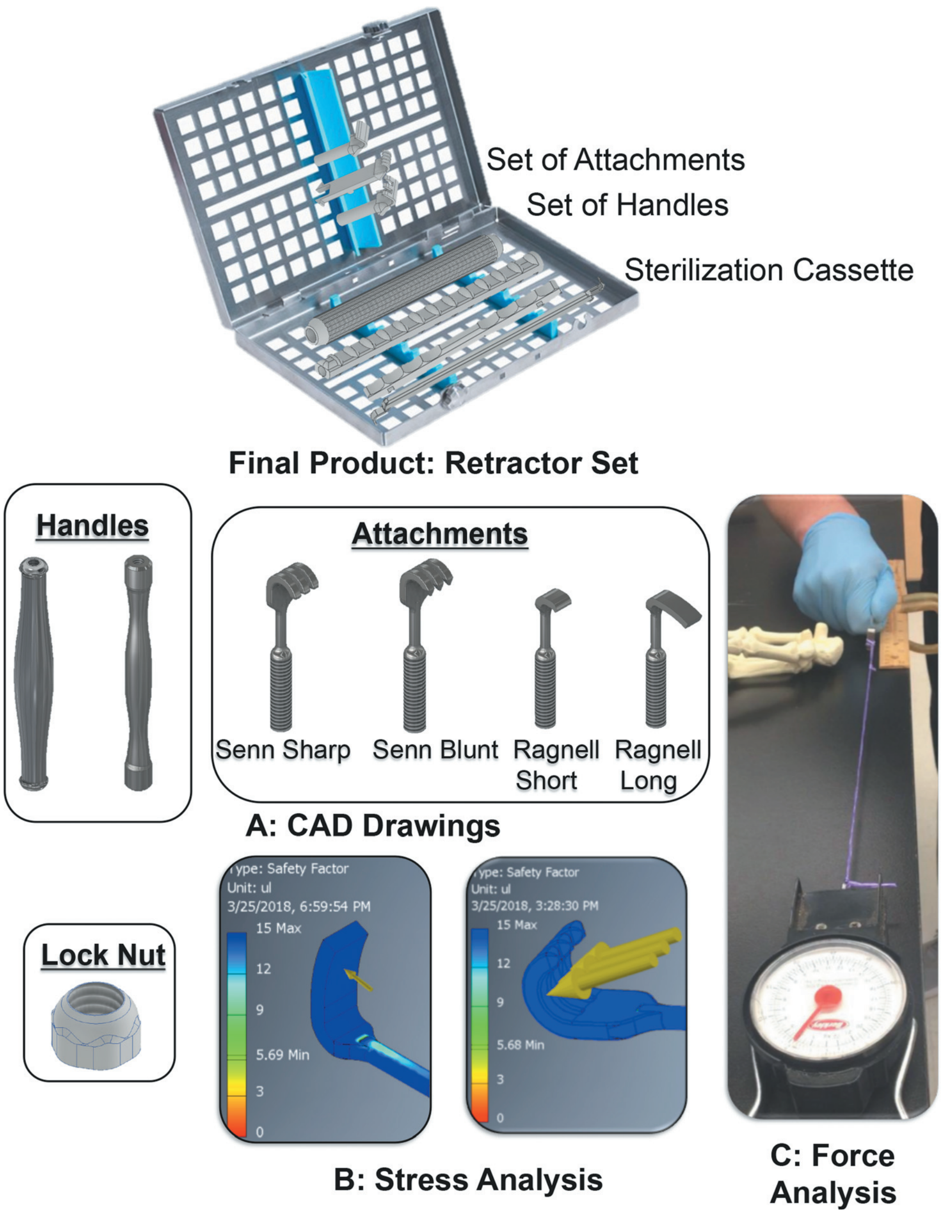

Fig. 3 ENGR401-402 senior design project related to an unmet need in a surgical retractor set identified during BME448 course: (*a*) CAD renderings of the design, (*b*) stress analysis using FEA, and (*c*) force analysis for retractor heads

them aware of their roles in troubleshooting the problem they were to observe in these settings. During the first simulation class, in teams of two comprising of one engineering and one nursing student, students attended two scenarios (10 min each). Both scenarios were device/equipment based. In the first scenario, an actor was positioned in the observation room while waiting to be diagnosed with a beeping intravenous device. In the second scenario, a mannequin was showing signs of distress while being hooked up to the gas. These scenarios were specifically created so that the team could successfully fix the problem through effective communication and coordinated actions. A 15-min debriefing was conducted immediately following each simulation where students assessed their performance and were provided with feedback from instructors, who were observing them throughout the process from the outside through a camera placed in the room. During the second simulation class, students were again teamed up in pairs consisting of one engineering and one nursing student and introduced to a scenario that was more clinically oriented. Also, another such student team observed their performance from outside the room through the camera placed in the room to offer student-oriented feedback during debriefing (Fig. 2). The scenario consisted of a mannequin who was admitted to the emergency room with blurred vision. The goals for the team were to make a diagnosis of his condition, administer the required medication, and offer the correct treatment option. The overall goal of this simulation was to better prepare engineering students for the upcoming real-world clinical visit. Knowing clinical settings, understanding roles played by all individuals in providing care to the patients and family, knowing procedures involved during the care process, and feeling comfortable in these environments to ask relevant questions are all critical to the training of biomedical engineers.

Clinical immersion in a real-world setting: These simulation classes were then followed by a visit to the real-world clinical setting where the team worked together to identify three unmet needs while attending one of the following surgeries or clinics: cataract surgery, hand surgery, robotic prostate surgery, emergency department, and physical therapy clinic. The unmet needs presented by the students were vetted by the instructors based on the criteria of clinical impact and available funds if the need was addressed successfully. Each team was then assigned one unmet need for which they proposed a viable engineering solution. Overall experience in this course enriched students with understanding their role in the healthcare industry while working toward finding a solution for healthcare needs. While the main goal of the course was to introduce interdisciplinary team-based training, by offering clinical immersion experiences and having the team propose solutions to their unmet needs, the course re-introduced components of adaptive and experiential learning.

Course 3: In the last course, students executed their proposed designs, from BME465 or BME448 courses, by taking one of the unmet needs and proposing a solution as a senior design project in the senior year ENGR401-402 senior design capstone courses. These two semester-long courses offer them an opportunity to work with a clinical advisor and a faculty advisor, while working in their interdisciplinary team, toward a common goal of presenting a viable engineering solution using the design process. Students start with an in-depth literature review of available products in the market, perform gap analysis, define specifications of their product including the wants, needs, and constraints and generate some concepts. These concepts are discussed with the clinical advisor before concept selection is done while matching against the wants, needs, and constraints. The selected concept is then prototyped and validated. As part of the course, the student teams are required to present the solution to a group of external reviewers, which challenged them to improve their communications skills. Overall, the course offers a highly interactive environment to engineering and nursing students while they worked on their self-initiated project. In the past year, one of the two BME teams ($n = 6$) along with their nursing partner ($n = 1$) executed their proposed solution through the senior design courses. The team visited the hand surgery site and focused on making improvements to the existing hand retractors used in the surgical setting. The team was able to successfully design, prototype, and test a series of ergonomic handles with changeable retractor heads that are commonly used in surgeries (Fig. 3). The designs focused on reduced operation room time, personnel, and cost associated with the surgery.

Surveys. With Institutional Review Board approval, voluntary anonymous student surveys to evaluate the impact of the clinical immersions through simulation and real-world clinical visits (BME465 and BME448/NURS338) and interdisciplinary team setting (BME448/NURS338 and ENGR401-402) were obtained at the end of these three courses. Data are reported from three cohorts of BME465, two cohorts of BME448 courses, and one cohort of ENGR401-402 courses. These items were measured on a yes/no and Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Open responses were also completed by the students in the following categories: Communication, Collaboration, Knowledge of other professions, and Shared understanding. Student responses are summarized in Tables 1–4.

Results

Overall, 94% of the students in BME465: Biomechanics and 97% of the students from BME448/NURS 338: medical devices/evidence-based practice and 100% from ENGR401-402: senior design courses completed responses to the survey questions. Analyses of the data indicated learner value for adaptive and experiential learning in an interdisciplinary environment. Survey responses are summarized in Tables 1–4: 75% or more student responses above 3 on 1–5 Likert-type scale and yes on the yes/no scale were indicative of a successful student-learning outcome.

Course 1: BME465-Biomechanics: responses from students were indicative of enhanced application of biomechanics field to the real-world (Table 1). Survey data indicate better preparedness of students for real-world problems. Furthermore, the data also indicate that students felt better prepared to identify needs in the field of biomechanics related to clinical settings. It was also reported that the knowledge learned in the classroom setting

Table 1 BME465: biomechanics course survey outcomes ($n = 50$)

Questions	Response rate
I learnt about real-world application of biomechanics knowledge	90%-Agree
The skills learned while working on the final project are life-long learning skills	85%-Agree
I am more confident in not just solving real-world problems in the field of biomechanics but also identifying them	90%-Agree
The topics discussed in the class helped me accomplish the goals of the final project	85%-Agree
This class included more real-world problems and critical thinking than other traditional engineering classes	85%-Agree
I think the sim-man laboratory visit should be a part of future course offerings	90%-Agree
The sim-man laboratory visit helped me learn about the real-world application of biomechanics knowledge	84%-Agree
Finding a problem in another discipline was exciting	90%-Agree
Finding a problem solution that is highly translational was exciting	85%-Agree

Table 2 BME448/NURS338-medical devices/evidence-based practice course survey outcomes ($n = 48$)

Questions	Response rate
Simulation Lab Survey	
Have you ever visited a simulation lab before?	70%-Yes
Have you ever been a part of a simulation lab before like the two you attended during this course?	100%-No
The knowledge gained through the simulation experience can be transferred to the clinical visit	80%-Agree
The offered simulation scenarios promote better learning than slides explaining these scenarios	77%-Agree
The individual simulation scenario allowed you to demonstrate your ability to communicate with the other providers of the healthcare team	87%-Agree
The individual scenario allowed you to use the critical thinking skills learned through the engineering program during the simulation	72%-Agree
You can provide specific rationales for your actions during the simulation scenarios	60%-Agree
The nursing partner in the room during the individual simulation scenario made the experience more realistic	88%-Agree
Simulation lab provided an active hands-on learning environment	77%-Agree
The simulation lab experience is novel to engineering education and should be offered in future offerings	77%-Agree
Simulation lab helps you better understand your role in the healthcare industry as an engineer	77%-Agree
Real-world Clinical Visit	
Do you better understand the steps involved in making clinical observations and the problem identification phase of the device development process?	90%-Agree
Did the clinical visit help meet the course objective of preparing students to enter the medical device industry or related field?	92%-Agree
How likely are you to take your unmet needs as a senior design project	50%-Likely to very likely
Overall, did this course help teach you how to identify and validate medical needs through clinical visits and observations?	100%-Agree

through traditional lectures helped students in proposing a solution for their unmet needs. Students felt excited about finding biomechanics-related problems in other disciplines and working to seek a solution for a highly translational problem. When compared to other traditional engineering courses, students felt that the BME465: biomechanics course offered them a life-long learning experience and enhanced their critical thinking. Students were in favor of offering a similar experience in future offerings of the course.

Course 2: BME448/NURS338-medical devices/evidence-based practice:

All Biomedical engineering students enrolled in BME448 had taken BME465: Biomechanics course and had already been introduced to the simulation lab. However, 30% of students (in the three cohorts) were from other engineering fields and had never been in a simulation laboratory setting. Also, while most of the students (all BMEs) had been in the simulation laboratory before, they were never introduced to a simulation scenario. Thus, all engineering students were new to clinical simulation scenarios and strongly felt that the knowledge gained through simulation scenarios could be applicable to real-world settings (Table 2). Furthermore, the three simulation scenarios promoted better learning than slides explaining these scenarios. These simulation scenarios allowed them to demonstrate their ability to communicate with the other providers of the healthcare team, to use critical thinking skills learned through the engineering program, and an active hands-on learning environment. Students agreed that having a nursing partner in the room during these individual simulation scenarios made the experience more realistic. Students felt confident in providing specific rationales for their actions during the simulation scenarios. Overall, the simulation scenarios helped students better understand their role in the healthcare industry as an

Table 3 Student open-ended responses from BME448: Biomechanics and NURS338: evidence-based practice courses ($n = 48$)

Categories	Student responses
Communication	"This experience has taught me about communication among other professionals"
	"Nursing terminology is crucial since knowing these terms allow you to better understand the patient's condition"
	"Being able to speak with the nurses about issues they face in the clinical setting really gave me a new perspective on how to design medical devices"
Collaboration	"Working with engineers and identifying unmet needs allowed me understand how to be a better advocate for my patient"
Knowledge of other professions	"I never realized how much equipment a nurse needed to understand in order to efficiently do their job for a given patient and how many things could go wrong"
	"Taking a step back and fully processing the steps and equipment used in patient care allowed me to get a better understanding of the patient's care holistically"
	"Through the engineers I was able to learn how their input and expertise could help not only my patients, but allow me to be more efficient with time"
	"I've gained a new appreciation for not only the engineers, but other majors because we can all benefit from each other and our expertise"
	"Having clinical simulations and an operating room experience has given me a better understanding of the goals and objectives of an engineer"
	"An operating room is stressful"
Shared understanding	"Improving patient recovery and safety are the most important goals of creating a medical device. If the nurses do not have the proper device to treat a patient, or if the device isn't easy to use, this can be harmful to patient recovery and safety"
	"Safety is always the priority in nursing. By establishing a rapport with more of the patient's healthcare team, better information would be provided to the patient"
	"It is important to follow procedures otherwise you will be putting the patient or yourself at risk"

Table 4 ENGR401-402: capstone senior design courses survey outcomes ($n = 6$, engineering students only)

Questions	Response Rate
Did BME 465 and BME 448 better prepare you for your senior design project?	100%-Agree
Did you feel more enthusiastic about your student-driven project where you identified a problem and sought a solution for it?	100%-Agree
Did the clinical project draw you close to the biomedical engineering field and its applications?	100%-Agree
Would you recommend other students to take their BME 448 project as their senior design project?	100%-Agree
Do you think continuing your work with nursing students helped you better design your product?	60%-Agree
Do you think the experience in this project is better than the traditional instructor- or industry-driven project?	80%-Agree
Do you feel better prepared for the real-world?	80%-Agree
Did you improve your communication skills through your interaction with the clinical advisor?	80%-Agree
Did you feel more confident in your problem understanding through clinical immersion?	100%-Agree
Do you think you successfully met the unmet clinical needs	100%-Agree
Would you patent your design?	100%-Agree
Does this project encourage the entrepreneur in you?	100%-Agree
Do you feel better prepared than others to solve unmet clinical needs?	100%-Agree
Do you feel you were able to use your technical proficiencies in solving the unmet need?	100%-Agree
Did doing this senior design project add to your understanding of the interdisciplinary and collaborative nature of the medical device innovation?	100%-Agree
Did this course offer you lifelong learning skills?	100%-Agree
Did the course encourage your critical thinking?	100%-Agree

engineer. Students agreed that the experience was novel to engineering education and should be part of future offerings. Other beneficial experience among learners included team coordination, communication, increased knowledge of other professions and understanding of distinct, and shared roles the healthcare industry with enhanced patient safety (see Table 3).

Course 3: ENGR401-402: senior design capstone courses: all BME students in ENGR401-402 were enrolled in BME465 and BME448 courses. Students agreed that the two previous courses better prepared them for their senior design project. Students were very enthusiastic about their self-driven project, and working on their clinical project drew them closer to their professional field while making them feel better prepared for the real-world. Most of them agreed that the experience gained through their project was better than if they were to work on a traditional instructor- or industry-driven project. Students also felt that working with their nursing partners did help with their engineering solution. However, this percentage was below the 75% acceptable response threshold. All students felt that the project encouraged the entrepreneur in them and they would like to patent their design. Students agreed that they were able to use their technical proficiencies in solving the unmet need. Overall, students agreed that doing their senior design project added to their understanding of the interdisciplinary and collaborative nature of the medical device innovation, encouraged their critical thinking skills, and added to their life-long learning skills.

To assess student success through this series of courses, we summarized the engineering students' placements after graduation in the last three cohorts. Data from last three cohorts indicate that 48% of graduates are working in the healthcare industry, 43% are pursuing graduate degrees, and 9% are working in other fields (Table 5). While we lack data from a control cohort that would have lacked the approaches proposed in this study, placement of over 70% of our graduates in the medical devise industry over other industries in the last three cohorts is indicative of students' confidence in pursuing this field.

Discussion

Biomedical engineering curricula continue to struggle to determine the best method to expand the knowledge and skills of engineers who need to solve complex problems at the interface of biology and engineering. The rapidly developing biomedical engineering industry has made it evident that engineering students need to build "adaptive expertise" [16]. It is reported that when concepts and ideas are presented outside a specific context, students have no way to associate the knowledge to a problem they will solve in the future [17–20]. Current biomedical engineering education has limited incorporation of techniques that can go beyond offering the subject knowledge and developing an ability in students to think innovatively in new contexts. It is evident that if students learn content within a context, they are more likely to generalize their knowledge to other contexts [21]. This in a boarder sense defines an experiential learning environment that promotes the inductive learning process [22]. Lack of training in adaptive expertise, especially in the field of biomedical engineering, may be contributing as a barrier to students' success as professionals. By acquiring adaptive expertise, students can be trained to apply their knowledge in new contexts and have the ability to account for multiple perspectives when designing solutions for problems in the rapidly advancing healthcare field. In this study, we share our experience of offering various immersion opportunities, through a series of BME courses that can help enhance adaptive expertise in BME students. By engaging students in identifying real-world unmet needs in various healthcare-related disciplines, including nursing education tools (Sim-Man), and developing solutions for these problems, we aim to increase student learning by increasing their awareness of the connections between knowledge acquired in the classroom and the real-world application of that knowledge to a new context in their future work.

Our courses were introduced later in the curriculum (Senior year) since students from early years in training may lack the training to structure their approaches to these open-ended problems. Learning engineering fundamentals and principles for a subject and applying them with an analysis strategy that is effective requires some training in the field [23]. We assumed that by the senior year these students have the core and required knowledge and skills that students should have and be able to use them during problem-solving steps. Using the success indicator for adaptive expertise, we aimed for our students to improve significantly in both the knowledge as well as the innovation aspects of adaptive

Table 5 Student placements after graduation ($n = 39$)

Years	Graduate degree	Medical device industry	Other industry	Other fields
2015	22%	56%	22%	0%
2016	45%	55%	0%	0%
2017	62%	32%	0%	6%

expertise [24]. This is evident from our findings where, through the senior design capstone courses, our students felt confident in execution of their proposed solution by applying correct equations and governing principles to their problem solution.

Another important factor in student success, especially in the field of biomedical engineering, is whether students considered the problem from multiple perspectives including the stakeholders and the system's environment. Inter-professional environments, such as healthcare, place special emphasis on developing theoretical understanding of the role of collaborative and experiential learning [9,10,25]. Biomedical engineers can succeed only through effective communication and clear understanding of roles and expertise of others involved in the innovation process. Student numbers in undergraduate settings, resources, college environment, and collaboration between various other healthcare related units within the institution can make developing an inter-professional environment for engineering students challenging. While challenging, these environments are not impossible to create. In the proposed courses, we offer a safe tool to develop technical and collaborative competencies in students through practice in environments that offer high-fidelity simulated scenarios as observed in actual operational conditions. In this study, we demonstrate the success of using simulation-based training as a promising alternative to real-world clinical immersion settings. Our findings report that a simulation-based setting was well received by the engineering students and it led to an improvement in their understanding of various other healthcare disciplines and their roles in the healthcare industry.

Another interesting finding of this study was that students expressed their limited knowledge of other professions placing constraints on their ability to give constructive feedback while raising questions of how their comments were perceived. So, while giving and receiving feedback from other professionals on their team was valuable, it was not easy. This highlights the importance of ensuring that such environments be created in more than one course to promote a gradual buildup of students' interdisciplinary skills and awareness [10]. However, another interesting finding of our study was that even with a series of two prior interdisciplinary courses, only 60% of engineering students reported nursing students to be helpful in better design of their product during the senior design capstone courses. This could also be attributed to the availability of a clinical advisor who was directly involved in the design process, thereby superseding the role of the nursing student. This is evident from 80% of the same students reporting an improvement in their communication skills through their interactions with clinical advisor. This indicates a possible correlation between having a clinical advisor and a reduced need for nursing student in the senior design project courses. We would like to continue to gather data in future offerings of the courses and confirm this finding.

Another aspect of adaptive and experiential learning in interdisciplinary settings is through real-world clinical immersion. Through the recent National Institutes of Health funding mechanism, clinical immersion for BMEs has emerged as one of the most effective ways to introduce engineers to real-world settings [26]. However, an important limitation to this approach is non-continuity in the experience, with usually just one course offering such an experience. Furthermore, the unmet needs identification is not promoted to execution through inclusion of executing the proposed solution as in the capstone design course projects. Most senior design capstone projects are instructor- or industry-driven projects. Only 15% of projects are student-driven projects [27]. Having students work on self-identified projects helps generate interest and enthusiasm toward their profession as evident from our student survey data.

In summary, this study reports student outcomes through a series of courses geared toward adaptive and experiential learning environments for engineers in an interdisciplinary team setting. Using high-fidelity simulated environments and real-world clinical scenarios, we develop adaptive expertise in students that leads to enhanced student learning. Furthermore, by having them work in interdisciplinary team settings, we engage them in a more realistic work environment while offering clarity of their roles in addressing the challenges of the healthcare industry. The study does offer some limitations. The results presented here are limited to single-university demographics. The surveys represent student perceptions and are not an objective assessment of student learning or content mastery. Furthermore, lack of data from a control cohort that took these courses in their traditional forms warrants future studies that can not only compare but also confirm the beneficial outcomes of adaptive and experiential learning environments in an interdisciplinary team setting as reported in this study to those lacking these approaches.

Acknowledgment

We would like to thank our clinicians and their staff for offering clinical immersion experience to our students.

Funding Data

- National Institute of Biomedical Imaging and Bioengineering (Award No R25EB023857).

References

[1] Yazdi, Y., and Prev, A., 2013, "Developing Innovative Clinicians and Biomedical Engineers: A Case Study," Am. J. Prev. Med., **44**(Suppl 1), pp. S48–S50.
[2] Newstetter, W. C., Behravesh, E., Nersessian, N. J., and Fasse, B. B., 2010, "Design Principles for Problem-Driven Learning Laboratories in Biomedical Engineering Education," Ann. Biomed. Eng., **38**(10), pp. 3257–3267.
[3] Hastings, D., 2004, "The Future of Engineering Systems: Development of Engineering Leaders," MIT Engineering System Division, Cambridge, MA, Engineering Systems Monograph, pp. 29–31.
[4] Todd, R. H., and Magleby, S. P., 2004, "Evaluation and Rewards for Faculty Involved in Engineering Design Education," Int. J. Eng. Educ., **20**(3), pp. 333–340.
[5] Dym, C., Agogino, A., Eris, O., Frey, D., and Leifer, L., 2005, "Engineering Design Thinking, Teaching, and Learning," J. Eng. Educ., **94**(1), pp. 103–120.
[6] Harris, T. R., and Brophy, S. P., 2005, "Challenge-Based Instruction in Biomedical Engineering: A Scalable Method to Increase the Efficiency and Effectiveness of Teaching and Learning in Biomedical Engineering," Med. Eng. Phys., **27**(7), pp. 617–624.
[7] Garceau, L. R., Ebben, W. P., and Knudson, D. V., 2012, "Teaching Practices of the Undergraduate Introductory Biomechanics Faculty: A North American Survey," Sport Biomech., **11**(6), pp. 542–558.
[8] King, A. E., Conrad, M., and Ahmed, R. A., 2013, "Improving Collaboration Among Medical, Nursing and Respiratory Therapy Students Through Interprofessional Simulation," J. Interprof. Care., **27**(3), pp. 269–271.
[9] Clark, P. G., 2006, "What Should a Theory of Interprofessional Education Look like? Some Suggestions for Developing a Theoretical Framework for Teamwork Training," J. Interprof. Care, **20**(6), pp. 577–589.
[10] D'Eon, M., 2005, "A Blueprint for Interprofessional Learning," J. Interprof. Care, **19**(Suppl. 1), pp. 49–59.
[11] Armstrong, M., Bull, G., and Biaglow, A., 2016, "Assessment of Student Ability to Identify Engineering Problems," ASEE Mid-Atlantic Section Conference.
[12] Vijayalakshmi, M., Desai, P., and Joshi, G., 2003, "Outcome Based Education Performance Evaluation of Capstone Project Using Assessment Rubrics and Matrix," IEEE International Conference in MOOC, Innovation and Technology in Education (MITE), Jaipur, India, Dec. 20–22, pp. 6–10.
[13] Sobek, D., II., and Jain, V., 2004, "The Engineering Problem-Solving Process: Good for Students?," American Society for Engineering Education Annual Conference & Exposition, Salt Lake City, UT.
[14] Singh, A., 2017, "A New Approach to Teaching Biomechanics Through Active, Adaptive, and Experiential Learning," ASME J. Biomech. Eng., **139**(7), p. 071001.
[15] Zenios, S., Makower, J., and Yock, P., 2010, *Biodesign*, Cambridge University Press, Cambridge, UK.
[16] Albanese, M. A., and Mitchell, S., 1993, "Problem-Based Learning: A Review of Literature on Its Outcomes and Implementation Issues," Acad. Med., **68**(1), pp. 52–81.
[17] Bransford, J., Brown, A., and Cocking, R., 2000, *How People Learn: MindBrain, Experience, and School*, National Academy Press, Washington, DC, p. 319.
[18] Hatano, G., and Inagaki, K., 1986, "Two Courses of Expertise," *Child Development and Education in Japan*, W. H. Freeman & Co, New York, pp. 262–272.
[19] Lesgold, A. M., Rubinson, H., Feltovich, P., Glaser, R., Klopfer, D., and Wang, Y., 1988, "Expertise in a Complex Skill: Diagnosing X-Ray Pictures," *The Nature of Expertise*, Erlbaum, NJ, pp. 311–342.
[20] Raufaste, E., Eyrolle, H., and Marine, C., 1998, "Pertinence Generation in Radiological Diagnosis: Spreading Activation and the Nature of Expertise," Cognit. Sci., **22**(4), pp. 517–548.

[21] Roselli, R. J., and Brophy, S. P., 2003, "Redesigning a Biomechanics Course Using Challenge-Based Instruction," IEEE Eng. Med. Biol. Mag., **22**(4), pp. 66–70.
[22] Felder, R. M., and Brent, R., 1996, "Navigating the Bumpy Road to Student-Centered Instruction," Coll. Teach., **44**(2), pp. 43–47.
[23] de Jong, T., 2006, "Computer Simulations: Technological Advances in Inquiry Learning," Science, **312**(5773), pp. 532–533.
[24] Martin, T., Petrosino, A. J., Rivale, S. R., and Diller, K. R., 2006, "The Development of Adaptive Expertise in Biotransport," New Dir. Teach. Learn., **108**, pp. 35–47.
[25] Hean, S., Craddock, D., and O'Halloran, C., 2009, "Learning Theories and Interprofessional Education: A User's Guide," Learn. Health Social Care, **25**(4), pp. 250–262.
[26] Kadlowec, J., Merrill, T., Hirsh, R., and Sood, S., 2015, "Work-in-Progress: Clinical Immersion and Team-Based Engineering Design," ASEE Annual Conference, Seattle, WA.
[27] Howe, S., 2010, "Where Are We Now? Statistics on Capstone Courses Nationwide," Adv. Eng. Educ., **2**(1), pp. 1–27.