Designing an Interprofessional Educational Undergraduate Clinical Experience

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1. ABSTRACT

Ongoing assessment of the biomedical engineering concentration in the Department of Engineering at East Carolina University, suggested that undergraduate students had difficulty adequately translating technical course content to real world biomedical engineering problems. East Carolina University is home to the Department of Engineering, Brody School of Medicine, School of Dental Medicine, College of Nursing, College of Allied Health Sciences, and is affiliated with a large regional medical center. Taking advantage of these resources, the goal of this project was to develop a multidisciplinary, collaborative educational experience, in a clinical environment, to improve student learning. Our objectives were to provide undergraduate engineering students with an understanding and appreciation of the needs and uses of technology in healthcare and to foster innovation in medical technology. The "Special Topics in Engineering Biomedical Innovation" course serves as an engineering technical elective, targeted to junior and senior undergraduates. The course was first offered in spring 2016 and includes a didactic component, observation component and team based project. Students receive instruction in observation techniques, clinical environments, professional behavior, entrepreneurship, technology transfer, and intellectual property. Clinic rotations focus on identifying unmet clinical needs with projects aimed at developing and designing a solution. In 2017, a new collaboration with the College of Business Miller School of Entrepreneurship was initiated. At the end of the term, the combined engineering and business teams pitch their ideas to a group of investors and clinic sponsors. Evaluation of the course is based on assessment of student surveys, project reports, presentations and clinic sponsor feedback. A total of 14 students have participated in the course. Student surveys were overwhelmingly positive, identifying course strengths in critical and innovative thinking, development of observation skills, applied engineering, and clinical exposure. Suggested course improvements include more scheduled project work time, access to engineering fabrication lab, and better coordination with the business students. Clinic sponsors rated the students good to excellent for professionalism, timeliness, respect for patients, asking questions, respect for clinic staff and preparedness. In summary, a new course, using a multidisciplinary team approach was developed that provided students with clinical experiences and the opportunities to identify and solve real world problems. New collaborations with the Health Sciences Campus and College of Business were established and will continue to be developed. Benefits of this course are the generation of novel, multidisciplinary capstone project ideas and new collaborative opportunities. Overall this course illustrates the importance of providing undergraduate students open-ended, loosely defined projects, and allowing project teams to assume responsibility for design and innovation.

2. INTRODUCTION

Engineers, clinicians and patients often struggle to find balance between innovative technology and the human side of medical care. Graduate level educational programs dedicated to teaching biomedical innovation have seen significant growth in the last decade [1-7]. In addition, the field of biomedical engineering has seen a dramatic escalation in activity over the past 20 years leading to innovative medical devices and procedures. Due to the multidisciplinary characteristic

of the field, biomedical engineering has a diverse research impact, often serving as a bridge builder between technological and clinical communities, identifying medical needs and impacting, clinical practice, creativity and collaboration.

Engineering approaches are becoming increasingly important in modern biological and medical research and in the development of new technologies that stem from recent discoveries. In 2012, the First IEEE Life Sciences Grand Challenges Conference recognized that, "Despite tremendous efforts to develop the knowledge and ability that are essential for addressing biomedical health and problems using engineering methodologies, the optimization of this approach toward engineering the life sciences and healthcare remain a grand challenge" [8]. Two of five areas identified were (1) the translation of discoveries to clinical applications and (2) education and training. New graduate level interdisciplinary education programs are being developed to address the need for translating medical innovation into practical clinical solutions. According to Kurpinski et. al., "a new generation of medical innovators must be taught to recognize, accept and effectively navigate the challenges of translational medicine" [7]. Key areas of focus include biomedical technology, clinical issues, leadership and technology management [7]. The educational programs currently offered are primarily Master's level programs focused on technology innovation, design and product development [3-6]. Noting the Grand Challenges and need to identify and train individuals to facilitate biomedical innovation, the goal of this project was to design and develop a multidisciplinary course for upper level undergraduate students in engineering, health science and other Science, Technology, Engineering and Math (STEM) disciplines.

Creating a course for undergraduate students was a deliberate choice aimed at addressing an identified need in the undergraduate curriculum. Ongoing assessment of the biomedical engineering concentration in the Department of Engineering at East Carolina University, suggested that undergraduate students had difficulty adequately translating technical course content to real world biomedical engineering problems. There was also a high demand by students for active engagement and access to translational research and shadowing opportunities in a clinical environment. The original concept for the course was to provide access to clinical and real world biomedical problems, use a multidisciplinary team approach for innovative biomedical technology solutions and introduce the process of translating new devices and technologies from the laboratory bench to the bedside. After the initial course offering, faculty from the College of Business Miller School of Entrepreneurship expressed interest in partnering with the Department of Engineering to support an innovation and entrepreneurship component. The overall goal to improve the student's understanding of the business aspect of invention, including market analysis, feasibility and obtaining investment capital [9,10]. In addition, this partnership supports the university's commitment to develop multidisciplinary collaborative teams among the various departments, colleges and schools.

East Carolina University is the only university within the University of North Carolina system that offers academic programs in engineering, medicine, dentistry and allied health on one campus and is located near a major-medical center. The proximity of the facilities and collaborative opportunities among faculty exist to provide a unique teaching/learning environment for multidisciplinary education. East Carolina University's mission seeks to transform health care, promote wellness, and reduce health disparities with a commitment to

serving and improving the health of the citizens in the region. In 2016, 43% of degree seeking students were enrolled in a STEM or health care program [11]. East Carolina University's Department of Engineering offers a bachelor of science in engineering with a concentration in biomedical engineering. The biomedical engineering concentration accounts for 25% of the undergraduate majors in the department and enrollment has more than tripled since 2010 when courses in the concentration were first offered.

This paper reports the development, implementation and assessment after two years of a one semester clinical immersion course for undergraduate engineering students, "Special Topics in Engineering Biomedical Innovation". The overall objectives of the course are to (a) provide an interprofessional educational clinical experience, (b) address contemporary health-technology issues by identifying unmet clinical needs with technological solutions, and (c) integrate medical principles with engineering and STEM fundamentals to develop innovative solutions in a multidisciplinary team environment.

3. COURSE STRUCTURE

The course serves as an engineering technical elective in the Department of Engineering and is targeted to junior and senior engineering students. This 3-credit hour course was first offered in spring 2016 and continues to be offered annually as a technical elective. The structure of the course is modeled after the "Clinical Observational Design Experience" course taught at Georgia Institute of Technology and Emory University [12] and is composed of a didactic component, observation component and team based project. Two 2-hour lab sections and one 50-minute lecture per week are scheduled. The course can accommodate 12 - 14 upper level undergraduate students. Students are recruited from the Departments of Engineering, Biology, Physics and College of Nursing. Before enrolling all students provide a short statement describing why they are interested in taking the course and expectations for how the course will improve their understanding of clinical and real world biomedical problems. Consent of instructor is required and students are accepted based on GPA, motivation and potential for success. Prior to the first day of class the students are provided with a "Course Handbook". The handbook was written as a guide and provides a basic overview of the course and expectations. Key components for success in the course are work ethic and professional behavior. Tardiness and unexcused absences (in-class or clinic rotation) may result in a course grade of F.

Didactic Component

To prepare students for observing in the clinical environment, an initial meeting with the instructor takes place about 5 weeks before the beginning of the semester. At this meeting, basic requirements for observing in the healthcare clinics are discussed. The students are provided with a check list and deadline for completing and submitting paperwork for all clinics. These documents are submitted before students begin the clinic rotations. Requirements include a visitor application, copy of health insurance card, verification of negative TB skin test, verification of flu vaccine, Health Insurance Portability and Accountability Act (HIPPA) and Collaborative Institutional Training Initiative (CITI) training and Code of Conduct. In addition, all students are required to obtain visitor badges for clinics in the medical center. These activities

require students to navigate and become familiar with offices and administration on the Health Science Campus.

Similar to the "Clinical Observational Design Experience" course [12], the first several weeks are focused on ethnography, developing observation skills, problem identification/selection, bioethics and professional behavior. All students are required to purchase a small bound notebook to record observations and notes. Several class periods are devoted to observing space, safety, processes, people and equipment in familiar university settings, e.g., library, cafeteria, bookstore, etc. Most of the students enrolled have never shadowed or observed in a clinical or healthcare setting. Therefore, several clinicians are invited to provide guest lectures to discuss what the students might observe and how to behave in a clinical environment. A session directed at "Fears and Concerns" is scheduled before visiting the clinics. For this assignment students are asked to address three questions, (1) What fears do you have about your clinical rotations? (2) What concerns or challenges do you see about working with clinicians? (3) What concerns or challenges do you see about making observations? In 2017, former students participated in this session to speak about their experiences and offer "tips" for observing in a clinical setting. Additional class sessions focus on appropriate dress, introductions and perfecting an elevator speech. One class session includes a walking tour of the Health Science Campus, medical and dental clinics. Later in the semester class sessions include topics on device specification, development and innovation, intellectual property and patents, regulatory requirements, entrepreneurship, marketing, [10,11] and medical ethics relevant to device design. One class period per week is used for team presentations and discussion of clinical rotations, projects, etc.

Clinical Rotations

Clinical and laboratory rotations provide students with an opportunity to observe patient-healthcare provider interactions and the role of technology in a clinical setting. The course takes advantage of the proximity and combined strengths of the technical and engineering sciences in the Department of Engineering; and the biological and medical sciences in the Brody School of Medicine, School of Dental Medicine and College of Allied Health Sciences. The proximity of the facilities and a collaborative spirit among faculty provide a unique environment for multidisciplinary educational and research experiences.

In teams of two, students participate in four clinical rotations, with 4 visits to each clinic, approximately 8 hours per clinic. In 2016, 13 clinical departments were involved, including Emergency Department, Vascular Surgery, Cardiac Electrophysiology, Physical Therapy, Radiology, Pediatric Hematology, General Surgery, Pathology, Obstetrics and Gynecology, Radiation Oncology, Neuroscience Intermediate Unit, Nephrology and School of Dental Medicine. In 2017, the Pitt County Care Clinic in association with state free and charitable clinics was added. This clinic is staffed by medical students and trainees. In 2018, the Departments of Rehabilitation Medicine and Family Medicine were added. The course instructor coordinates initial contact and scheduling of the clinic rotations. All clinic rotations are scheduled during the two-hour lab sessions, Tuesday and Thursday mornings. Students can revisit clinics at other times to add to their observations. Clinic rotations are completed during the first eight weeks of the semester with the goal of identifying an unmet clinical need. The only

clinic rotation common to all student teams is the Pitt County Care Clinic which is only open on weekends.

At the beginning of each clinic rotation, student teams are assigned a clinic and contact person. It is the teams' responsibility to contact the clinic, and make arrangements, prior to the initial meeting to establish location, time and follow-up visits. The clinic contact provides guidance and oversight for each student team and facilitates interaction with physicians and staff. During the clinic visits, student teams are asked to focus on four areas. (1) overall environment, layout, furniture, (2) systems and processes, (3) safety and (4) devices/equipment with the goal of identifying "problems". When appropriate and if time permits, students can interview physicians and staff addressing specific observations. Observation notebooks are reviewed weekly by the course instructor. Each student is required to provide a total of four observation summaries (i.e. one per clinic) to include data recorded/observed, interpretation of what the data means and the resulting problem statement. Each summary briefly proposes several possible solutions and comments on what the student would expect to see changed if the solution were implemented. During the period of clinic rotations, one 50-minute class period per week is used for the teams to discuss observations made during their weekly clinical rotation.

Project

The project component focuses on the design process and provides students with an understanding of the environment in which modern medical systems and devices are used. Team projects are expected to establish new collaborative translational research opportunities, identify capstone or honors projects, and/or lead to entrepreneurial partnerships.

Students spend 8 - 10 weeks developing and designing a solution to an identified unmet clinical need. In spring 2017, the Department of Engineering partnered with an entrepreneurship course in the College of Business Miller School of Entrepreneurship. Multidisciplinary student teams consisting of 2 engineering students and 4 business students were formed. The business students did not participate in clinic observations. Based on clinic observations, the engineering students present problem ideas to business students who vet the concepts from a business standpoint. Working in multidisciplinary teams, students identify and address a specific unmet clinical need and develop a commercially viable solution or product. The engineering students focus on problem solving and design of the solution while the business students focus on developing a business and marketing plan. The students enrolled in the "Special Topics in Engineering Biomedical Innovation" are expected to spend a minimum of 4 hours per week outside of class developing a solution, designing, building and testing prototypes. An engineering fabrication laboratory and technical staff are available. During the 8 – 10 week project development stage it is expected that the engineering and business teams work closely to develop a proposal, marketing plan, financial plan, business plan and final report. This includes time outside of the regularly scheduled class time.

Assessment

As noted by R.H. Allen et. al. [13], assessment of a dynamic, non-traditional engineering design course requires alternate means of evaluation. The course evaluation relies on course work/project assessment and investor/business feedback, student surveys, and sponsor reports.

Over the course of the semester, each student's progress is assessed via several assignments including written homework assignments, attendance, participation, observation notebooks and the final oral and written project. The students enrolled in the "Special Topics in Engineering Biomedical Innovation" course submit a final written report and presentation. Both the written and oral presentations include a detailed description of the engineering design process. In addition, a final presentation for the combined multidisciplinary engineering and business teams includes a "pitch" of their ideas to a group of investors, university's director of technology transfer office, engineering and business faculty and clinic sponsors. Feedback from project evaluators includes assessment of project, business plan & feasibility and overall team presentation. Evaluations are considered in each team's overall grade. Feedback is also used for course improvement. The multidisciplinary nature of the course is associated with ABET outcomes assessed for the course and listed in Table 1.

Table 1 – Project Assessment

Learning Outcomes	Assessment Instrument
Apply advanced math, science and engineering to improve public health. (Program Outcome A)	Project report, presentation, student survey
Assess technological challenges in biomedical and health-related topics and develop innovative solutions. (Program Outcome E)	Project report, presentation, student survey
Develop problem-solving skills and participate in a multidisciplinary team-based project. (Program Outcome D)	Project report, presentation, student survey

At the completion of the course a selected-response survey is implemented to assess student perceived importance on learning outcomes. A five-level Likert scale (1: strongly disagree; 5: strongly agree) is used for questions in Table 2.

Table 2 – Example of Student Survey

Student Feedback Survey
1. I am able to apply advanced math, science and engineering to improve public health.
2. I am able to problem solve and participate in a multidisciplinary team-based project.
3. I am able to assess technological challenges in biomedical and health-related topics and develop innovative solutions**.**
4. I am able to understand the impact of engineering solutions in a global, economic, environmental and social context.
5. I am able to understand professional and ethical responsibility in biomedical engineering.

6.	I am able to integrate medical principles with engineering and STEM fundamentals to develop innovative solutions.
7.	Participation in this course enhanced my skills in translation of theory to practical application.
8.	Participate in this course enhanced my skills in creative problem solving and innovation.
9.	Participation in this course enhanced my skills in analysis of problems from different points of view.

In addition, students are asked to complete open ended questions addressing their overall course experience (Table 3).

Table 3 – Open Ended Student Survey Questions

Student Feedback Survey – Additional Comments	
1.	About how many hours per week on average do you spend outside the class preparing, studying or doing assignments for this course?
2.	How can this course be improved?
3.	What are the strengths of the course?
4.	What did you learn from this experience?

Clinic sponsors are surveyed to assess student participation. Sponsors are also asked to respond to questions regarding what they liked and disliked about the clinical rotations, course material and suggestions for improvement.

With each course offering the instructors review all observation notebooks and assessments to identify new multidisciplinary collaborative research projects, capstone and honors projects, and potential entrepreneurial initiatives. Follow-up information is collected to track oral/poster presentations, published manuscripts and patent applications resulting from course projects.

4. RESULTS AND DISCUSSION

Eight engineering students enrolled in the course in spring 2016 and six in 2017. The engineering students included students from the biomedical engineering, mechanical engineering, and industrial systems concentrations. In 2017, 3 teams of engineering students partnered with 12 students from the entrepreneurship course in the College of Business (4 per team). Students reported spending an average of 6.3 ± 2.4 hours per week outside of class and clinic, preparing, studying or doing assignments for the course. All enrolled students successfully completed the course.

Instructor consent is required before students enroll in the course and all students provide a short statement describing their interests and expectations. Table 4 is a sampling from personal statements provided by students. A shared interest is the opportunity to observe in a real-world clinical setting.

Table 4 – Sample of student interest and expectations of the course

"This course will provide me with the opportunity to build upon my communication skills with patients and healthcare professionals alike, as well as develop a background on the vast array of medical devices used in the operating room and the purposes for which they serve."
"My interest stems from the course description that discussed not only the opportunity to participate in clinical/laboratory rotations, but also applying engineering problem solving techniques and processes to the rotations. At this time, I have had minimal shadowing opportunities and do not completely grasp the concept of biomedical engineering in clinical setting and this course is a window into that discipline."
"This class would allow me to gain experience in the clinical setting and help me in making my decision for graduate school. By participating in this class, I would also gain valuable insight on problems that occur in the clinical setting and be challenged to think of solutions."
"I expect this course to give me knowledge of biomedical clinical settings and of real life problems I should be expecting as an engineer."
"I expect to gain insight on what the real world applications of the biomedical engineering field are and what might really interest me as career/internship/research pathways after I graduate."
"Taking this course, I will develop greater insight into what I will be doing in the field when I graduate. Through the clinical observations and discussions, my problem-solving and leadership skills will improve while my experience and knowledge in biomedical engineering will increase."
"When I research biomedical engineering, what I find generally gives a narrow look and broad explanation at what exactly I can do with my degree. Although I am very interested in what I find, I have never experienced anything up close compared to what this class would present. This course will allow me to completely comprehend and fully examine how I will use my biomedical engineering degree upon graduation in the real world through interacting with professional physicians."
"I am also interested in the design portion of the class. Having experience working with real-world problems in an environment where mistakes cannot be tolerated is something that most undergraduate students do not have the opportunity to experience. I believe having this type of design work, along with the multi-disciplinary project group, is an occasion which will be irreplaceable
"This class will also provide a more unobstructed view of the potentials biomedical engineering not seen from the classroom, allowing me to become more aware of the possibilities I may want to pursue in the future."

While most students focus on the positive benefits of the course, few comment on any apprehension or anticipated challenges. A written assignment completed before clinic rotations includes a student reflection on "Fears and Concerns". Table 5 lists the most common responses from the engineering students. The course syllabus and handbook include topics addressing these issues and may have influenced the students' responses.

Table 5 - Common answers to "Fears and Concerns"

Questions	Common Answers
1. What fears do you have about your clinical rotations?	• Overwhelmed by environment • Getting lost or being late • Overlooking important information • Making a good first impression • Observing death of a patient
2. What concerns or challenges do you see about working with clinicians?	• Interrupting workflow • Knowing when to ask questions • Intimidation by authority • Being in the way • Understanding medical terminology
3. What concerns or challenges do you see about making observations?	• Distinguish between observations and opinions • Overlook important details • Miscommunication or interpretation • Understand objectives of clinic environment

Based on the answers reported in 2016, specific topics are emphasized and repeated throughout the semester. In 2017, former students were invited to speak about their experiences and offer "tips" for observing in a clinical setting. The course instructors have intentionally addressed and reinforced specific topics to address student perceived challenges.

- Advanced planning for each clinic visit and rotation is encouraged. Each team is provided with information of their scheduled clinic rotation at least 1 week in advance of the first visit. This provides time for team members to contact the clinic, research the specialty and identify the clinic location. All clinics are located about 5 miles from the main campus and require personal, university or local transportation.
- One technique discussed and presented by several systems engineers, is to prepare a plan for each clinic visit and prepare a list of questions or objectives to accomplish during the visit. Having a partner to rely on, often the students divide observation tasks to efficiently cover the four areas of environment, systems/processes, safety and devices/equipment.
- Discussing professional, comfortable dress and refining their elevator speech provides students with control over first impressions when meeting clinic sponsors.

Course instructors observed improved student confidence with each clinic rotation. During the weekly 50-minute lecture period, increased team interactions were observed and students readily offered suggestions to other teams in navigating difficult situations. As teams observed in different clinics, the weekly "debriefing" sessions provided course participants with an overview of multiple clinic environments and challenges.

Overall evaluation of the course was based on assessment of project reports, presentations, student surveys, clinic sponsor feedback and "business" feedback. The average grades assigned for both the written report and presentations was 75% - 80%. Students enrolled in a senior capstone design course tended to score higher on both the written and oral assignments as reflected in organization, design and detail. Currently, faculty from the Department of Communications provide one guest lecture that focuses on presentation content and delivery. Future course offerings will consider adding assignments to improve written and oral communication. The course instructors have one year of business feedback from the final presentation for the combined multidisciplinary engineering and business teams project "pitch". Overall, the event was well attended by local investors and representatives from the Office of Technology Transfer. None of the projects advanced or were funded. However, both students and judges rated this a positive experience. Current efforts are focused on improved integration of the project design, marketing components and timeline.

During the period of clinic rotations, the one 50-minute class period per week was used to discuss potential projects identified in the clinic. Students vetted their projects with both the engineering and business students. Examples of course projects are listed in Table 6. In fall 2018, the "Augmented reality system for improved bronchoscopy" was adopted for a senior biomedical engineering capstone design project. One student enrolled in the "2017 Special Topics" course and one student from the 2016 course, were assigned to a capstone team to advance this project. In addition, this project established in a new collaboration between faculty in the Department of Engineering and Departments of Radiation Oncology and Internal Medicine. The "Hands-free data entry system" and "Cost efficient stretcher lift for EMS" are currently under review for fall 2018 senior capstone design projects. Many of the "unmet clinical needs" identified are projects that cannot be completed in a semester. A number of complex projects identified during 2016, 2017 and 2018 clinical observations and vetting process are under consideration for future capstone design and/or research projects. Managing project scope and maintaining sponsor commitment are two major factors that influence project implementation. Course strengths in critical and innovative thinking have been positively influenced through the partnership with the Miller School of Entrepreneurship and working with an engaged Technology Transfer Office.

Table 6 – 2016, 2017 "Special Topics in Engineering Biomedical Innovation" Projects

Area(s)	Project	Clinical Department
Systems/Equipment	Sanitizing method for ultrasound probe	Radiology
Equipment	Exoskeleton to support lead vests for radiation procedures	Nephrology
Systems/Equipment	Hands-free data entry system	Pathology
Environment/Safety	Cable management system electrophysiology suite	Cardiovascular Sciences
Environment/Furniture/ Equipment	Ergonomic OB ultrasound support	Obstetrics and Gynecology
Equipment	Augmented reality system for improved bronchoscopy	Radiation Oncology
Systems/Equipment	Cost efficient stretcher lift for EMS	Emergency Medicine

Results of the student survey to assess learning outcomes is shown in Table 7. Student response to the course was overwhelmingly positive. The course strengths most frequently listed were improved critical and innovative thinking, development of observation skills, opportunity to apply engineering knowledge, and clinical exposure. Students were enthusiastic and engaged when describing their clinical experiences. Working on multidisciplinary teams across two curriculums was a new experience for both the engineering and business students. Overall, the group dynamics were positive, students tended to learn from each other and project outcomes were successful. Suggested course improvements included more time devoted to project work, improved access to engineering fabrication laboratories, better coordination with the business students' schedules, recruitment of more students, and clarify assignment expectations. The survey data while positive, does represent student's perceptions of the course. In the future, more detailed assessment will focus on specific assignments related to learning outcomes. One observation, which requires follow-up, suggests an increase in applications to the Department of Engineering's graduate program in biomedical engineering from course participants.

Table 7 – Project Assessment Outcomes

Learning Outcome	Average Score	% rating at 4 or 5
1. Apply advanced math, science and engineering to improve public health **(Program Outcome A)**	4.6	100%
2. Assess technological challenges in biomedical and health-related topics and develop innovative solutions **(Program Outcome E).**	4.7	100%
3. Develop problem-solving skills and participate in a multidisciplinary team-based project **(Program Outcome D)**.	4.6	100%
4. I am able to understand the impact of engineering solutions in a global, economic, environmental and social context.	4.3	100%
5. I am able to understand professional and ethical responsibility in biomedical engineering.	4.5	100%
6. I am able to integrate medical principles with engineering and STEM fundamentals to develop innovative solutions.	4.5	100%
7. Participation in this course enhanced my skills in translation of theory to practical application	4.5	100%
8. Participate in this course enhanced my skills in creative problem solving and innovation	4.5	100%
9. Participation in this course enhanced my skills in analysis of problems from different points of view	4.3	100%

This course is evolving. However, the focus of this course was to provide access to clinical and real world biomedical problems. Based on the positive responses, this goal was accomplished. All student teams were exposed to 3 to 4 medical clinics representing multiple health-care specialties and environments. Teams were provided with opportunities to interact and foster relationships with all levels of health-care providers and clinic sponsors. The course provided

supervised class time to review, develop and advance project ideas. Adding the business component, while challenging, added breadth to each project. Interacting in a multidisciplinary project provided students with "real-world" work environment. Course weaknesses mainly concern the logistics of working in multidisciplinary teams and the accelerated timeline of completing the project. Integrating the students from the College of Business Miller School of Entrepreneurship with the engineering teams, added an important multidisciplinary component and challenge for the engineering students. While the engineering students were focused on design, innovation and problem solving, the business students provided a marketing perspective. Overall, the final projects were more comprehensive. Presently, the engineering students and business students are enrolled in separate courses. Improved timelines for involving the business component earlier in the semester were implemented in 2018 and will continue to be reviewed. Creating a new course across the colleges is also under consideration.

Clinical Evaluation

Twelve of the fourteen clinic sponsors completed the assessment survey. Clinic sponsors rated the students good to excellent for all criteria as shown in Figure 1. All clinic sponsors reported they would definitely or probably host an engineering student team in the future. Thirteen of the original clinic hosts in 2016 sponsored student teams in 2017 and 2018. Several clinicians and clinic representatives attended the final engineering presentations and/or pitch. They continued to provide support and mentorship throughout the semester. Their feedback and support is key in transitioning novel projects to multidisciplinary capstone projects and fostering new collaborative opportunities.

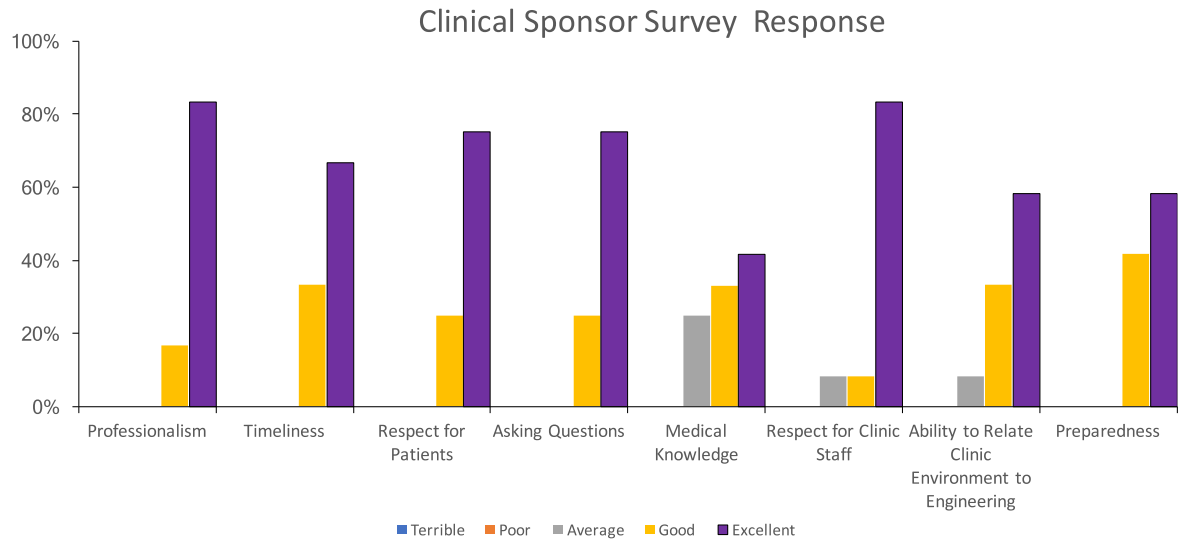

Figure 1 – Clinic sponsor assessment of engineering student's clinical participation.

5. PROGRAM CHALLENGES AND MODIFICATIONS

One of the major lessons learned after offering the course in 2016 was to better prepare for the time commitment to complete and process the clearance paperwork for the multiple clinics. The

medical practice, dental practice and medical center all required different forms, although similar information. Initially a background check was required for all students observing in the medical center. This requirement was eventually waived; however, it did negatively impact how quickly students could start the clinical rotations. In the second year, the paperwork and checklists were provided several weeks prior to the beginning of the semester to give students time to complete the medical records information and receive TB tests, flu shots etc. Completing the paperwork is now the first graded assignment. Students may be dropped from the course if the assignment is late or incomplete. This change has improved the timeline for starting students in clinic rotations by at least 2 weeks.

Initially this course required a significant amount of advanced planning to contact and schedule clinical rotations. However, after the first year, clinic contacts and referrals by colleagues improved. This is a student driven course. It requires some flexibility on the part of the instructors and students concerning scheduling and working in multidisciplinary teams. Engineers are trained to be problem solvers. Training in observation techniques is challenging as many students immediately focus on a "problem" and "solution". Weekly discussions on clinic observations improved student focus with each clinic rotation. Based on former student suggestions all students enrolled in 2018 were assigned their first clinical rotation at the Pitt County Care Clinic. This environment is less formal and possibly less intimidating. Undergraduate students primarily work with medical students in this environment and are able to practice observation and interview skills in a more relaxed setting.

This one semester course requires an accelerated timeline for the design process. This has proved to be a challenge as many of the unmet clinical needs are complex and require more time and effort. Working with students to focus on a "feasible" project is ongoing. Vetting the potential projects in class provides a unique, interactive environment to enhance student learning and the design process. Including representatives from the Technology Transfer Office with focused lectures on intellectual property, patents and regulatory requirements facilitates improved background research and understanding of identified unmet needs. Adding students from the Miller School of Entrepreneurship fostered multidisciplinary collaboration. However, accommodating class schedules to integrate the engineering and business students tended to slow progress and increase student anxiety near assignment due dates. Integrating multiple disciplines is an important goal of this course, is supported by the university's mission and part of the ongoing course assessment and development.

6. CONCLUSIONS

A new course to (1) develop a multidisciplinary, collaborative educational experience, in a clinical environment, to improve student learning (2) provide undergraduate engineering students with an understanding and appreciation of the needs and uses of technology in healthcare (3) foster innovation in medical technology was developed. This course was specifically designed as a one semester course for undergraduate students to observe in multiple clinical environments. While the course content is similar to other clinical immersion programs [1-6, 12,14-15], the integration of multiple disciplines provided a unique learning environment for the undergraduate engineering students. The collaborations with the Health Sciences Campus and College of Business at East Carolina University have been successful and will continue to be developed to

facilitate the translation of new devices and technologies from the laboratory bench to the bedside and business market. The course supports the university's mission to transform health care, promote wellness, and reduce health disparities while serving and improving the health of the citizens in the region. Additional benefits of this course are the generation of novel capstone project ideas and new multidisciplinary research collaborations. Continued support from clinic sponsors is expected to improve these measured outcomes. Overall this course has illustrated the importance of providing undergraduate students open-ended, loosely defined projects and allowing project multidisciplinary teams to assume responsibility for design and innovation. As with similar design and clinical immersion courses the true impact of this course will be felt in the future. Our goal is to provide the education, opportunity and ongoing continuous improvement to facilitate biomedical innovation.

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