Interdisciplinary Clinical Immersion: from Needs Identification to Concept Generation

Dr. Anthony E. Felder, University of Illinois, Chicago

Anthony E. Felder is a Clinical Assistant Professor in the Richard and Loan Hill Department of Bioengineering at the University of Illinois at Chicago. Anthony's current focus is on undergraduate engineering education and its restructuring to better meet the diverse needs of students and industries. Accordingly, Anthony teaches a wide array of Bioengineering courses, from Introduction to BioE to Senior Design, Bioinstrumentation, and Cell and Tissue Engineering. Anthony is also active in ophthalmology research - having co-formed and currently serving as a Technical Director for the ophthalmology-based medical device design lab (ORBITLab) at the UIC Innovation Center. Anthony holds a B.S. and Ph.D. in Bioengineering.

Dr. Miiri Kotche, University of Illinois, Chicago

Miiri Kotche is a Clinical Associate Professor of Bioengineering at the University of Illinois at Chicago, and currently serves as Director of the Medical Accelerator for Devices Laboratory (MAD Lab) at the UIC Innovation Center. Prior to joining the faculty at UIC, she worked in new product development. She teaches capstone design courses, including the longstanding core senior design sequence and Interdisciplinary Medical Product Development. She also serves as co-Director of the Freshman Engineering Success Program, and is actively involved in engineering outreach for global health. Miiri received her Ph.D. in Bioengineering and M.S. in Mechanical Engineering from the University of Illinois at Chicago and a B.S. in General Engineering from the University of Illinois at Urbana Champaign.

Prof. Susan Stirling, University of Illinois at Chicago

Susan Stirling is a a designer, researcher and educator. She has an undergraduate degree from the University of Wisconsin-Madison and a graduate degree from the Institute of Design at the Illinois Institute of Technology.

At the University of Illinois at Chicago she teaches Design Research Methods, Human Experience in Design and Interdisciplinary Product Development. Susan collaborates with non-design faculty to teach the design process, and helps students discover opportunities and solve problems with design. She is the co-instructor of the Clinical Immersion program in the Department of BioEngineering. Susan balances teaching with her professional career as a design researcher, consultant and strategist.

Prof. Kimberlee M Wilkens, University of Illinois at Chicago

Kimberlee Wilkens is an alumna and instructor in the School of Design, the Director of Undergraduate Studies for Industrial Design, with an affiliate position in the Department of Urology. Kimberlee's drive for interdisciplinary collaboration has resulted in work within UIC's Innovation Center as the dedicated design faculty and resource for many differing disciplines. Her involvement focuses on providing guidance and education on the research and development process for doctors, faculty, and students of all levels and backgrounds.

Kimberlee has had a significant impact on the world of design having developed products for many prominent brands such as McDonald's, Kraft, and Hefty. She recently started her own design studio: 5by5 design lab – a product development firm that services companies from around the world. Kimberlee balances out her research and professional pursuits through her design teaching – which has not only resulted in globally presented and award-winning student work, but has even been featured in the IDSA's 2017 Educational Symposium, What's Trending in ID Education?

Interdisciplinary clinical immersion: from needs identification to concept generation

Abstract:

The development of medical devices is a tremendous challenge necessitating both a deep understanding of the user as well as interdisciplinary collaboration. The first step in the user-centered design process is needs identification, in which designers observe and empathize with stakeholders (e.g. patients, physicians, nurses) to identify unmet user needs both implicit and tacit. Historically, for engineering students, there has been a gap between understanding technical requirements and unmet user need. Commonly this gap arises from a lack of primary research, including observation and interviewing of relevant users prior to concept generation. To address this gap, the Richard and Loan Hill department of Bioengineering at the University of Illinois at Chicago (UIC) developed a novel clinical immersion internship to introduce students to needs identification and user-centered design. In the first year of the Clinical Immersion Program (CIP), small teams consisting of undergraduate bioengineering students rotated through two, three-week long periods in varying clinical departments, where they worked together to methodically observe environments, interview users, and identify opportunities. In the third year of the CIP, we enhanced the needs identification process by transitioning to interdisciplinary teams of both bioengineering and second-year medical students. In this current study, we report on the fourth, and most recent, year of the CIP. Here, the program was expanded so that interdisciplinary student teams were immersed full-time in a single clinical environment for the duration of the program, which culminated in initial concept exploration based on the identified clinical needs. Efficacy of the CIP was assessed by mixed-method analysis surveys administered pre- and post-program. On a five-point Likert scale from "strongly disagree" to "strongly agree" (0 and 4, respectively), students scored 3.6 ± 0.5 in response to "I feel confident working with an interdisciplinary team" and 3.9 ± 0.3 to "needs identification is necessary for the development of medical products" according to the program surveys. Additionally, students indicated 3.5 ± 0.7 when prompted "early concept generation enhanced my experience in this program". These scores indicate that students were towards strong agreement and responded well to the program changes this year.

Introduction:

The healthcare industry is riddled with outdated, ineffective devices and delivery systems that do not adequately meet the needs of users. To design better devices and delivery systems, engineers utilize the engineering design cycle, and, while there are many variations of this cycle, design always begins with identifying user needs. However, while engineers are familiar with the technical aspects of the engineering design cycle, they historically lack experience in needs identification. This disconnect often results in designs which do not address the true needs of users [1]-[9]. Thus, it is imperative for engineers to be educated in both the technical aspects of design and in needs identification. One method of identifying these needs is user-centered design. User-centered design (also referred to as human factors engineering or human-centered design) is a methodical approach to design and has been used extensively in the healthcare industry [1]-[11]. The goal of this methodology is to design solutions around end-users' needs, both implicit and tacit [12], [13]. This is accomplished using an empathetic approach to users at each stage of the design process, resulting in long-lasting and impactful solutions [14]. Indeed, failure to identify and meet user needs has been well studied, specifically in infusion pumps [15], [16], where unidentified needs and poor design resulted in numerous injuries, death, and eventual device recalls [17]. Therefore, the goal of the Clinical Immersion Program (CIP) at University of Illinois at Chicago (UIC) is to enable engineering students to create more impactful devices by introducing them to needs identification through user-centered design.

The purpose of this paper is to report on the fourth year of the CIP. The program has continually evolved over the past several years according to feedback from program faculty, clinical mentors, and participating students. In 2014, teams consisting solely of undergraduate bioengineering (BioE) students were immersed sequentially through two, three-week long rotations in one of six UIC hospital clinical environments [10]. In 2015, the team and rotation structure remained unchanged, but three more clinical environments were added [10]. In 2016, the program expanded to accommodate interdisciplinary teams of BioE and second-year medical students from the University's Innovation in Medicine (IMED) program. The IMED program is a four-year longitudinal, co-curricular experience which emphasizes the intersection of technology, medical device development, and health care delivery. In addition, rotation structure remained the same, but an additional three clinical environments were added to maintain small team size [11]. In the current reporting year of 2017, we maintained interdisciplinary teams of BioE and IMED students, but modified the rotation structure for a single, six week long immersion. This modification allowed teams to become more immersed in their clinical departments and begin concept exploration to address their identified clinical needs. This change was implemented due to overwhelming feedback from students and program faculty in previous program years. Ultimately, we believe this implementation allows students to more holistically understand the design process by not only identifying needs, but also reflecting on them in the context of exploring appropriate solutions.

Methods:

<u>Program Structure:</u>

The CIP is a six week long immersion experience designed to familiarize students with needs identification as part of the engineering design process. Since 2016, students are placed into interdisciplinary teams comprised of two BioE (rising seniors) and two IMED (rising second year) students. Each week, student teams participate in a Monday workshop (six hours) and spend Tuesday-Friday in clinical immersion (35 hours). This program year, teams spent all six program weeks in a single clinical environment and supplemented their experience with needs identification by including initial concept exploration.

The CIP is currently a paid summer experience for BioE students, whereas IMED students earn a partial tuition waiver. Due to ongoing program evolution, participant reimbursement, and availability of space in clinical environments, the program is currently offered to a limited number of students. Up to 12 BioE students are offered a position in the program annually (~17% of rising seniors), whereas all IMED students (~4% of all medical students) are required to participate. However, the limited availability of the program also presents an opportunity for comparative analysis between engineering students with and without the CIP - a comparison we aim to assess at the conclusion of the program's fifth year.

Student Teams and Departmental Affiliation:

This year, 11 rising senior BioE and 12 rising M2 IMED students participated in the CIP. Bioengineering students were selected based on an application process, academic qualifications, and an in-person interview with the bioengineering faculty. IMED students were selected after admission to medical school based on an application process, academic qualifications, and an in-person interview with IMED faculty. Students were assigned to a team based on medical specialty preference, and were subsequently placed in one of six clinical departments. Table 1 indicates student distribution per clinical department. Each team coordinated their weekly activity in their respective clinical environment with a faculty mentor from the affiliated department.

Table 1. Student Distribution in Clinical Environments

Department	Number of BioE Students	Number of IMED Students
Anesthesiology	2	2
Cardiology	2	2
Interventional Radiology	2	2
Ophthalmology	2	2
Pulmonary Critical Care	2	2
Urology	1	2

Monday Workshops:

Each week of the CIP began with a six hour interactive workshop where faculty provided guided instruction, coordinated team-based activities, and facilitated working sessions for teams. These workshops were designed to introduce students to both the engineering design cycle and user-centered design. Weekly workshop topics included: user-centered design basics, contextual inquiry, primary research skills (observation basics, stakeholder interviewing), qualitative analysis of research data (developing needs statements), and initial concept exploration. Students were also supplied with a notebook to document their observations and thoughts from their clinical immersion. To further guide students through the design process, team-based activities related to workshop topic(s), readings, and case studies were assigned for individual team discussions.

Program Deliverables and Surveys:

By the conclusion of the CIP, teams were expected to generate a single, succinct problem statement based on their primary research in a clinical environment. Moreover, new to this program year, students were taught the basics of concept exploration and were expected to apply this knowledge to their identified problem. Three deliverables were generated by the program participants: individual blog entries, a written team report, and team presentation. The individual public blog aimed to document each student's experience throughout the CIP. Blogs from the 2017 program, as well as those from previous years, may be found online at https://clinicalimmersion.uic.edu/. Students were asked to post 11 blog entries through the entirety of the program (twice weekly for the first five weeks and once in the final week). The final presentation and written report described each team's primary research, their qualitative analyses to generate a succinct problem statement, and documentation of their initial concept exploration. The written reports were then compiled and published in a documentation book representing the collective efforts of the program participants.

To assess the effect of the CIP program, students were requested to participate in mixed-methods, pre- and post-program surveys. The surveys included both quantitative and qualitative questions (Likert scale and open-ended short answer, respectively) to assess student's understanding of needs identification, interdisciplinary teams, and exploration of initial concept solutions. The administration and data collection of the surveys was approved by the Institutional Review Board at UIC.

Data Analyses:

Quantitative questions on surveys were answered using a 5-point Likert scale between strongly disagree/negative (0) to strongly agree/positive (4). A generalized linear model (repeated measures) was used to determine both the effects of the program (i.e., time) and discipline (i.e., BioE vs. IMED) from paired pre- and post-program survey questions. Unpaired student's t-test was used to determine the effect of discipline on post-program survey questions. All statistical analyses were performed using SPSS statistical software (version 24, SPSS, Chicago, IL, USA). Statistical significance was accepted at $P < 0.05$.

Results:

Public Blogs:

Overall, students posted 8.8 ± 2.1 blog entries (N = 23). While the number of blog posts decreased from BioE to IMED students (9.5 ± 1.5, N = 11 and 8.3 ± 2.4, N = 12 respectively), there was no significant difference between the two disciplines (P = 0.166).

Pre-Program Survey:

Students' answers to questions from the pre-program survey are stratified by discipline and presented in Table 2. Data here correspond to a count of "Yes"/"No". Of note, only one BioE student claimed prior experience with "needs identification/assessment" whereas 50% of IMED student claimed prior experience. This was closely related to the number of BioE and IMED students who had previously worked on interdisciplinary teams. Further, nearly 50% of students had prior experience with early concept generation.

Table 2. Questions and students' answers from the pre-program survey stratified by discipline. Data are presented as a count of "Yes"/"No".

Question	BioE (N = 11)	IMED (N = 10)	Total (N = 21)
(Q3) Have you previously worked on an interdisciplinary team?	2/9	4/6	6/15
(Q9) Do you have any prior experience in "needs identification" or "needs assessment"?	1/10	5/5	6/15
(Q13) Have you ever worked in a clinical environment?	4/7	9/1	13/8
(Q15) Do you have prior experience with early concept generation?	6/5	4/6	10/11

Paired Pre- and Post-Program Survey Questions:

Students' answers to paired questions from both surveys are stratified by time (i.e., pre- and post-program) and discipline, and presented in Table 3. Data here correspond to a 5-point Likert scale from strongly disagree to strongly agree (0 and 4, respectively). Significance is indicated for main effects and their interaction on answers; due to no significant interactions, simple effects were not assessed. In brief, regardless of discipline, students' agreement with feeling confident working in an interdisciplinary team (Q5) increased after completion of the program with a trend approaching significance ($P = 0.062$). Interestingly, there was a significant difference between BioE and IMED students in their agreement with interdisciplinary teamwork being necessary for the development of medical products (Q7), with BioE students more strongly in agreement ($P = 0.026$). Students indicated strong agreement with needs identification being necessary for the development of medical products (Q11), such that there was no effect of program or discipline on agreement ($P \geq 0.219$). Students were generally in agreement that they felt confident participating in early concept generation for clinical problems (Q17), such that there was no significant effect of program or discipline on answers ($P \geq 0.123$)

Table 3. Paired questions and students' answers from both surveys stratified by time (i.e., pre- and post-program) and discipline. Data correspond to a 5-point Likert scale from strongly disagree to strongly agree (scores of 0 and 4, respectively). Data are presented as mean ± standard deviation. One asterisk indicates approaching statistical significance (P < 0.1) and two asterisks indicates statistical significance (P < 0.05).

	Pre-Program			**Post-Program**			**P-value**		
Question	**BioE (N=11)**	**IMED (N=8)**	**Total (N=19)**	**BioE (N=11)**	**IMED (N=8)**	**Total (N=19)**	**Program**	**Discipline**	**Program * Discipline**
(Q5) I feel confident working with an interdisciplinary team.	3.45 ± 0.82	3.12 ± 0.83	3.31 ± 0.82	3.54 ± 0.52	3.62 ± 0.51	3.57 ± 0.50	0.062*	0.666	0.185
(Q7) Interdisciplinary teamwork is necessary for the development of medical products.	3.90 ± 0.30	3.37 ± 0.74	3.68 ± 0.582	3.90 ± 0.30	3.37 ± 0.74	3.68 ± 0.582	1.000	0.026**	1.000

(Q11) Needs identification is necessary for the development of medical products.	3.81 ± 0.60	3.62 ± 0.51	3.73 ± 0.56	4.00 ± 0.00	3.75 ± 0.46	3.87 ± 0.31	0.217	0.219	0.815
(Q17) I feel confident participating in early concept generation for clinical problems.	3.09 ± 0.94	2.62 ± 0.91	2.89 ± 0.93	3.45 ± 0.68	2.87 ± 1.35	3.21 ± 1.03	0.350	0.123	0.861

Post-Program Survey:

Students' answers to questions from the post-program survey are stratified by discipline and presented in Table 4. Data here correspond to a 5-point Likert scale from strongly disagree/negative to strongly agree/positive (0 and 4, respectively). Significance is indicated for effect of discipline on answers. Briefly, students were positively impacted by their clinical mentors and positively rated their experience as part of an interdisciplinary team, without significant difference between disciplines ($P \geq 0.297$). Further, students were in agreement that the internship helped them think differently about needs identification and that early concept generation enhanced their experience in the program, again with no significant difference between disciplines ($P \geq 0.121$). To assess student's sentiment to changes in this program year, we prompted students with the following question: "*[l]ast year, participants had two clinical rotations focused specifically on needs identification. This year, participants spent time in a single department and practiced both needs identification AND early concept generation. [Which] would [you] prefer?*" Overwhelmingly, 9 of 11 BioE and 9 of 10 IMED students indicated they preferred the latter option, which included concept generation. However, there was a significant difference in sentiment that Monday workshops were helpful, with BioE students being close to agreement and IMED students being close to neutral ($P = 0.032$). Similarly, there was a significant difference in agreement that students felt better prepared for the next design course after participating in the program, with BioE students close to strong agreement and IMED students close to agreement ($P = 0.005$). Overall, students agreed that participating in the program impacted their career goals and that they would recommend this program to others, although there was a significant difference in agreement between disciplines for the latter ($P = 0.020$).

Table 4. Questions and students' answers from the post-program survey stratified by discipline. Data correspond to a 5-point Likert scale from strongly disagree/negative to strongly agree/positive (scores of 0 and 4, respectively). Data are presented as mean ± standard deviation. One asterisk indicates approaching statistical significance (P < 0.1) and two asterisks indicates statistical significance (P < 0.05).

Question	BioE (N = 11)	IMED (N = 10)	Total (N = 21)	P-value
(Q3) How did your clinical mentor(s) influence your experience in the program?	3.82 ± 0.40	3.70 ± 0.67	3.76 ± 0.53	0.628
(Q4) How would you rate your experience with your interdisciplinary team?	3.55 ± 0.68	3.2 ± 0.78	3.38 ± 0.74	0.297
(Q10) This internship helped me think differently about needs identification.	3.45 ± 0.52	2.90 ± 0.99	3.19 ± 0.81	0.121
(Q15) Early concept generation enhanced my experience in this program.	3.55 ± 0.68	3.10 ± 1.28	3.33 ± 1.01	0.328
(Q20) The Monday workshops were helpful.	2.82 ± 0.75	1.8 ± 1.22	2.33 ± 1.11	0.032**
(Q26) I feel better prepared for my design course (IPD or Senior Design) after participating in this internship.	3.64 ± 0.50	2.7 ± 0.82	3.19 ± 0.81	0.005**
(Q27) Participation in the Clinical Immersion program impacted my career goals.	3.27 ± 0.90	3.00 ± 0.66	3.14 ± 0.79	0.445
(Q28) I would recommend this internship to other students.	3.73 ± 0.46	3.00 ± 0.81	3.38 ± 0.74	0.020**

Discussion:

In the fourth year of the Clinical Immersion Program, interdisciplinary teams of bioengineering and medical students were immersed in individual clinical environments for six weeks. In their environments, teams employed user-centered design methodology to identify unmet user needs and opportunities. Teams ultimately generated a needs statement and concluded the program with initial concept exploration to address their identified clinical needs. This year of the program is distinct from past years due to an expansion of Monday workshops, a single clinical immersion experience, and the inclusion of initial concept ideation.

Monday Workshops:

This program year, the Monday workshops were extended from three to six hours. This change was made to permit a deeper exploration of the design process. Specifically this change allowed us to introduce didactic lectures and group activities regarding synthesis of primary research and concept generation. However, during the program we received conflicting student feedback concerning these weekly workshops. On the post-program survey, there was a significant difference in agreement between disciplines that the Monday workshops were helpful. According to one IMED student: "*many of the lectures were not helpful.*" However, a BioE student reported: "*I felt that I wouldn't have developed needs identification skills without the Monday workshops.*" After reading all responses, we noticed a general theme regarding Monday workshops: *"I liked the activity portions. I wish we had more dedicated time to work together as a team in a space with more outlets.*[BioE]", "*time to work with our groups was the most helpful aspect.*[IMED]"

Public Blogs:

As in previous years, students were requested to document their experience throughout the program using a public blog. This year, students published 8.8 ± 2.1 of the 11 requested blogs, yielding a mean completion rate of 80%. By contrast, the number of blogs from 2016 program year was 10.9 ± 1.3 (of the requested 12), indicating a completion rate of ~91% (unpublished data). On the post-program survey, students were asked what they enjoyed least about the program and what changes they would like to see; from their responses, it is clear that the requisite number of blog posts continued to be an issue: "*I thought two blogs for each week was more than necessary. I prefer one blog per week.*[BioE]" Moreover, students also demonstrated a concern over privacy, requesting "*semi-private blogs that require a [username] and password to access.*[IMED]" Another IMED student went further and requested: "*[n]o blog post requirement or make the blogs private.*" In confidence, some medical students explained that they feared how these blogs could impact their opportunities when seeking internship and residency.

Initial Concept Exploration:

The single largest change to the program this year was the substitution of a second clinical environment for initial concept exploration to address teams identified clinical needs. This change was heavily requested in previous years of the program [11]. We posit that, while the purpose of this program is to teach needs identification, the inclusion of concept exploration helps students to not only validate their identified needs, but also to reinforce the entirety of the design process. Indeed, students agreed that early concept generation enhanced their experience in the program. Moreover, given the choice between two clinical rotations with no concept generation and a single rotation with concept generation, students overwhelmingly preferred the latter. From the post-program survey, students wrote: "*finding a feasible solution was the interesting part of this program. Finding needs is also equally important, but that creation part is more enjoyable.*[BioE]", "*Concept generation is the whole reason that I can rate my experience in the program as positive.*[IMED]"

Apart from the feedback of students, the introduction of concept generation in the CIP also permitted other metrics to indicate program success. Between two teams, three invention disclosure were filed with the University. These invention disclosures represent hard work and engagement of teams that would not have occurred without concept exploration. While we encourage the student teams to pursue their identified needs in their senior design or interdisciplinary medical product development class during the following semester, this is optional and at their discretion. However, some of the projects have undergone continued development through existing specialized medical design initiatives at the University's Innovation Center. Further, some students joined these initiatives, where they may contribute their expertise to teams including medical, engineering, business, and design faculty.

<u>Paired Pre- and Post-Program Survey Questions:</u>

To assess the effect of the program on working in interdisciplinary teams and needs identification, students were prompted with paired pre- and post-program survey questions. As expected, student's agreement with feeling confident working in an interdisciplinary team increased as a result of the program. Indeed, many free-response comments from the post-program survey spoke to the value of working in an interdisciplinary team: "*[t]he interdisciplinary team gave me a better sense of what working with people of different backgrounds in the real world will be like.*[BioE]" However, this increase in agreement did not reach significance. We found this result interesting, especially since only six of the 21 students indicated that they previously worked on an interdisciplinary team. However, inability to demonstrate significance is likely due to the limited sample size of the current cohort.

We also note a significant difference between BioE and IMED students in their agreement that interdisciplinary teams are necessary for the development of medical products. This is likely influenced by the background of the IMED students themselves, many of whom have technical (e.g., science and engineering) undergraduate degrees and felt as though the BioE students did not contribute a similar level of expertise. Accordingly, one IMED student provided the following from the post-program survey: "*[m]ost IMED students already have strong backgrounds in science and engineering. The interdisciplinary team in clinical immersion did not allow me to learn to communicate to an audience with a different technical vocabulary.*" Interestingly, there was no significant effect of the program on students' agreement that needs identification is necessary for the development of medical products. Indeed, although only six of 21 students had previously participated in needs identification prior to CIP, students indicated strong agreement with the original statement both pre- and post-program. Often student self-assessment is misleading [18]-[20], and we attribute inability to demonstrate a significant effect of the program to leading questions on the surveys, for which students could intuitively deduce the faculty's desired answer.

From the last of the paired questions, we found that students' confidence working with early concept generation increased as a result of the program. From the post-program survey, one student wrote: "*[t]his program strengthened and reinforced my ability to perform early concept generation.*[BioE]" However, this increase did not reach significance. We again attribute the inability to demonstrate a significant change to the limited sample size of the cohort. Furthermore, the wide range of program participant backgrounds (nearly 50% of students indicated they had previous experience in early concept generation) contributes to the larger standard deviation of these data, further obfuscating a significance in trend.

<u>Future Plans:</u>

We plan to make several modifications for the 2018 Clinical Immersion Program. First, considering the feedback regarding Monday working sessions, we plan to modify Monday workshops. We will scale didactic lectures and activities to three hours and dedicate the remainder of the workshop time to team collaboration. This time will be punctuated by faculty meeting with the teams to provide individual guidance. Second, due to the overwhelmingly positive feedback this year, we plan to again include initial concept exploration. We believe offering this expansion not only reinforces students experience with needs identification but also provided a more natural environment for students to begin exploring the entirety of the design process. Third, we will decrease the required number of blog entries to once per week as well as issue specific prompts for each entry. These prompts will focus on weekly objectives and highlight where students/teams should put their focus in a particular week. Lastly, we recognize that student self-assessment, as presented here, is a relatively weak tool and we will integrate more stringent assessment methodology to determine the effects of the program. These tools include expert assessment and better written questions to accurately determine student content knowledge.

Conclusion:

In conclusion, we report on the fourth year of the Clinical Immersion Program at the University of Illinois at Chicago. This year was successful at introducing interdisciplinary teams of bioengineering and medical students to needs identification through user-centered design. New to this program year, each interdisciplinary team spent six weeks in a single clinical environment to further their immersion into the design process. Additionally, teams engaged in initial concept exploration for their identified clinical needs. Students responded well to these changes.

Acknowledgements:

Research reported in this publication was supported by National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health under award number R25EB018239. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

References:

[1] D. Sawyer, K. J. Aziz, C. L. Backinger, E. T. Beers, A. Lowery, S. M. Sykes, A. Thomas, and K. A. Trautman, *Do it by design: an introduction to human factors in medical devices*. U.S. Department of Health and Human Resources, 1997.

[2] A. G. Money, J. Barnett, J. Kuljis, M. P. Craven, J. L. Martin, and T. Young, "The role of the user within the medical device design and development process: medical device manufacturers perspectives," *BMC Medical Informatics and Decision Making*, vol. 11, no. 1, 2011.

[3] M. B. Privitera, M. Design, and D. L. Murray. "Applied Ergonomics: Determining User Needs in Medical Device Design," presented at the 31st Annual International Conference of the IEEE EMBS, Minneapolis, MN, 2009.

[4] M. Maguire. "Methods to Support Human-Centered Design," International Journal of Human-Computer Studies, vol. 55, no. 4, pp. 587-634, 2001.

[5] M. Gertner. "Biomedical Innovation, Surgical Innovation, and Beyond," presented at the 9th Annual National Collegiate Inventors and Innovators, San Diego, CA, 2005.

[6] J. L. Martin, E. Murphy, J. A. Crowe, and B. J. Norris, "Capturing user requirements in medical device development: the role of ergonomics," *Physiological Measurement*, vol. 27, no. 8, pp. 49-62, 2006.

[7] S. Rich, “How human factors lead to medical device adverse events,” *Nursing*, vol. 38, no. 6, pp. 62–63, 2008.

[8] *Human factors engineering - design of medical devices.* ANSI/AAMI Standard HE75, 2009.

[9] C. B. Zoltowski, W. C. Oakes, and M. E. Cardella, “Students Ways of Experiencing Human-Centered Design,” *Journal of Engineering Education*, vol. 101, no. 1, pp. 28–59, 2012.

[10] M. Kotche. “Clinical Immersion Internship Introduces Students to Needs Assessment,” presented at the 2016 ASEE Annual Conference & Exposition, New Orleans, LA, 2016.

[11] S. Stirling and M. Kotche. “Clinical Immersion Program for Bioengineering and Medical Students,” presented at the 2017 ASEE Annual Conference & Exposition, Columbus, OH, 2017.

[12] F. J. de Ana, K. A. Umstead, G. J. Phillips, and C. P. Conner, “Value Driven Innovation in Medical Device Design: A Process for Balancing Stakeholder Voices,” *Annals of Biomedical Engineering*, vol. 41, no. 9, pp. 1811–1821, 2013.

[13] D. Kaufman-Rivi, J. Collins-Mitchell, and R. Jetley, “Design considerations for medical devices in the home environment,” *Biomed Instrum Technol*, vol. 21, no. 6, 2010.

[14] I. Hosking, K. Cornish, M. Bradley, and P. J. Clarkson, “Empathic engineering: helping deliver dignity through design,” *Journal of Medical Engineering & Technology*, vol. 39, no. 7, pp. 388–394, Mar. 2015.

[15] E. Liljegren, A.-L. Osvalder, and S. Dahlman, “Setting the Requirements for a User-Friendly Infusion Pump,” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 44, no. 1, pp. 132–135, 2000.

[16] L. Lin, R. Isla, K. Doniz, H. Harkness, K. J. Vicente, and D. J. Doyle, “Applying human factors to the design of medical equipment: patient-controlled analgesia,” *J Clin Monit Comput*, vol. 14, no. 4, pp. 253–63, May 1998.

[17] Center for Devices and Radiological Health, “Infusion Pumps,” *U S Food and Drug Administration Home Page*. [Online]. Available: https://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/GeneralHospitalDevicesandSupplies/InfusionPumps/. [Accessed: Jan-2018].

[18] N. Falchikov and D. Boud, “Student Self-Assessment in Higher Education: A Meta-Analysis,” *Review of Educational Research*, vol. 59, no. 4, p. 395, 1989.

[19] M. J. Gordon, “A review of the validity and accuracy of self-assessments in health professions training,” *Academic Medicine*, vol. 66, no. 12, pp. 762–9, 1991.

[20] M. Ward, L. Gruppen, and G. Regehr. "Measuring self-assessment: current state of the art," *Advances in Health Sciences Education*, vol. 7, no. 1, pp. 63-80, 2002.