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Mechanical Engineering Design for Complex Environments: Incorporating Industrial Design Perspectives into a Multidisciplinary Capstone Design Project

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Abstract

The rapid pace of global communications development coupled with an unprecedented increase in technological advancement has increased the need for multi-disciplinary teams to solve the complex engineering problems of the future. The well-structured, multi-part 'complicated' problems of the past have transformed into the interdependent, multi-part 'complex' problems of today and the future. These problems prevent one person or disciplinary-specific group from having the requisite knowledge and skills to solve the problem independently. ABET acknowledges this reality by requiring undergraduate engineering programs demonstrate the ability of their students to work within a multi-disciplinary team upon graduation. Faculty may be challenged to meet this requirement because of a lack of sufficiently complex problems that may require a multi-disciplinary approach. One such problem was a Defense Advanced Research Projects Agency (DARPA) sponsored project that asked West Point cadets to design a system that would sustain SquadX in a dense urban combat environment for up to 72 hours. A multi-disciplinary team of Mechanical Engineering, Systems Engineering, Engineering Management, and Defense Strategic Studies students embarked on this design challenge during the 2017-2018 academic year. The team quickly realized the need to better understand the dense urban operating environment. To remedy this gap, the faculty at West Point collaborated with the Industrial Design department at the Rhode Island School of design (RISD) to create an intensive, two-day experience that allowed both West Point cadets and RISD students the opportunity to better understand the challenges associated with a dense urban operating environment and military operations more generally.

The purpose of this paper is to describe an intensive, two-day design experience conducted by faculty and students from West Point and RISD. This session brought together cadets assigned to a DARPA-sponsored SquadX urban sustainment project and students from the Design, Culture and Global Security course at RISD in Providence, Rhode Island. The students from both institutions were divided into five separate teams aligned with the preliminary functional decomposition of systems to be designed. After a preliminary orientation and team formation meeting the night prior, the teams spent a total of five hours collecting data around the city of Providence, synthesizing the results of the data collection, and presenting their work to the larger group. An analysis of student feedback from the experience shows that despite initial ambivalence or assumptions of unhelpfulness regarding the potential benefits of the multi-disciplinary collaboration, students gained some unique insights. Students were exposed to various design perspectives, a fresh perspective of their design challenge, and described the experience as 'eye-opening'. The overall success of this experience provided the faculty a desire to further refine the relationship between RISD and West Point, to allow continued collaboration on future complex design problems.

Introduction

The rapid pace of global communications development coupled with an unprecedented increase in technological advancement has increased the need for multi-disciplinary teams to solve the complex engineering problems of the future [1]. The well-structured, multi-part 'complicated' problems of the past have transformed into the interdependent, multi-part 'complex' problems of today and the future [2]. These problems prevent one person or disciplinary-specific group from having the requisite knowledge and skills to solve the problem independently [1], [3], [4]. ABET acknowledges this reality by requiring undergraduate engineering programs demonstrate the ability of their students to work within a multi-disciplinary team upon graduation [5]. Faculty may be challenged to meet this requirement because of a lack of sufficiently complex problems that may require a multi-disciplinary approach.

One such problem was a DARPA sponsored project that asked West Point cadets to design a system that would sustain SquadX [6] in a dense urban combat environment for up to 72 hours. A multi-disciplinary team of Mechanical Engineering, Systems Engineering, Engineering Management, and Defense Strategic Studies students embarked on this design challenge during the 2017-2018 academic year. The team quickly realized the need to better understand the dense urban operating environment. To remedy this gap, the faculty advisors for the SquadX design team at West Point collaborated with the Design, Culture and Global Security course director at RISD to create an intensive, two-day experience that allowed both West Point and RISD students the opportunity to better understand the challenges associated with a dense urban operating environment.

Background

The term 'design' is used in a wide variety of contexts such that it is often unclear what one means by design, even when the context is relatively clear. There have been numerous books published in the last decade on design thinking e.g., [7]–[9], usually in a business context. Engineers apply a design process to engineering problems [10]. Industrial designers apply a design process to a variety of problem types. Even the United States Army has taken up a design process in service to operational planning [11]. Then there is architecture, graphic design, fashion, organizational design, and so forth. It is not our aim here to pin down a firm definition of design. In a recent work on creative practice, Kees Dorst, Professor of Design Innovation at the University of Technology Sydney, discusses design as: applied creativity, problem solving, learning, evolution, a social process, rhetoric, and even as a game [12]. Indeed, Dorst goes on to say "Design as such does not exist, not as a single discipline that you can clearly define or point to" [12]. Design processes come in many forms as well. It is not our aim to pin down a universally acceptable definition of design, and we do not consider there to be such a thing as "*the* design process." There are a variety of design skills and processes. Emeritus Professor of Design Studies at the Open University, Nigel Cross, argues that "The most essential thing that any designer does is to provide, for those who will make the artefact, a description of what that artefact should look like" [13]. So long as we do not limit 'artefact' to a physical object (e.g., it could be a digital product or an abstract concept), this description seems to apply to what designers do in all the contexts listed above. Much more could be said here but defining the limits of design activities and what counts as design is beyond the scope of this paper. Suffice to say that the students engaged in the multi-disciplinary capstone course, ME404, at West Point

are applying a design process taught in their course and described below. Additionally, the industrial design students at RISD enrolled in the Design, Culture, and Global Security course apply their own distinct design process to the challenges presented in their course. We have two very different courses, each with students facing complex problems and applying a design process to address those problems. As Godfrey [14] acknowledges, various disciplines may create their own specific culture, which may not always be compatible with the desires of a collaborative experience. The faculty were aware of these dynamics and wanted to scaffold a positive experience for all involved.

For our purposes, we emphasize the usefulness of both a design process and a variety of associated design skills to equip undergraduates to address complex problems. Many of the most interesting and impactful contemporary problems, from healthcare to government policy to urban planning, are entirely too complex to be addressed by any single discipline. They require a multidisciplinary approach, and the solutions benefit greatly from a variety of perspectives. Design, as a problem-solving process, is conducive to this sort of interdisciplinary work.

West Point Course Description: ME404: Mechanical Engineering Design

The ME404 Mechanical Engineering Design course was the first course in the year-long capstone design sequence taught in the Department of Civil and Mechanical Engineering at West Point. In this course, cadets are assigned to externally sponsored team-based engineering design problems as part of their ABET accredited mechanical engineering degree requirements. The course spends the first 10 lessons of the 40-lesson course teaching the students the mechanical engineering design process using a rapid design sequence. During this sequence, the students individually apply the mechanical engineering design process from problem definition through conceptual design down-selection. This sequence culminates with a design showcase where each student presents her/his conceptual design to the rest of their teammates and faculty advisors. Following the design showcase, the student teams spend the remainder of the fall semester in design studios, applying the design process in a second iteration, to achieve a sponsor-approved conceptual design that may be fabricated and tested in the follow-on spring semester course. The course teaches students a hybrid design process that is informed largely by the work of Dym and Little [10] (Figure 1).

ME404 Course Objectives

- Apply the design process to identify a need, generate alternatives, and determine the best alternative to solve a real-world, engineering problem.
- Select materials and processing techniques appropriate for a proposed design.
- Apply risk management tools to identify, assess and mitigate project risks and incorporate safety into the design process.
- Clearly communicate design decisions, considerations, and results.
- Operate as an effective leader or team member in a multi-disciplinary project team.
- Incorporate societal considerations into the engineering design process.
- Identify the ethical standards expected of a mechanical engineer

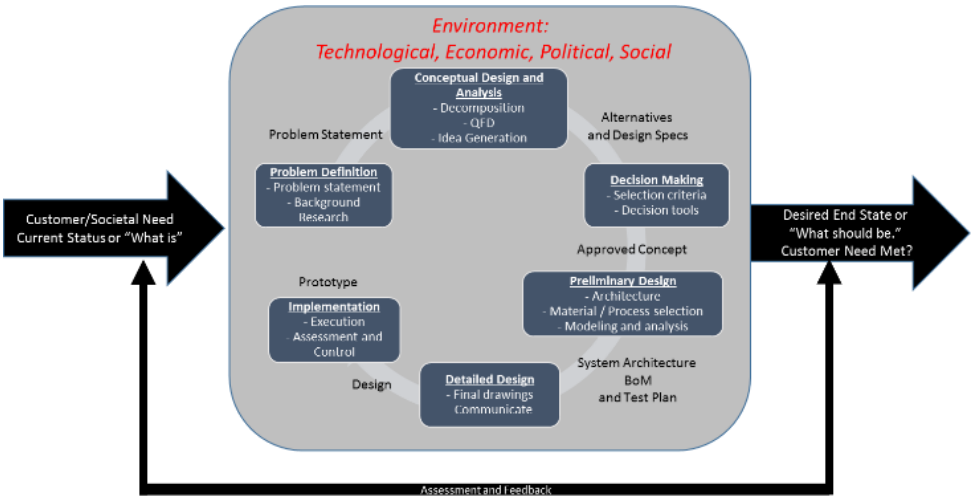

Figure 1: ME404 Design Process Graphic from Student Notebook

RISD Course Description: ID-24ST-06 Design, Culture and Global Security

Each day we consume news, information and media about countless global crises or threats. In many cases, these threats appear too complex for the average citizen to contribute toward a more positive outcome. The Design Culture, and Global Security course at RISD explored the role that design can take to shape culture, public perception and policy around global security and nuclear weapons.

Course Goals

The purpose of the RISD Design, Culture, and Global Security course was to employ the tools and processes of industrial design to approach complex problems with multiple stakeholders and possible outcomes. These processes included research, user testing and prototyping. Students created frameworks for innovation that encouraged diverse subject matter experts to work together. The frameworks and activities in this course can be applied to a broad range of topics and challenges.

Course Objectives

- Students will learn and develop the ability to frame questions based on insights and inquiries with user groups and experts.
- Students will learn and develop new communication platforms across diverse areas of expertise.
- Students will learn to design and build objects that illustrate and communicate complex stories and narratives.
- Students will design stories/messaging to reach specific audiences and exploring metrics for measuring impact and effectiveness.
- Students will practice and refine presentation skills.
- Students will learn and develop strong time/project management skills.

Throughout the semester, students worked on several projects and exercises that relied on user testing and feedback to inform their process and directions. Projects included the design of objects, tools or creative activities that linked to and complement new ways of thinking and working collaboratively about global security. Students developed engagement strategies that pushed the conventional messaging of nuclear issues and linked these strategies to specific calls to action established by subject matter experts. Nsquare [15], an innovation collaborative focusing on nuclear issues, provided access to guests, mentors and supporting materials for this class.

DARPA Design Team

Within the ME404 design course, a team of six West Point cadets were assigned to a DARPA sponsored project that asked the students to design a system that would logistically sustain (resupply) a nine-person Army squad (SquadX) in a dense urban combat environment for up to 72 hours. At the request of the sponsor, the West Point faculty assembled a multi-disciplinary team of Mechanical Engineering, Systems Engineering, Engineering Management, and Defense Strategic Studies students for the 2017-2018 academic year. These students were voluntarily assigned to the teams based on their preference selection within their own majors. All were enrolled in the ME404 design course. DARPA asked the West Point cadets to address a very complex and difficult problem, the sort of problem that defies solution by a single person or even a single discipline. We assembled a cadet team from a variety of disciplines with a firm belief that insights from a variety of perspectives would absolutely yield better solutions than the best possible solutions that may result from a discipline-pure team.

West Point-RISD Collaboration

The course director for the RISD Design, Culture, and Global Security course and faculty advisors for the West Point SquadX design team began conversations about a potential collaboration several months prior to the September 2017 joint workshop. It was clear that both parties might benefit from a shared experience, but to what end was not entirely certain. Students in the RISD Industrial Design (ID) studio were seniors coming into the course with skills including prototyping, CAD, problem definition and some user testing. When possible, advanced studios in the ID department attempt to provide students with opportunities to work with subject matter experts or user groups that might inform their work beyond the merely conceptual. Students would be exploring future conflict scenarios throughout the semester and while the RISD students scheduled visits with a range of policy makers, think tanks and political scientists, the chance to work directly with military officers in training afforded an opportunity to gain military perspectives in a unique way. For the West Point cadets, collaboration with RISD students afforded an opportunity to experience the empathetic and artistic industrial design methodology taught at RISD which may facilitate a broader aperture of design concepts for the West Point team. The location of RISD in the city of Providence, Rhode Island also provided a dense urban context, which was a critical facet of the SquadX design problem but of which the West Point cadets had little understanding. Following multiple planning sessions and conference calls, faculty from RISD and West Point agreed on the outline for the workshop with the understanding that it would bring two very distinctive groups together. The faculty decided that a team-based data collection process within the city of Providence, focused on the SquadX team

project would facilitate collaboration among the RISD and West Point students. Teams were formed around functional aspects of the SquadX design problem as defined by the West Point team (Table 1):

Table 1: Team Breakdown for West Point-RISD Student Collaboration

Team Title	**Team Objective**
Operational Environment Assessment	Develop an understanding of how the dense urban environment may impact military operations.
Navigating the Environment	Evaluate the unique challenges associated with travel within a dense urban environment.
Get "Stuff"	Identify the resources available within a dense urban environment for resupply of a squad.
Secure "Stuff"	Identify how residents of an urban environment secure their belongings to prevent theft.
Receive "Stuff"	Identify opportunities for a squad to receive supplies within an urban environment.

To facilitate the collaboration between the students during the workshop, a scripted timeline was developed to help develop relationships that would allow for the most productive use of the students' time while collecting data within the city (Table 2)

The workshop deliverable was a multi-media presentation to the entire group that would meet the team objectives as specified in Table 1 above. The teams used a combination of photos, video, voice recordings, and sketching to capture qualitative data pursuant to the team objectives. The presentations ranged from analog map presentations using photos and overlays to multi-media slide presentations. The teams were encouraged to use the media they deemed best suited for relaying the team's ideas.

Faculty from both sides of the collaboration witnessed an incredible depth of engagement among all students during the workshop despite indications of trepidation and skepticism among the students prior to the engagement and are addressed in the discussion section of this paper. As a result, the faculty involved in the collaboration wanted to capture the experience in a scholarly manner to inform other engineering and design educators regarding this experience. The student benefits and the richness of the experience could not have been predicted based on the initial impressions of the students prior to the engagement. The purpose of this paper was to capture those overarching student perceptions.

Table 2: Collaboration Workshop Schedule

Day	Timing	Activity
Day 1	6:30-7:30 pm	Dinner and Student Introductions, ice-breaker activity
	7:30-8:00 pm	West Point and RISD Orientation Presentations
	8:00-utc	Workshop objectives and team assignment
Day 2	9:00-11:00 am	RISD Tour (West Point Only)
	11:00-1:00 pm	Working lunch, team prep

	1:00-2:30 pm	Teams collect data in Providence Rhode Island
	2:30-3:45 pm	Teams synthesize findings
	3:45-6:00 pm	Team presentations

Methods

This paper synthesizes the perspectives expressed by both West Point and RISD students who responded to a post-experience qualitative survey. This online survey was sent to all involved students by West Point's office of institutional research upon completion of the experience. This study specifically addressed the following research questions:

1) What assumptions do undergraduate students bring to a multi-disciplinary design experience?
2) What insights do undergraduate students gain from combining a multi-disciplinary engineering capstone design team with industrial design students?

A total of five students responded to the survey (40%). The responses represented 67% of West Point participants and 22% of RISD students (Table 3).

Table 3: Summary of Student Responses

Institution	# Responses	#Female	Majors
West Point	4/6	0	Mechanical Engineering (1) Defense Strategic Studies (2) Engineering Management (1)
RISD	2/9	1	Industrial Design (2)

The survey was administered using the SurveySelect online platform. The survey asked the students a series of ten qualitative questions regarding their experience while also asking for their gender, international status, and academic major. Reviewing survey responses, two distinct topic areas emerged from the qualitative data that may best inform faculty involved in multi-disciplinary engineering and design education: 1) the underlying assumptions students brought forward to the collaboration and 2) the specific insight students gained from the multi-disciplinary workshop. Specific prompts that informed the results of this study are addressed in the results and discussion section below. The authors were concerned by the low response rate for the survey which may be attributed at least partially to an un-remedied access issue for the RISD students. Multiple RISD students expressed concern to their faculty that they could not access or submit the online survey. The RISD faculty offered to receive hardcopy printouts of the survey in lieu of the online submission, which resulted in one of the two submission from RISD. The authors correspondingly acknowledge the limitations of this study, but determined the richness of the participant responses worthy of publication.

It is important to note that the authors were responsible for both coordinating and conducting the multi-disciplinary design experience and were the primary advisors for the students involved. This first-hand accounting of the student experiences allowed them to provide context to the student responses. To conduct analyses, the aggregated responses of participants were given in vivo (in the participants' language) codes by one of the authors. See [16] for a

detailed description of coding techniques. These codes were then aggregated into larger themes. These themes were subsequently reviewed by the remaining authors to add trustworthiness to the findings. Finally, the results were shared with the students at both institutions to verify that the findings were aligned with their perceptions of the experience. Although the authors used these multiple reviews to add trustworthiness to the findings, the results are not meant to be generalized across all multi-disciplinary design experiences. As Merriam [17] describes, this qualitative study is intended proved insights into the perspectives of the students involved with the experience; the generalizability of the results to other contexts is left to the reader. This study was classified as exempt research by the West Point IRB.

Results and Discussion:

Several themes emerged from the student responses regarding the assumptions each brought forward to the collaboration and the various insights the students gained from the multi-disciplinary workshop experience.

Assumptions:

When asked to reflect on any underlying assumptions or perceptions the students may have brought with them into the collaboration with the prompt, "what assumptions or perceptions did you have about your counterparts prior to the experience?" Two themes emerged from the student responses: 1) No Assumptions and 2) Unhelpfulness (Table 4)

Table 4: Summary of Assumption Themes

Prompt: What assumptions or perceptions did you have about your counterparts prior to the experience?	
Assumption Themes	**Description**
No Assumptions	A lack of awareness regarding counterparts prevented any preconceptions.
Unhelpfulness	The differences between the two groups of students would prevent useful collaboration.

The No Assumption theme emerged from the data of both a RISD and a West Point student. The West Point student described his lack of assumptions saying, "Absolutely nothing, I had never heard of RISD before going on that trip." These data indicated that these students brought little pre-conceived notions with them into the collaboration.

The Unhelpfulness theme emerged from three of the West Point students. Two students described a pre-conceived apprehension to working with the RISD students because of the RISD students' lack of military experience. One student thought the RISD students would be, "no help given a military problem," while another thought the RISD students, "would not be capable or willing to use their industrial design background to assist with such a complex military problem." The third West Point student assumed the RISD students to be, "total free spirits," which the authors included in the theme of unhelpfulness. These data all indicated that the West Point cadets assumed that the RISD student may be unhelpful in their design work.

Prior to the collaboration, students from both schools largely expressed ambivalence or skepticism regarding the experience and that results would range from neutral to negative. The student survey responses bore similar results. The faculty appreciated the student honesty and knew they needed to create a human connection early. The students converged on a Monday evening and the faculty had the students spread out around a table where one of the RISD professors led them through an introduction exercise where, through a series of strategic questions, individuals opened up through personal stories. The group exchanged presentations of the work on which the respective classes were focused and then ate dinner together. Several hours later, late into the evening, the faculty essentially had to push the students out. Human connection between the students were made that evening and the faculty believe the combination of a social activity and sharing a meal helped make that happen. Curiosity on both sides piqued. This depth of engagement was surprising result number one for the faculty, and the formal portion of the workshop had yet to begin.

Insights Gained:

Themes regarding the insights gained from the students emerged from the aggregated responses of student to three prompts from the online survey:

1. Describe your experience working with your counterparts at West Point/RISD.
2. What was most unexpected about your experience working with your RISD/West Point counterparts?
3. What expertise/value did your counterparts bring to the collaboration?

Four themes emerged from these response data: 1) Design Perspective, 2) Fresh Perspective, and 3) Eye-Opening (Table 5).

The Design Perspective theme emerged from both RISD and West Point student data and was the most pervasive insight theme as shown by the multiple sub-themes involved. This theme describes the changed perspectives by both RISD and West Point cadets regarding the design process. One West Point cadet expressed how the RISD students and faculty taught him that design is a highly iterative process, while a second cadet describe how interesting it was to, "experience a new design methodology." A third cadet expressed a desire to be less rigid in his design approach stating, "I should be less rigid in my design approach. Start with some abstract idea and then develop and refine it." He further described that RISD students brought, "the creative design approach to the collaboration." The RISD student also saw a difference in design thinking, stating, "the design process is vastly different thinking than engineering or how the Army thinks through." These data all indicated that the experience gave both sets of students new insights into how their counterparts approach design work differently.

The Fresh Perspective theme emerged from West Point cadets' data. This theme describes how the West Point cadets valued the fresh perspectives of their RISD counterparts regarding the design challenge they were faced with. One cadet expressed how it was good to have an outside opinion of the problem they were faced with and how the "fresh perspective" was the value RISD students brought to the experience. He further described how the need to describe the design problem to the RISD students helped the West Point team further understand the problem they faced. Another West Point cadet described how he learned the value of getting both civilian

and military perspectives on the same problem. A third cadet described the value of the experience to assist with brainstorming ideas. These data all indicated that the West Point cadets gained value from the interaction with the RISD students who were "outside" the problem.

Table 5: Summary of Insight Themes

Prompts: 1. Describe your experience working with your counterparts at West Point/RISD. 2. What was most unexpected about your experience working with your RISD/West Point counterparts? 3. What expertise/value did your counterparts bring to the collaboration?	
Insight Themes	**Description**
Design Perspectives	Students gained a better understanding of the design process by witnessing other ways of, "doing design" **Sub-Themes:** • Design Thinking • New Design Methodology • Ways of Thinking • Creative Design • Less Rigidity
Fresh Perspective	West Point cadets expressed value in getting a fresh perspective on their design problem **Sub-Themes:** • Outside Opinion • Idea Generation • Fresh Eyes • Multiple Perspectives • Problem Understanding
Eye-Opening	Students expressed a change of perspective because of interacting with their counterparts.

The Eye-Opening theme emerged from both West Point and RISD student data. The RISD student and one of the West Point cadets described the experience as "eye opening". In both instances these comments were qualified. The RISD student expressed how she learned more about military missions and reconnaissance. The West Point cadet followed his description with his comment about the goodness of an outside opinion, which was mentioned in the Fresh Perspective theme above. Because other descriptions were pre-ceded by the eye-opening comments, these data provided indications that the students were undergoing a change in perspective as a part of the collaboration experience.

These insights gained constituted surprise finding number two for the faculty. Both student sides realized their assumptions about the usefulness of the workshop were mostly wrong. Not only was it not useless, it was positively valuable for both sides. The West Point cadets had been engaging the DARPA problem for two months. They were more familiar with the problem, but they were also stuck in some specific ways of viewing the problem. Interaction with RISD gave them a variety of fresh perspectives. Both groups of students realized that they both applied something they called a "design process," but the culture built around their design processes

were markedly different. The West Point cadets tended to work in a more structured, less-messy manner, consistent with the themes of the ME404 course. Conversely, the RISD students tended to operate in a messier, less-structured, but more empathic way. Simply noticing those differences were insightful for each group, but more than that, they realized that there is more than one way to move through a design process and that many ways could yield valuable results. Cultures of design may be different but need not necessarily be better or worse.

The faculty entered into the engagement with a firm conviction that "outside" perspectives would be valuable for all involved. As mentioned before, from the student perspective, this was suspect at best early in the process. Given the shift in student perspective after the interaction, it occurred to the faculty that students may value an outside perspective but sometimes simply do not realize the relevance of a particular outside perspective. In other words, the "worlds" of industrial design students and future Army officers are perceived to be so far apart that it simply does not occur to them that interaction and collaboration could be mutually beneficial. The students experienced the opposite.

The authors believe that faculty should look for additional ways to create these sorts of cross-cultural interactions. Faculty may need to help facilitate the connections between disciplines that seem otherwise unrelated. Students need to become convinced that outside (sometimes way outside) perspectives are valuable and will add substantively to their eventual solutions. This is not intended to imply that having disparate groups collide will always yield positive results. It may not. But the potential for gaining perspective through interaction with those who think differently, approach problems differently, and so forth is strong. Recent quantitative results from Lattuca et al. [18] corroborate these assertions, indicating that faculty emphasis on multi-disciplinary approaches to problem solving relate positively to student self-reported interdisciplinary abilities. In this particular instance, the RISD students gained some valuable insights into the complexities and ambiguities of warfare. The West Point cadets became more comfortable with the messiness of design and the need to hold onto ideas lightly, allowing new ideas to emerge throughout the collaborative design process.

Conclusions

This study provides a qualitative examination of a particular multi-disciplinary design experience that provided positive benefit to students across both engineering and industrial design backgrounds. Although the faculty perceived student benefit from the collaboration of industrial design and engineering design students, the cultural differences between West Point and RISD were many. Although students approached the collaboration with ambivalence and skepticism, the students had an extremely rich and rewarding experience that could not have been possible within their single institutions. The experience helped inform the students' follow-on coursework and gave each fresh perspective that they otherwise would not have gained. The authors are actively seeking future collaboration opportunities that would allow for continued intersection of the institutions, but acknowledge that there must be a sufficiently interdisciplinary design problem that would allow for mutual benefit. The authors encourage other engineering and design faculty to seek unlikely collaboration opportunities to provide students with an appreciation for the benefit other disciplinary cultures may bring to solving the complex problems society will face today and in the future.

References

[1] N. J. Nersessian and W. C. Newstetter, "Interdisciplinarity in Engineering Research and Learning," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. New York: Cambridge University Press, 2014, pp. 713–730.

[2] S. McChrystal, T. Collins, D. Silverman, and C. Fussell, *Team of Teams: New Rules of Engagement for a Complex World*. New York: Penguin, 2015.

[3] R. Stevens, A. Johri, and K. O'Connor, "Professional Engineering Work," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. New York: Cambridge, 2014, pp. 119–137.

[4] D. H. Jonassen, "Engineers as Problem Solvers," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. New York: Cambridge, 2014, pp. 103–118.

[5] ABET, "2016-2017 Criteria for Accrediting Engineering Programs," ABET, Baltimore, 2017.

[6] LTC Philip Root, "Squad X Core Technologies (SXCT)." [Online]. Available: https://www.darpa.mil/program/squad-x-core-technologies. [Accessed: 01-Feb-2018].

[7] T. Brown, *Change By Design*. New York: Harper Collins, 2009.

[8] R. Martin, *The Design of Business*. Cambridge: Harvard Business Review Press, 2009.

[9] T. Liedtka, Jeanne; Olgivie, *Designing for Growth*. New York: Columbia University Press, 2011.

[10] C. L. Dym and P. Little, *Engineering Design: A Project Based Introduction*, 2nd. New York: Wiley, 2003.

[11] United States Army, *Army Doctrinal Reference Publication (ADRP) 5-0: The Operations Process*. Washington, DC, 2012.

[12] K. Dorst, *Notes on Design: How Creative Practice Works*. The Netherlands: BIS Publishers, 2017.

[13] N. Cross, "The nature and nurture of design ability," *Des. Stud.*, vol. 11, no. 3, pp. 127–140, 1990.

[14] E. Godfrey, "Understanding Disciplinary Cultures," in *Cambridge Handbook of Engineering Education*, B. M. Johri, Aditya; Olds, Ed. New York: Cambridge University Press, 2014, pp. 437–456.

[15] NQUARE, "NSQUARE: About Us." [Online]. Available: http://www.nsquarecollaborative.org/. [Accessed: 01-Feb-2018].

[16] A. Strauss, J. Corbin, and A. Strauss, *Basics of Qualitative Research*, 2nd. Thousand Oaks: Sage, 1998.

[17] S. B. Merriam, "What can you tell from an N of 1: Issues of Validity and Reliability in Qualitative Research," *PAACE J. Life Long Learn.*, vol. 4, pp. 51–60, 1995.

[18] L. R. Lattuca, H. K. Ro, D. B. Knight, and B. N. Novoselich, "Promoting Interdisciplinarity: Identifying student experiences and faculty beliefs that support the development of engineers' interdisciplinary competence," *J. Eng. Educ.*, vol. 106, no. 1, pp. 71–97, 2017.