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Analysis of Engineering and Nursing Student Communication Strategies in an Undergraduate, Cross-Disciplinary, Collaborative Course

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Communication is a critical aspect of the workforce, with interactions across multiple disciplines proving ever more crucial. In the fields of engineering and nursing, specifically, this skill has been identified as essential to students' professional success and growth in these disciplines (Broome, 2016; Hill, 2011; Massachusetts Institute of Technology [MIT], 2018). In formulating its "vision" for the engineer working in the year 2020, the National Academy of Engineering (NAE) (2005) expressed "communication" as one of a list of key attributes that such an engineer should possess. The concepts of a "T-shaped engineer" (Rogers & Frueler, 2015) and holistic engineering (Grasso & Burkins, 2010) provide representations of engineering in which cross-disciplinary communication is regarded as one of many skills that allow engineers to leverage their knowledge base and awareness of engineering systems towards positive impact. Among other outcomes, ABET (2016) -which accredits engineering and other programs - stipulates, "an ability to function on multidisciplinary teams" and "an ability to communicate effectively" as key student outcomes for such programs.

From the nursing side, nurses are key contributors in the delivery of quality healthcare, working with professionals in medicine, pharmacy, social science, and psychology, among others (Foronda, MacWilliams, & MacArthur, 2016). The nursing literature is rich with references to interprofessional communication (Foronda, MacWilliams, & MacArthur, 2016; Hill, 2011; Jasovsky, Morrow, Clementi, & Hindle, 2010; Kitto et al., 2015). In addition, interprofessional communication is a key standard on the National Council Licensure Examination (NCLEX©), and this type of communication is also reflected in the benchmarks put forth from nursing accreditation agencies.

Cross-disciplinary interactions among these disciplines are also crucial to the progression of the health and engineering sciences. Accordingly, the NAE (2008) communicated a list of 14 grand challenges that, as examples, covered foci in energy, water, and healthcare. Presentations at national conferences such as the American Institute of Chemical Engineering, the Biomedical Engineering Society, and VentureWell OPEN, showcase the ever-increasing relevance of engineering and nursing and other disciplines to improvements of healthcare with communications within and between disciplines proving ever-more-critical. Along these lines, a Nursing (NURS) and Chemical Engineering (CHE) faculty member developed and implemented a Clinical Immersion at Disciplinary Interfaces (CIDI) course designed to bring nursing and engineering students together for authentic clinical immersion and prototype development (Geist, Sanders, Harris, Arce-Trigatti, & Hitchcock-Cass, 2019; Sanders & Geist, 2016). The student learning outcomes for the course are as follows:

- compare and contrast the nursing process to the engineering design process (by exploring common human-centered design aspects);
- develop skills for effective cross-disciplinary communication;
- develop skills for effective teamwork; analyze a situation from the clinical setting and define a problem;
- and design and build a prototype as a response to the identified problem.

The purpose of this research is to further understand the influence of a cross-disciplinary inquiry-based pedagogical approach on students' communication skills. We aim to understand these influences with the purpose of providing a roadmap for educators wishing to implement similar innovative environments for cross-disciplinary student learning. Our clinical immersion program has been described in Geist et al. (2019) where we established the effectiveness of this approach in cultivating critical thinking, problem solving, creativity, and innovation.

Founded within an interpretive case study framework, we use a qualitative, case study approach to answer the following research questions: 1) How do students navigate cross-disciplinary communication? and 2) What role does cross-disciplinary communication play in the identification of challenges and the development of innovative prototypes? Utilizing qualitative data in the form of focus group transcripts, briefing notes, and student artifacts, we employ an open coding analytic strategy aligned with the interpretivist framework to identify salient themes within this data that provide insight into these questions (Patton, 2002; Saldaña, 2009). Results from this analysis will be discussed and implications for pedagogy and the implementation of cross-disciplinary courses at the undergraduate level will be developed.

Background

Precedence for Collaborative Partnerships

The work described herein is at the interface of the nursing and chemical engineering disciplines. The pairing of these disciplines at the undergraduate level is purposeful, as the above-referenced professional requisites currently being encouraged from both professions create an academic opportunity in which to engage with new pedagogical strategies that benefit both disciplines (Grasso & Burkins, 2010; Young & Weymouth, 2013). The clinical immersion course was developed in response to the need to produce graduates in both spheres who possess skills that allow for flexibility, have an enhanced respect for the contributions and interdependence of several disciplines, carry the ability to effectively communicate and work in teams, and have a proclivity for creative and innovative thinking, while at the same time strengthening their knowledge regarding their own disciplines (Broome, 2016; Carter, 2008; Jasovsky, Morrow, Clementi, & Hindle, 2010; Sanders & Geist, 2016). The course is therefore inherently cross-disciplinary and utilizes various pedagogical techniques rooted in constructivist approaches to capitalize on social learning strategies designed to develop these skills.

Further, the logic for this pairing of disciplines is also founded on tenets that include the above-mentioned national priorities as well as recognized synergies between the fields of nursing and engineering. The National Research Council's (NRC) (2003) Board on Chemical Sciences and Technology researched and classified global challenges present at the interface of the fields of chemical sciences and engineering. The resulting publication from this effort, entitled *Beyond the Molecular Frontier*, presents an overview of this frontier which encompasses such tasks as the development of better drugs to treat ever-evolving diseases and the determination of the function of genetic sequences – challenges also relevant to the field of nursing (NRC, 2003; Sanders & Geist, 2016). In addition, *A New Biology for the 21st Century*, another document developed under commission by the National Research Council, provides numerous examples of opportunities for application of chemical engineering fundamentals to solve problems involving a variety of biological-based processes (NRC, 2009a). The area has become so popular, that according to the ABET website, there are at least 13 chemical engineering programs that reflect some aspect of "bio" in the department name (ABET, 2016). Further, at these same institutions, at least five also have nursing programs that are accredited by the Commission on Collegiate Nursing Education or the Accreditation Commission for Education in Nursing (Accreditation Commission for Education in Nursing [ACEN], 2016; Commission on Collegiate Nursing Education Accreditation [CCNEA], 2016). Finally, we recognize that we are not alone in our efforts to address this national interest as several programs are currently in existence that function at the interface of these disciplines.

For example, engineering and nursing disciplines at Johns Hopkins University (JHU) partner to offer joint degree programs. Dr. Martha Hill, Professor and now Dean Emerita of Nursing at JHU, stated the following when referring to the partnership between engineering and nursing that exists on that campus:

> As our healthcare becomes increasingly technological in nature, we will need one another; and as we initiate that cross-disciplinary reliance, we will develop hybrids between our professions. That's why we are seeing some of the best ideas and most promising solutions coming from partnerships that years ago might have seemed out of character (Hill, 2011, para. 5).

Duquesne University has launched a dual degree program that offers a five-year curriculum in which students will graduate with degrees in both biomedical engineering and nursing (Robert Wood Johnson Foundation [RWJF], 2014). At the University of Massachusetts, Amherst, benefactors provided funding for an engineering and nursing graduate student team "to support cross-disciplinary research in clinical healthcare" (University of Massachusetts, Amherst [UMA], 2008). In addition to this, faculty from engineering, nursing, and biology at James Madison University currently teach a cross-disciplinary course combining the concepts of ethics in innovation, cross-disciplinary collaboration, and Human-Centered Design (Nagel, Ludwig, & Lewis, 2017). Acknowledging the academic and scholastic efforts of these programs, with this contribution we add preliminary findings from our experience to the ever-expanding literature on cross-disciplinary pedagogical innovations at the interface of nursing and engineering, specifically with regards to cross-disciplinary communication.

Learning Theory and Pedagogical Framework

The primary learning theories driving the design of this course are constructivism and social constructivism. Whereas constructivism is a learning theory that assumes that knowledge is created within a contextual set of meanings, social constructivism extends that the creation of such knowledge is advanced through social interaction (Schunk, 2014). Both theories contend that students must play an active role in their learning, engaging not only with the content and context but with each other in order to create new knowledge (Shapiro, 2013). Thus, when applied to an interactive and cross-disciplinary learning space, the tenets of these theories help guide the purposeful development of skills which include cross-disciplinary flexibility, communication, and respect. Further, two learning frameworks - the Renaissance Foundry (Arce et al., 2015) and the Legacy Cycle (Schwartz, Brophy, Lin, & Bransford, 1999) – provide the pedagogical foundations for this course (Geist et al., 2019; Sanders & Geist, 2016). Developed as a pedagogical model for fostering innovation-focused learning, the Foundry utilizes two academic "pistons" (i.e., Knowledge Acquisition and Knowledge Transfer) to guide students through an iterative design process that is initiated by a student identified challenge and finalized by the creation of a team-based prototype of innovative technology (Arce et al., 2015). Much of the challenge identification and team-based components of this course are inspired and motivated by elements encompassed in the Foundry (Arce et al., 2015). Elements of the Legacy Cycle (Schwartz, Brophy, Lin, & Branford, 1999) – a challenge-based learning model – are also integrated into the classroom sessions of the course; specifically, students are encouraged to test, generate, and research their ideas regarding the challenge that they identify, working through an iterative and alternating cycle pattern. Together, these pedagogical elements expose students in the course to collaboration, communication, design, and cross-disciplinary skills that are aimed at fostering creative and innovative thinking at the interface of these disciplines.

Course Logistics

While the clinical immersion course has been hitherto taught on the same campus for three years (2015-2018), this case study is based on research conducted during one semester that the course has been offered. The three-credit hour course was dual-listed in the university catalog as CHE 4973 (special topics) and NURS 4240, allowing students from each discipline to sign up for the course corresponding to the discipline in which they were enrolled. The course was co-taught by faculty from the Department of Chemical Engineering and the School of Nursing. The class met at various locations (e.g., fundamentals lab in the nursing school, regional medical center, CHE classrooms and lab spaces, Maker Space on campus, etc.) in a single three-hour block of time each week with each instructor being present for each class session. Enrollment in the course was 14 students with half of the students coming from each discipline. At the beginning of the course, as is typically the case, the focus was on getting the CHE students ready to enter the clinical setting and on cross-disciplinary team formation and development. There is a required orientation checklist that the students complete prior to entering the hospital units. The class spends time in the nursing fundamentals lab where the nursing students teach the CHE students about various topics including the Healthcare Insurance Portability and Accountability Act (HIPAA), infection control, and hospital etiquette (i.e., introducing oneself to a patient, working with hospital staff, therapeutic communication, etc.). There is also time devoted to having the students form teams and develop a teamwork contract (Geist et al., 2019; Sanders & Geist, 2016).

The faculty led a discussion about working in teams, starting with these probing questions:

a. Think about experiences where you have had to work in a team.
b. Identify the positives and negatives of those experiences.
c. What are the characteristics of a good team member and bad team member?

From this conversation, the students were then tasked with developing a teamwork contract including an agreed upon definition of a team, individual roles and responsibilities, and indicators for success (Biernacki, 2011; Rogers & Frueler, 2015). In the next phase of the semester, which focuses on the clinical immersion experience, the students were immersed at the local hospital (or another healthcare facility) in cross-disciplinary teams to take part in problem identification and customer discovery. The teams were tasked with identifying a suitable challenge (i.e., an opportunity to improve health outcomes) utilizing various research-based and exploratory techniques including open-ended interviews, self and team-based observations, debriefing notes, and general reflections (Geist et al., 2019; Sanders & Geist, 2016). As part of enhancing student exposure to new perspectives and potential resources (i.e., knowledge acquisition), as well as fostering exploration in the clinical setting, students (as always) were encouraged to talk to as many different people as possible including, but not limited to, nurses, respiratory therapists, housekeeping staff, and patients (Arce, et al., 2015; Schwartz et al., 1999).

In the final part of the course, the teams worked to create a prototype of innovative technology that is utilized to show proof-of-concept (Arce et al., 2015; Sanders & Geist, 2016). In this phase, the teams engaged in various cognitive and design-based activities relevant to the development of their idea (i.e., knowledge transfer) (Arce et al., 2-15; Schwartz et al., 1999). For example, teams conducted iterative brainstorming and planning sessions with regards to their project (i.e., assessing the feasibility of their product and revising their design accordingly) and were challenged to access and incorporate the information they acquired during their clinical immersion experiences (e.g., nurses' opinions, consumer feedback, impact, etc.). As part of the design process, the teams engaged in a variety of methods to develop and test their initial ideas via various levels of prototype testing (Cross, 2011; Martin & Hanington, 2012). Such testing ranged from low-fidelity prototyping (e.g., drawing, electronically mapping, graphic design, COMSOL® modeling) to more high-fidelity prototyping models (e.g., creating a model with available materials or utilizing the 3D printer in the university's iMaker Space) (Geist et al., 2019; Martin & Harrington, 2012; Sanders & Geist, 2016). As a final project, the teams developed a presentation highlighting the journey from problem identification to brainstorming solutions, reiterative design, and proof-of-concept for the ultimate solution to the problem. Stakeholders from the university and from the community attended the presentations, asked probing questions, and provided feedback to the student teams (Geist et al., 2019; Sanders & Geist, 2016).

Methodology Interpretive Case Study Framework

Within this study, it was vital to utilize a framework in which students' perceptions and experiences within the CIDI course would be the central focus. In accordance, a qualitative methodology that employs an interpretive framework allows not only that the data collected is generated from student perceptions, but also that it is analyzed in such a way that students' experiences are highlighted (Patton, 2002). In turn, a case study approach permits the focus to be solely on the contextual framework provided by the CIDI course. As this course implements a forward-thinking pedagogical platform for fostering cross-disciplinary communication and the generation of innovative prototypes of novel technologies, it provides a unique contextual framework at the undergraduate level within which to investigate these questions (Arce et al., 2015; Ary, Jacobs, Irvine, & Walker, 2010; Yin, 2006). The specific unit of analysis for this study, therefore, is bounded by the data collected within one semester of the CIDI course and the voices of the students that were enrolled in this course. Their experiences and perceptions are what are captured within the analysis of the data for this study.

Data Collection

The data collected for this project originates from a larger study entitled, *An Exploration of Communication, Idea Generation, and Prototype Development at Disciplinary Interfaces*, conducted at a four-year, public, Southeastern University. The purpose of this larger study was to evaluate the influence of nursing and chemical engineering student engagement in the CIDI course on critical thinking, cross-disciplinary communication, and prototype design. This multi-semester research study (including the semester highlighted in this manuscript) commenced in the Fall 2015 semester and was completed in the Spring 2017 semester, totaling four semesters. Data for this larger study encompassed both quantitative and qualitative data. Quantitative data was collected each semester for the entirety of the study and was comprised of a pre- and post-test design in which students completed the Critical-thinking Assessment Test (CAT) (Stein et al., 2009). The results of the CAT quantitative measure are discussed in detail in Geist et al. (2019). The qualitative element of this study included the following items: eight focus group interviews (two per group); student team observations; student debriefing notes; and student artifacts (including student class and design notes). As described above, the qualitative data from this larger study was collected during one semester of the CIDI course and is what comprises the data for the current study.

Participants

The participants for this study included junior and senior level undergraduate students from the School of Nursing (5 female and 2 male) and the Department of Chemical Engineering

(3 female and 4 male). Dependent on their major, the students enrolled in NURS 4240: Clinical Immersion at Disciplinary Interfaces or CHE 4973: Clinical Immersion at Disciplinary Interfaces. All students enrolled in these two courses participated in the research study.

Aligned with the nature and purpose of the CIDI course, the students were placed in cross-disciplinary teams based on academic discipline and gender as follows:

Team 1: 1 female CHE, 1 male CHE, 1 male NURS

Team 2: 1 female CHE, 1 male CHE, 2 female NURS

Team 3: 1 female CHE, 1 male CHE, 1 female NURS, 1 male NURS Team 4: 1 male CHE, 2 female NURS.

The composition of the course for the semester targeted for the case study analysis arguably presented an even distribution of disciplinary representation (seven students per major) with demographic characteristics also representative of the larger, university context.

Ethical Considerations

The study was approved by the Institutional Review Board for the Protection of Human Subjects at the university where the research was conducted. The study was subsequently explained to all students, and after consideration, each student provided informed consent. Questions developed for the debriefing notes and the focus groups were semi-structured and approved by the IRB prior to the collection of data. These questions were designed utilizing the principles outlined by Rubin and Rubin (2012) for qualitative interviewing. All qualitative data collected for the semester in question was stored in a password-protected and secure database location. Specific student identifiers were excluded within the data with the intention of maintaining confidentiality.

Trustworthiness

Consistent with qualitative research methodology guidelines, we employed various strategies throughout the data collection process to ensure that measures of rigor were established with regards to trustworthiness (e.g., credibility, transferability, dependability, and confirmability) (Marshall & Rossman, 2006; Patton, 2002). These strategies included: the integration of a reflexivity journal that documented the emotions, experiences, and general perceptions of the principal investigators for the debriefing and focus group sessions; members checking the data with outside collaborators and student participants when possible; prolonged engagement within the context of study; establishing an audit trail for all components of the data; and persistent observation of both the environment and the participants within the study (Ary et al., 2010; Rubin & Rubin, 2012).

Reflexivity

We acknowledge that there are professional interests as both educators and researchers that influence the way that we have read, interpreted, and analyzed this data. For example, all three authors are contributing members of the Renaissance Foundry Research Group - a cross-disciplinary team of scholars interested in developing and understanding innovation-driven pedagogy - that highlights our proclivity to want to research student-centered educational innovations. Further, two of the authors were principal instructors for the CIDI course, and all three authors were principal investigators within the larger research project. Our individual and collective participation in the teaching of this course and the overall data collection process influenced our understanding and familiarization with the context which are, in turn, arguably present in the analysis developed for this study.

Data Analysis & Results Analytical Strategy

The purpose of this study was to identify answers regarding students' perceptions of cross-disciplinary communication, creative thinking, and prototype development. Specifically, the following questions guide this investigation: 1) How do students navigate cross-disciplinary communication? and 2) What role does cross-disciplinary communication play in the identification of challenges and development of innovative prototypes? To investigate these questions, we utilized an open coding analytic strategy within an interpretive case study framework (Ary et al., 2010; Saldaña, 2009). Specifically, we integrated several steps from the data collection process that allowed us to advance the coding of the qualitative data for this project, including familiarization with the data and initial coding of patterns (Saldaña, 2012). By being part of the data collection process, we were able to note not only the idiosyncrasies contained within this data but also the contextual framework within which we could better understand the relevance of these observations (Ary et al., 2010; Saldaña, 2009). These patterns were noted and conserved as part of a pre-coding process for this work. Once all items for this study were collected, this pre-coding process helped guide the final coding of the qualitative data (Saldaña, 2009). We employed an open coding process to formalize these patterns and, upon further review, we refined and connected these codes to highlight major themes that captured the nuances of the processes enveloped within the links between the codes (Saldaña, 2009). In total, this process resulted in four major themes (See Table 1, column 1).

Table 1

Description of Themes and Respective Categories

Themes	Definitions	Categories
Transformation of Technical Terms	This theme outlines the various ways that students began to decipher the complex vocabulary utilized by their counterparts.	Technical terms Shared vocabulary New words New experiences Common ties
Use of Artistic Expression	This theme encompasses the various ways students utilized artistic expression to communicate with one another.	Drawing Acting Modeling
Disciplinary Growth	This theme reviews the ways in which students expressed disciplinary growth through familiarity and comfort with unfamiliar spaces and terms.	Familiarity Comfort Leadership Confidence
Cross-over Communication Patterns	This theme reviews the ways in which students engaged in cross-over communication patterns not only between disciplines but also between one another.	Between students Between disciplines Effective language Generalizing terms

Discussion of Themes

Transformation of Technical Terms. This theme captures instances within the course wherein students from both disciplines identified issues with technical terminology rooted in specific disciplinary backgrounds and created ways to deepen their understanding of these concepts. As upper-level engineering and nursing students, both student groups arguably entered their interdisciplinary teams with advanced levels of knowledge pertaining to their discipline specific vocabulary. However, at the beginning of the semester, the level of familiarity with the other discipline's vocabulary was significantly limited. This was evident when student teams entered the clinical experiences and identified a common issue with regards to understanding specific, clinical terminology. In this phase of the course, nursing students volunteered to create a glossary of terms for the entire course in order for all students to have some familiarity with the concepts being shared within the immersion experiences.

Further, student data provided instances of this type of transformation of technical terms by offering perspectives on how students integrated new vocabulary into their own disciplinary lexicon via their application to their team's prototype design. The following exchange between two engineering students and one nursing student in the course during a virtual reality simulation of a heart displays this type of interaction:

> Engineer 1: "I want one of these in my room. Ok, so, what's this?
>
> Nurse: "I think that would be part of the artery…So like, whenever you're at the hospital and you hear that someone has had heart failure it is most likely that one of these arteries has closed and blood is not going to the heart."
>
> Engineer 1: "Mm hm. So, like if I go through here…"
>
> Engineer 2: "But, how do they close up?"
>
> Engineer 1: "So, it's like a contraction…"
>
> Nurse: "Yeah, so if you have the blood coming from one section of the heart and…"

Such interaction facilitated the acquisition and understanding of new vocabulary necessary to navigate new, complex environments for students of either discipline. Another engineering student indicated this sentiment as part of their debriefing reflection in the following: "It is a different experience. I am understanding more new terms and my team is helping me with that."

Use of Artistic Expression. Interacting with individuals and environments outside of their respective disciplines also allowed students the possibility of expanding their own cross-disciplinary communication through the use of other, unique forms of communication. For example, several student teams noted that in order to exchange initial ideas, artistic forms of expression - including drawing, acting, or modeling - became a second form of communication. The concepts in this theme captured how students utilized these various artistic forms of communication to exchange and express ideas from a specific, disciplinary perspective to their cross-disciplinary counterparts. The following exchange between a team of two engineering and one nursing student provides evidence to the types of uses that artistic expression had during this process as applied to a course activity to design and build a new dosing device:

> Nurse: "Still trying to figure out how to make this device though"
>
> Engineer 1: "Yeah you would have to …"
>
> Engineer 2: "So, we could use it to get what we want in a syringe or in a cup"
>
> Nurse: "Yeah, yeah, you could draw it out however you wanted, in a syringe, in a cup, in whatever, you just have to tell it…
>
> *[silence – Nurse goes back to drawing out the idea]*
>
> Engineer 2: "I think most of the error in the cups is because some of the liquid gets stuck at the bottom"
>
> *[Nurse looks up and keeps drawing]*
>
> Engineer 1: "So we are kind of making like a vending machine for the medication dosages…"

Another exchange between a group of two engineering and two nursing students provides a similar display of the use of artistic expression in communication:

> Nurse 1: "Yes, go get another cup then"
>
> *[Engineer 1 goes to find another cup]*
>
> Engineer 2: "What if we find something else for the bottom or something else for the hole?"
>
> Nurse 2: "You didn't like my whole idea for the device?"
>
> Engineer 2: "No I mean, what if we tried to make it flip so that it fills itself"
>
> Nurse 1: "How you going to get that to happen?"
>
> *[Engineer 2 answers this question with a drawing of the idea]*

Engineer 1: "Yeah, I could see that"

Disciplinary Growth. The unique cross-disciplinary exchanges and immersion into different clinical environments also provided students an opportunity to combine ideas from these spaces and interactions that could not have been accomplished in a typical, discipline specific learning environment. For example, after one month of engaging with their nursing counterparts and after only one session within a clinical immersion environment, one engineering student stated, "I am surprised how after just one session I got a lot more comfortable in the [clinical] environment," emphasizing that they were able to speak to more nurses and clinical professionals than they had the previous visit. It was also noted that within their debriefing notes for the clinical immersion experiences, engineering students readily identified their nursing counterparts as vital in helping them to navigate and understand the clinical space in order to better identify challenges and engage in problem solving behavior. One nursing student observed this in their debriefing reflection, stating: "[the biggest challenge was] understanding how we could improve something we didn't completely understand...I need to be able to give my team insight about what everything is used for." For nursing students in this space, although some noted that they were taking on leadership roles, they understood that such roles might be switched upon entering the design phase. One nursing student acknowledged that they were having trouble identifying an initial challenge in the space, however having an engineering student allowed them to see the environment from a different perspective. This student noted, "We are both very observant," and stated that viewing different machines and their functions helped them to understand the purpose and potential problems with this equipment.

Cross-over Communication Patterns. This theme identifies patterns within the data revealing ways that students engage in communications between disciplines and others. The efforts put in by students from both disciplines to learn to communicate with one another for the purpose of this course allowed students the possibility of establishing strong cross-over communication patterns. The responses of both nursing and engineering students concerning communication questions asked during focus group sessions illustrate how this interaction contributes to cross-disciplinary understanding. For example, the following response from an engineering student describes how the communication aspect of the cross-disciplinary process developed within their group and why it was impactful:

> Like, there's been kind of a communication thing like that we've definitely learned. And it's just been eye-opening, like, "this is how I communicate with a group that's not just a bunch of engineers just trying to work through it, like a group project." Um, but, I, I, it's been really enjoyable too, just to get, like, a different perspective and to open, uh, your mind up to something that, uh, you wouldn't have thought of. Like, uh, I wouldn't have paired nursing and engineering but it, it's extremely relatable on both, on both ends of it.

Within the same team, the perspective of a nursing student reflects a similar sentiment: Yeah, I

> agree, I mean - two totally different mindsets but uh somehow you mesh ideas together and, I don't know, [they're] thinking in systems, I'm thinking, "People are coming in and their system's not working". So, I'm trying to fix it and [they're] trying to come up with a valve to fix it. So, uh, um, it's, I mean, it's pretty cool the, uh, just the different mindsets you get. Where I think, when, like, when typically like where nursing is, um - like you may have your patients but I mean, like, as a nurse you're working with your whole group, you're communicating, um, you gotta relay messages and uh engineers are doing the same thing but with different, different aspects and so, that whole, um, that whole mindset of communicating with them, and having them think differently than what you're thinking, I mean it's just, there's no telling what you're gonna come up with, so uh, yeah.

Thus, what these responses illustrate is the continual, positive influence of cross-disciplinary collaboration on the development of cross-disciplinary understanding and respect through the creation of mutual communication patterns.

Discussion

The primary purpose of this research was to investigate how students within a dual enrolled nursing and engineering course, working in cross-disciplinary teams, navigate communication barriers and what role communication facilitates the identification of health related challenges and the responsive prototypes. The examples provided as part of the themes of Transformation of Technical Terms and Use of Artistic Expression provide insight into how students navigated cross-disciplinary communication over the course of the semester. A principal learning objective for the course is that students develop strategies for cross-disciplinary communication that promote respect and understanding for their respective contributions. Embedded into the cross-disciplinary teamwork component of the course, this type of communication is a continuous learning process that is an inseparable element of the exploratory, brainstorming and design evolution (Cross, 2011; Sanders & Geist, 2016).

While the above research question dealt with the strategies utilized by students to navigate cross-disciplinary communication, the second research question explored the role played by this cross-disciplinary communication in the identification of a challenge and development of an innovative prototype. The illustrations encompassed within the themes of Disciplinary Growth and Cross-Over Communication Patterns provide evidence towards this type of progression. Through the development of cross-disciplinary communication skills, students became leaders within their teams in their attempts to help the team reach its goal (challenge identification and prototype development). This is evident in the communication evolution that the students demonstrated. At the first meeting between the engineering and nursing students, there is a discovery and budding understanding of what each discipline consists of and has to offer. Early in the semester, students participate in an active learning, low-stakes design challenge that highlights the similarities between the processes that nurses and engineers pursue in performing their roles (Sanders & Geist, 2016). As the class progressed, this initial discovery set the tone for effective communication of ideas that gradually developed into a deeper respect for each profession, a greater sensitivity and openness to ideas, and an increased appreciation for the benefits that cross-disciplinary collaboration brings (Broome, 2016; Carter, 2015).

Implications & Future Work

In recent years, the nursing and engineering professions have recognized the need for effective cross-disciplinary communication to improve health outcomes and to develop quality solutions to increasingly complex global challenges (ACEN, 2016; Borrego & Newswander, 2008; CCNEA, 2016; NRC, 2009a, 2009b). This research provides an exploration of the different mechanisms that have developed between students to foster these skills within an undergraduate, cross-disciplinary course. The techniques, strategies, and resulting outcomes that have been explored in this study concerning cross-disciplinary communication patterns can be attributed to or connected with elements of design thinking that are interspersed within the pedagogical platform used for this course (Arce et al., 2015; Geist et al., 2019). For example, the first step in Design Thinking, an updated and human-centered approach to design, is to develop empathy with the user (Beaird, Geist, & Lewis, 2018; Roberts, Fisher, Trowbridge, & Brent, 2016). Within the CIDI course, the students develop vocabulary based on the field of impact and problem they have identified and the possible solutions they explore. In any given semester one CHE student might become well-versed in Continuous Renal Replacement Therapy (CRRT), while another CHE student can explain the function and maintenance of a nasogastric tube. During the first clinical experience, the nursing students tend to ask questions and control the conversations. However, as evidenced by the data presented in this study, in subsequent clinical rotations the CHE students develop enough confidence in their new vocabulary to formulate and pose questions to the nurses, respiratory therapists, and other end-user stakeholders. This confidence can be associated with the increasing level of expertise in cross-disciplinary matters via the experiences fostered in this course (Cross, 2011; Martin & Hanington, 2012). This same pattern is reflected in the third phase of the class in which the faculty notice the nursing students fully participating in typical engineering design conversations. By placing the students in cross-disciplinary teams and then immersing them in the healthcare facility setting, the CIDI course inherently taps into the Design Thinking approach and encourages cross-disciplinary communication, merging the language and values of each discipline to support high-quality solutions to health-related problems (Beaird, Geist, & Lewis, 2018; Cross, 2011; Roberts, Fisher, Trowbridge, & Brent, 2016).

Further, this study demonstrates the changes in communication that result when nursing and engineering students are brought together for authentic cross-disciplinary and challenge based learning. Specifically, through the transference of technical terms from both disciplines, the use of artistic expressions, the progression of disciplinary growth in areas related to their primary content areas, and the development of common cross-disciplinary patterns, students' overall communication skills have evolved. At the beginning of the course, the participants' language is steeped in their respective disciplines. For example, the CHE students do not know about HIPAA, disease processes requiring specific infection control measures, or about devices such as nasogastric tubes or sequential compression devices (SCD). By the end of the semester, having learned from their student nurse teammates as well as nurses and other hospital staff, the engineering students are able to use "hospital" language to describe their problem and resulting prototype. On the other side, nursing students are not familiar with 3D printing programs, the concept of scale, or the process of diagraming or sketching as a way of communicating ideas. By the end of the semester, the nursing students understand the power of these engineering tools to solve problems. It is interesting to note that in some semesters these disciplinary interests have shifted with some of the nursing students becoming the experts in 3D software knowledge on their teams, fully embracing the technology, while at the same time CHE students develop pathophysiologic knowledge based on their clinical experiences.

Ultimately, the results from this work demonstrate the potential impact of cross-disciplinary courses in encouraging the development of cross-disciplinary communication skills in students. As indicated, both instructors of the course hold expertise in different disciplines and were always present during the class sessions; in combination with the innovative pedagogical platform utilized in this course, this combination of expertise provided a transformative catalyst for student learning through which students could showcase and leverage their disciplinary knowledge and integrate unique strategies to facilitate communication and learning (Arce et al., 2015; Geist et al., 2019). For educators in higher education wanting to contribute to student training in cross-disciplinary environments, the insights provided through this research highlight the need for flexibility in the pedagogical strategies pursued to optimally support students in progressing through the process of design thinking.

This study has also provided a foundation for exploration of this topic in various areas. For example, equally important to identifying cross-disciplinary communication strategies is also understanding how this type of communication contributes to creativity and teamwork. From a pedagogical perspective, it would also be beneficial to better understand the strategies that students use in developing these skills to leverage them as part of the main components of this course. Future work in these directions will help contribute to the rapidly advancing literature in these areas and provide more insight into how to enhance the student preparation for the future of work at the intersection of disciplines. Such efforts at improving cross-disciplinary communication skills are responsive to challenges from numerous think tanks and are highly important for producing graduates with the ability to expertly navigate the complicated problem spaces of the present and future.

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