Work in Progress: Structured Teamwork for Learning Equity in First-Year Engineering Design

Dr. Emma Tevaarwerk DeCosta, Northwestern University

Dr. Tevaarwerk DeCosta works as a dedicated first year adviser at the McCormick School of Engineering, where she advises incoming first year students and teaches courses in freshmen design and materials science.

Kathleen Carmichael PhD, Northwestern University
Dr. Lisa M. Davidson, Northwestern University

Senior Assessment Associate, Searle Center for Advancing Learning and Teaching

Dr. Ordel Brown, Northwestern University

Dr. Ordel Brown is an instructional professor in the McCormick School of Engineering and Applied Science at Northwestern University, where she currently teaches first-year engineering design courses. Her research interests in engineering education include the identification of variables that impact the first-year experience and the development of strategies to enhance it, retention of underrepresented populations in STEM fields and service-learning in engineering.

Elise Gruneisen, Northwestern University

Work in Progress: Structured Teamwork for Learning Equity in First-Year Engineering Design

Introduction

Engineering programs have long struggled to create inclusive and equitable learning environments, and many engineering administrators remain skeptical about the benefits of such initiatives [1]. Thus, most of such work has been spearheaded by administrative groups such as departments of Diversity and Inclusion and Gender Studies who typically seek to promote equity through changes to broader institutional culture [2-4]. Student classroom experiences, however, remain relatively neglected and thus such efforts rarely inspire STEM faculty buy-in. Consequently, students from historically underrepresented groups, especially students perceived to have lower social capital than their peers, may still face disparities in their classroom experiences, disparities that may include exclusion from high-profile team roles [5-9].

Recent research indicates that first-year, team-based design courses represent a unique opportunity to address such disparities and providing early collaborative learning experiences supports the success of students from underrepresented groups in engineering [10-13]. While lectures and readings may provide teams with basic tools for team and project management, these correlate team success with the creation of a high-quality final design [14]. Such tools may inadvertently cue students to distribute work according to stereotypical social roles in the belief that by having team members "play to their strengths," they are doing what is best for the team [15]. Such task distribution may limit new learning across team members, exclude historically underrepresented students from high profile team tasks (such as design and fabrication) [16], and thus promote the entrenchment of implicit biases. This study leverages a cooperative learning approach [23] to teamwork and learning in a first-year engineering design course at Northwestern University's McCormick School of Engineering in order to provide more equitable access to learning for all students. Implementation of such approaches in first-year contexts is of particular importance, as these classes are formative for how students view teamwork. The study analyzes results from the use of a novel curricular intervention piloted in Design Thinking and Communication 1 (DTC 1) at Northwestern University. Specifically, the intervention required that students on a team rotate through leadership roles in four key areas: primary research, secondary research, training-building-testing, and project management. The team lead for each role completed associated documentation and coached their successor on how to succeed in that role.

Research Context

This research took place in a required first-year design course during Fall 2019 and Winter 2020 quarters at Northwestern University. The course (entitled Design Thinking and Communication I) focuses on user-centered design for individuals with disabilities, and requires students to collaborate with real-world clients and users. Approximately 140 student participants were enrolled among nine control sections (5 in fall, 4 in winter) that retained the standard course design format or nine experimental sections (5 in fall, 4 in winter), which piloted intentional team role rotation as the curricular innovation. The team roles were (i) primary research, (ii) secondary research, (iii) training-building-testing, and (iv) project management and are described

below. Team members submitted a written assignment for each role rotation to underscore that technical communication is a core engineering competency and ensure individual accountability for team members to the instructors.

- **Project Management Lead:** Guides the team in setting priorities, goals, tasks and deadlines for a given timeframe; documents team progress, planning and evolution of design plan
- **Primary Research Lead:** Plans and leads client interview, user observations, user testing; oversees documentation of this research
- **Secondary Research Lead:** Establishes relationships and conducts interviews with subject-matter experts, discovers and extracts standards, ideas, and opportunities from relevant and credible sources; oversees analysis, synthesis, and documentation of these findings
- **Training-Building-Testing Lead:** Establishes relationships with shop staff, lab directors, and key equipment vendors, arranges training on equipment, places materials orders, coordinates team fabrication; oversees documentation of these communications and processes

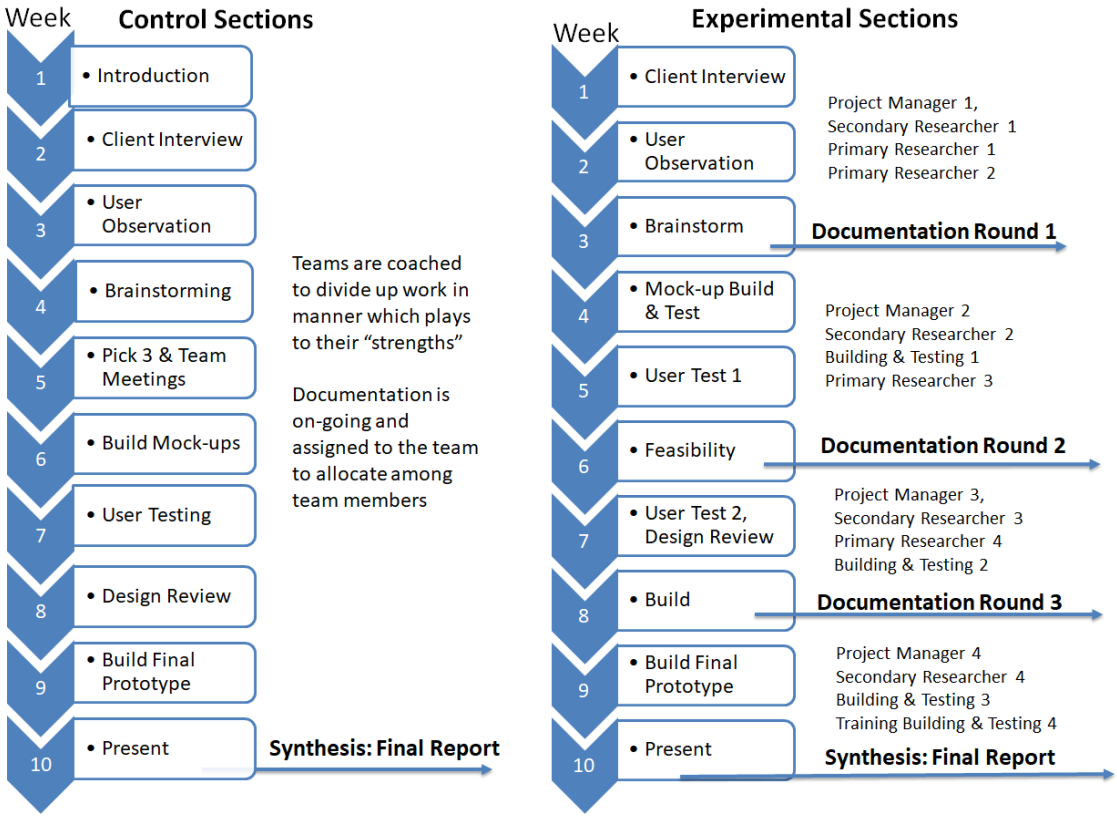

Figure 1: Overall structure of control and experimental sections

Figure 1 highlights key focus and teamwork structures in the course for control and experimental sections. For each role rotation in experimental sections, every student was tasked with planning, executing, and documenting results for one key activity associated with their role.

Research Questions

This study answers five research questions (RQ). Answers to the first two RQ describe critical characteristics related to incoming engineering students. Findings related to RQ1 illuminate students' baseline knowledge, which often mediate students' roles when self-selected. Findings related to RQ2 place students' perceived teamwork abilities in conversation with how easy or difficult they perceive this work. Answers to the final three RQ illuminate whether the curricular innovations relate to observable differences across control and experimental course sections.

RQ1: What are incoming first-year engineering students' design-related knowledge and prior experience?
RQ2: Do entering first-year students' perceptions of their inclusive team-based *abilities* differ from their perceived *comfort levels*?
RQ3: Do students in the control and experimental course sections report different perceptions of inclusive team-based learning outcomes?
RQ4: Do students in the control and experimental course sections report different perceptions of learning related to the course learning objectives?
RQ5: Do students in the control and experimental course sections report different levels of team role execution during the term?

Methods

All students enrolled in the control and experimental sections who were at least 18 years of age at the beginning of the term were invited to participate in this study. Data used were obtained from three online surveys: a personal information questionnaire developed by course instructors, and pre/post-course surveys developed by the authors. For the Fall 2019 quarter, a total of approximately 140 students were invited to complete the surveys (described below). Researchers obtained 119 responses for the personal information questionnaire (Appendix A), 57 responses for the pre-course survey (Appendix B), and 56 responses for the post-course survey (Appendix C). Researchers collected demographic information only on the post-course survey. Those respondents identified as white (30%), Asian (21%), Hispanic/Latinx (4%), Multi-racial (4%), and Black/African American (2%), with a large proportion of students (37%) preferring not to respond or skipping this item. Respondents were also mostly men (68%), not international students (84%), and not first-generation college students (54%), mirroring the student population profile of the 2019 first-year cohort of respondents.

The personal information questionnaire collected information such as students' pre-college experiences related to work involved in the first-year design course and any perceived class-related concerns. It included both scaled- and free-response items that allowed for comparisons of students' self-reported confidence in particular knowledge/skills (scaled-response items) with the actual amount of experience shared through their written responses (free-response items).

The pre-course survey consisted of three sections: 16 items that measured students' perceived abilities relative to inclusive team-based learning, 16 items that measured the perceived ease or difficulty of team-based activities, and eight items that measured students' prior experience and knowledge related to team lead roles. The authors defined inclusive team-based learning as

students' abilities to value diverse perspectives within a group, facilitate contributions from all group members, assess their own and others' contributions to the group, enable a constructive team climate, and promote a constructive conflict response [18]. This concept guided the development of survey questions that measured students' perceived abilities, in alignment with literature on project-based teams in engineering educational contexts [24]. The inclusive team-based learning items used the same response scale as the General Self-efficacy Scale, given the evidence of high reliability and cross-cultural validity [25]. Additionally, the survey asked students to rate how easy or difficult the 16 inclusive team-based learning activities felt, given that team-based activities can involve intercultural exchange. This strategy was informed by the concept of intercultural effort [19], which explains that measuring students' intergroup engagement without also measuring the effort required to engage across such differences is to incorrectly assume these types of tasks are equally easy, welcoming, and educative for all students. Information from this survey served a primarily descriptive purpose, detailing students' baseline perceived abilities and comfort levels in team-based processes.

At the end of the course, students were invited to complete the post-course survey. This survey used a retrospective pre-post assessment method [17] that asked students at the end of the course to simultaneously rate their perceived abilities at the course outset and course conclusion on several dimensions of learning. This survey contained the same 16 pre/post inclusive team-based learning items as the pre-course survey, 14 pre/post items that measured students' perceived abilities related to the course learning objectives, and four pre/post items that measured students' abilities related to the four different team lead roles. The post-course survey also asked students to indicate how much time they wanted to spend in each of the course's team lead roles and how much time they actually spent in these roles during the term. Finally, the survey invited students to complete open-ended items about any obstacles they encountered related to teamwork, design, and communication dimensions of the course.

Data Analyses

This paper presents results from Fall 2019 students only. To answer RQ1, we examined students' personal information form responses. We coded these responses into the categories "no experience," "some experience," "considerable experience" and "a great deal of experience" based on the number of and depth of experiences the students described in their free responses. "Some experience" was coded for 1-2 experiences mentioned; "considerable experience" was coded for 3-4 experiences; and "a great deal of experience" was coded for 5 or more experiences. See Appendix D for examples of responses and coded trends. To answer RQ2, we examined descriptive statistics related to students' perceived abilities as they related to inclusive team-based learning and their perceived comfort with regard to these same items.

To answer RQ3, RQ4, and RQ5, we compared control and experimental groups' item means using a variety of *t* tests (explained in detail below). We used Likert items in our surveys, which raised considerations (i.e., responses are categorical values, limited range of scores) related to employing parametric (e.g., using *t* tests) or non-parametric statistical procedures (e.g., using the rank-based Mann-Whitney-Wilcoxon [MWW]). We analyzed Likert items using *t* tests based on evidence from a rigorous simulation that compared the results of *t* tests and the MWW [26]. Results across the distributions tested suggested that the *t* test and MWW have similar power and

nearly *identical* Type I error rates (i.e., differences between the samples were large enough to be detected at the $\alpha = .05$ level by either method for all sample sizes and combinations of distributions), suggesting that for both *t* tests and the MWW, those analyzing Likert item-level data do not need to worry about observing false positive findings (i.e., erroneously concluding that there are differences between groups) [26].

Proceeding with this evidence, to answer RQ3 and RQ4, we first compared control and experimental groups' item means using independent-samples *t* tests for inclusive team-based learning, team role, and learning objective items. This identified any differences in students' pre-/post-course perceived abilities. We noted any statistically significant ($p < .05$) findings and examined effect sizes for those, highlighting below only the findings with large effect sizes ($d > .8$). We then isolated control and experimental groups to examine within-group pre-/post-item mean differences using paired-samples *t* tests. This identified differences between control and experimental groups relative to pre-/post-course perceived abilities. To answer RQ5, we compared control and experimental groups' item means using independent-samples *t* tests for the items that asked them "During the last quarter, how much *did you want to be* in this team role" and "During the last quarter, how much *were you actually in* this team role" for the design, primary research, secondary research, and project management roles.

Results and Discussion

RQ1: What are incoming first-year engineering students' design-related knowledge and prior experience?

We compared students' self-reported confidence levels related to the four team lead roles to students' relevant narrative responses. A majority of students (65%, $n = 77$) reported having enough or a lot of knowledge of project and team management. Students' narrative responses showed 80% reporting at least some experience in project/team management. The majority of students (65%, $n = 77$) reported having at least enough knowledge of secondary research. Students' narrative responses showed 91% reporting some or a great deal of experience in secondary research. This aligns with instructor experience that students exiting secondary education have typically completed at least one assignment or project that requires secondary research as a major component. Related to primary research, only 19% of students (n=23) reported having enough or a lot of knowledge of primary research, with narrative responses showing 36% reporting some or a great deal of experience in primary research.

In the area of training, building and testing 37% of students (n= 44) students reported at least enough or a lot of knowledge of training, building and testing, and 42% (n=49) reported they didn't know anything or were not sure whether they know enough about it. Coding was developed based on whether students' written responses indicated significant experience with building physical objects only (28%), computer/robotics coding only (28%), both physical objects and programming (20%), or neither (24%). These data show that the vast majority of students entering the design course perceive themselves to have a lot of experience in both project management and secondary research, and minimal experience with primary research. Half of the students have experience building/testing physical objects, and half do not.

RQ2: Do entering first-year students' perceptions of their inclusive team-based abilities differ from their perceived comfort levels?

There were disparities between students' self-perceived abilities to complete team-based tasks and their comfort in engaging in these types of group work. For example, when asked how able they were to respond to any concerns expressed by group project members, just 2% said "hardly true"/"not at all true." Yet, when asked how difficult or easy it was for them to do this task, 14.3% answered "a little difficult"/"very difficult." In a similar vein, when asked about their ability to mediate with group members in conflict, 16.3% said "hardly true"/"not at all true." When asked about how difficult or easy this task was, 30.6% said "a little difficult"/"very difficult." These differences indicate that though very few students *felt unable* to respond to team members' concerns and mediate in conflicts, far more students *felt uncomfortable* doing so. Another noted difference was in students' confidence and self-perceived ability to divide group project work fairly among group members. When responding about ability, 14.3% responded "hardly true"/"not at all true." Yet, when responding to comfort level, 22.4% said "a little difficult"/"very difficult." Though a minority of students felt unable to do this, more felt uncomfortable in working to divide up teamwork fairly. Considered together, these findings suggest that to actualize inclusive team-based learning contexts, more attention might be paid to entering students' *perceived difficulties* with some of these interpersonal demands. Their self-reported abilities are consistently higher than the perceived ease with which they feel able to execute these tasks, which has course design and instructional implications.

RQ3: Do students in the control and experimental course sections report different inclusive team-based learning outcomes?

Statistically significant differences existed between students in control ($n = 26$) and experimental course sections ($n = 30$) related to several inclusive team-based learning measures. First, students in experimental sections reported significantly higher scores *at the end of the course* related to their ability to receive feedback from fellow students ($t(40) = 2.81$, $p = .008$), their course instructors ($t(40) = 3.75$, $p = .001$), and clients ($t(40) = 2.73$, $p = .009$) during the different phases of the design process. While we cannot be certain why, these results suggest an interesting difference between the experimental and control sections relative to their abilities to receive feedback from the course's various stakeholders.

Second, students in control sections reported significantly higher abilities *at the end of the course* related to determining how much others had contributed to the group project ($t(35) = -2.33$, $p = .026$). We did not observe any additional statistically significant differences in perceived abilities at either the course outset or end of the course across the control and experimental sections. In experimental sections, the majority of team tasks were broken down and assigned, whereas in the control sections this was left up to the team. It is possible that students in control sections were more aware of each other's work because task assignments required ongoing negotiation throughout the quarter. Alternatively, control teams who divided tasks throughout the quarter according to teammates' perceived strengths may have felt able to assess teammates' contributions by referencing the perceived quality of the deliverable(s) for which each teammate was primarily responsible.

To gain additional insight, we isolated control and experimental groups to examine within-group pre-/post-item mean differences using paired-samples *t* tests. Several findings emerged. For control sections, we observed statistically non-significant ($p > .05$) pre-/post-changes for five items that showed statistically significant pre-/post-changes within the experimental sections. Specifically, for experimental sections we observed highly significant pre-/post-changes related to (i) encouraging other group members to share ideas about a project ($t(20) = -5.59$, $p < .001$), (ii) talking about ideas for a group project with other group members ($t(20) = -4.96$, $p < .001$), (iii) understanding that a group project allows them to complete more complex work than they could do by themselves ($t(20) = -3.99$, $p = .001$), (iv) discussing with other group members when tension or conflict is present ($t(20) = -4.24$, $p < .001$), and (v) listening respectfully to others' ideas ($t(20) = -2.83$, $p = .01$). These findings suggest that team members in experimental sections may attend more to interpersonal dimensions in team processes. From an inclusion and equity perspective, these findings are particularly encouraging. Ensuring that students rotate roles throughout the term--so that each student executes each team role--could provide a structure that helps students perceive the value of diverse perspectives and interdependence in the design process.

RQ4: Do students in the control and experimental course sections report different perceptions of learning related to the course learning objectives?

A few statistically significant differences were observed between control and experimental courses related to students' perceived learning over the course. Students in experimental sections reported significantly higher perceived abilities *at the end of the course* related to using findings from primary research to inform design requirements ($t(40) = 2.61$, $p = .013$) as well as significantly higher abilities related to using evidence to justify design decisions ($t(38) = 5.78$, $p < .001$) and using evidence to make design-related recommendations to others ($t(38) = 3.09$, $p = .004$). Students in control sections reported a significantly higher ability *at the end of the course* to successfully do the work involved in the project management team role ($t(35) = -2.68$, $p = .011$). On one hand, from an equity standpoint, we expected to see more significant differences across experimental and control sections, assuming systematic access to all the team roles would help ensure access to all the course learning opportunities (and, therefore, higher self-reported scores across many of these items for the experimental sections). We did observe that systematically rotating team roles to ensure all students execute the various work involved appears to relate to students feeling that they are relatively more able to integrate research and other evidence into their design work. On the other hand, these results again suggest that students in the control sections gained more experience dividing up the work.

RQ5: Do students in the control and experimental course sections report different levels of team role execution during the term?

Students were asked about the extent that they wanted to be in each team role and the extent that they were actually in these roles throughout the term. Compared to experimental sections, students in the control group reported spending significantly more time actually in the design role (i.e., problem definition, ideation, building, testing) throughout the term ($t(35) = -2.73$, $p = .01$). This result needs further investigation, since teams in experimental sections were prototyping in the shop by week 3 on average, in comparison to week 4 or 5 in the control

sections, which implies that students in the experimental sections, not control sections, should report more exposure to design. Furthermore, students in experimental sections were coached to iterate more rapidly, leaving less time for problem definition and ideation in favor of more building and testing. It is possible that students in experimental sections were cued differently about how to conceptualize "design" work in relation to building and testing with physical mockups. Interviews with students from different sections may clarify these results.

In addition to rotating roles, load leveling, a second user testing, and extension of the building and testing portion of the quarter were implemented to provide equal and timely access for each student to each of the roles over the course of the quarter. Teams in experimental sections produced progress memos that required teammates to intermittently share and synthesize findings from research. Researchers cannot therefore attribute changes in student learning and team processes in the experimental sections solely to task identification and role rotation.

Conclusions and Next Steps

Early results suggest that the addition of instructor-mediated work breakdown and role rotation in first-year engineering design teams may shift the team's focus from division of tasks to more interpersonal aspects such as offering and receiving feedback, discussing ideas, making decisions, and justifying evidence-based design decisions. This is particularly encouraging given the relationship between collaborative learning and undergraduates' success [10-13]. These findings also align with the competencies required to execute convergence research (i.e., teamwork, collaboration, and leadership) [20] and team science (i.e., collaborative problem solving [21] and team communication [22]), which underlie how contemporary scientific inquiry ought to proceed. In contrast, students on teams coached to identify work and divide tasks on their own according to "strengths" of individual team members showed more growth in areas related to determining how much individual teammates had contributed to the final design. Researchers note that this study used *indirect* measures of students' learning (i.e., survey items that asked students to rate their abilities relative to inclusive team-based and course learning outcomes) rather than *direct* measures (e.g., work produced by students evaluated against criteria that reflect the learning outcomes). While beyond the scope of the present study, examining direct evidence of students' learning and development in this course context would be a useful next step. Our future work also seeks to understand how students identify their own and others' strengths and their conceptions of the design process. Individual student interviews along with analysis of student free responses around design and project management will be used to further investigate these questions. In the present study, researchers hoped for a higher survey response rate to allow for group comparisons across various identities (i.e., race, ethnicity, gender, first-generation status, national origin). Informed by the context surrounding our inquiry, this would have allowed us to observe any differences in pre-college knowledge and experience, learning outcome achievement, and role rotations. Going forward, researchers hope to increase the survey response rates to more closely examine the role of minoritized identities in students' experiences across control and experimental sections.

References

[1] J. Peters, "Designing Inclusion into engineering education: A fresh, practical look at how diversity impacts on engineering and strategies for change," Royal Academy of Engineering, London, UK. July 2018.

[2] C. Leicht-scholten, A. Weheliye, and A. Wolffram, "Institutionalization of gender and diversity management in engineering education," *European Journal of Engineering Education,* vol. 34, no. 5, pp. 447-454, Sep. 2009. [Online.] Available: https://doi.org/10.1080/03043790903137700. [Accessed June 9, 2019].

[3] J. E. Mills, M. E. Ayre, and J. Gill, *Gender Inclusive Engineering Education*. New York: Routledge, 2010. [E-book] Available: Taylor & Francis e-Library.

[4] D. Riley, A. E. Slaton, and A. L. Pawley, "Social justice and inclusion: Women and minorities in engineering," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B.M. Olds, Eds. New York: Cambridge University Press, 2014, pp. 335-356.

[5] C. H. Paguyo et al., *Creating Inclusive Environments in First-Year Engineering Classes to Support Student Retention and Learning*: 12401. American Society of Engineering Education (ASEE) Annual Conference and Exposition, June 14-17, 2015, Seattle, WA. American Society for Engineering Education, 2015.

[6] X. Y. Du, "Gendered practices of constructing an engineering identity in a problem-based learning environment," *European Journal of Engineering Education*, vol. 31, no. 1, pp. 35-42, Mar. 2006.

[7] J. E. Bennett and D. Sekaquaptewa, "Setting an egalitarian social norm in the classroom: Improving attitudes toward diversity among male engineering students," *Social Psychology Education*, vol. 17, pp. 343-355, Mar. 2014.

[8] T. S. Isaac et al., "Reviewing engineering curricula to meet industrial and societal needs," in *2014 IEEE International Conference on Interactive Collaborative Learning (ICL), Dubai, UAE, December 3-6, 2014*. IEEE, pp. 55-99.

[9] J. Bass et. al., *Advancing Diversity and Inclusion in Higher Education*. November 2016. Available: U.S. Department of Education, https://www2.ed.gov/rschstat/research/pubs/advancing-diversity-inclusion.pdf. [Accessed June 9, 2019].

[10] K. Reid, M. Ross, and N. Yates. "Paving the Way: Engagement Strategies for Improving the Success of Underrepresented Minority Engineering Students," *Institutional Engagement Strategies for Success in Engineering*, vol. 2, pp. 1-50. Mar. 2016.

[11] K. Sheppard, P. Dominick, and Z. Aronzon, *Preparing engineering students for the new business paradigm of international team work and global orientation.* Enhancement of the Global Perspective for Engineering Students by Providing anInternational Experience: Engineering Conferences International, 2003. Available: ECI Digital Archives, http://dc.engconfintl.org/enhancement/27. [Accessed June 9, 2019].

[12] R. Lent et al., *Relation of collective efficacy beliefs to group cohesion and performance in student project teams*: 1353, ASEE Annual Conference and Exposition, June 20-23, 2004, Lake City, Utah. American Society for Engineering Education, 2004.

[13] M. F. Ercan and R. Khan, "Teamwork as a fundamental skill for engineering graduates," in *2017 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Hong Kong, China, December 12-14, 2017*. IEEE, pp. 24-28.

[14] M. Albert, P. Balve and K. Spang, "Evaluation of project success: a structured literature review," *International Journal of Managing Projects in Business,* vol. 10, *(4),* pp. 796-821, 2017.
[15] C. Yarnoff et al., *Design Thinking and Communication*, Evanston, IL, USA: Northwestern University, 2015, ch. 12, pp. 141–144.
[16] M. Keogh, M. S. Zarske, and J. Y. Tsai, *Active Learning Group Work: Helpful or Harmful for Women in Engineering?*: 21888, ASEE Annual Conference & Exposition, June 25-27, 2018, Salt Lake City, Utah. American Society for Engineering Education, 2018.
[17] F. Bhanji et al., "The retrospective pre–post: A practical method to evaluate learning from an educational program," *Academic Emergency Medicine,* vol. 19, pp. 189-194, Feb. 2012.
[18] "Teamwork VALUE Rubric." Association of American Colleges & Universities (AAC&U). Available: https://www.aacu.org/value/rubrics/teamwork.
[19] G. Tanaka. "Higher education's self-reflexive turn: Toward an intercultural theory of student development." *Journal of Higher Education*, vol. 73, no. 2, p. 263+, 2002.
[20] S.R. Springer, "Learning in a world of convergence," in *Handbook of science and technology convergence*, W.S. Bainbridge and M.C. Roco Eds., New York, NY: Springer International, 2016, pp. 1059-1072
[21] A.C. Graesser et al., "Advancing the science of collaborative problem solving," *Psychological Science in the Public Interest*, vol. 19, no. 2, pp. 59-92. 2018.
[22] J. T. Klein, S. Misra, and G. R. Lotrecchiano, "Introduction: Communication in inter- and trans-disciplinary teams," in *Communication in transdisciplinary teams*, G. R. Lotrecchiano and S. Misra, Eds. Santa Rosa, CA: Informing Science Press, 2020, pp. 13–20.
[23] D. W. Johnson, R. T. Johnson, and K. A. Smith, "Cooperative Learning: Improving University Instruction by Basing Practice on Validated Theory," *Journal on Excellence in College Teaching*, vol. 25, no. 3–4, pp. 85-118, 2014.
[24] S. P. Schaffer *et al*, "Self-Efficacy for Cross-Disciplinary Learning in Project-Based Teams," *Journal Of Engineering Education,* vol. 101, no. 1*,* pp. 82-94, 2012.
[25] A. Luszczynska, U. Scholz and R. Schwarzer, "The General Self-Efficacy Scale: Multicultural Validation Studies," *The Journal of Psychology,* vol. 139, no. 5*,* pp. 439-57, 2005.
[26] J.C.F. de Winter and D. Dodou, "Five-Point Likert Items: t test versus Mann-Whitney-Wilcoxon," *Practical Assessment, Research & Evaluation*, vol. 15, no. 1, pp. 1-16, 2010.

Appendix A: Course Previous Experience Form

Each year, instructors survey students at the start of the quarter to learn more about their experiences. Please complete this brief survey, which should take about 10 minutes.

Thank you for participating in this survey. We value your feedback!

To begin, your course instructors would like to learn about some of your experiences before college. The information you share will only be used by your instructors to understand students' past experiences so that they can structure the class to respond to your experiences and interests. Please answer honestly and know that the information you share will not impact your standing in this course.

Describe your work experience. What jobs have you held and what responsibilities did you have? Include unpaid job-like experiences: charity or volunteer work, extracurricular activities etc.
[Text box/open-ended response]

Describe any previous experiences and how much you currently know about the following. Examples could be from school, work, or other experiences.

	Any Previous Experience (*Write in any experience or select "I do not yet have experience with this"*)	**How Much I Know Right Now**				
		I know a lot about this	I know enough about this, however I want to know more about it	I'm not sure whether I know enough about this	I do not know enough about this to fully understand it	I do not know anything about this
Managing a team of my peers as we work on a group project	_____[open-ended] not yet have experience with this.					
Gathering information for a research project by interviewing or observing people	_____[open-ended] not yet have experience with this.					
Gathering information for a research project by finding and selecting material from written sources	_____[open-ended] not yet have experience with this.					
Building something in order to solve a problem or perform a function (this can include working with tools and physical	_____[open-ended] not yet have experience with this.					

materials and/or building a virtual object, as in programming)						

If you have experience with any of the activities listed above, please specify what part of each activity you found easiest or most difficult. If you do not have experience, please answer N/A.

[Text box short answer/fill in the blank]

Managing a team of my peers

- The easiest part was…
- The most difficult part was…

Gathering information by interviewing or observing people

- The easiest part was…
- The most difficult part was…

Gathering information by finding and selecting material from written sources

- The easiest part was…
- The most difficult part was…

Building something in order to solve a problem

- The easiest part was…
- The most difficult part was…

Finally, your course instructors want to understand how their students are feeling about starting this course to inform how they teach the course.

What are you most concerned about for this course?
[Open-ended]

What are you most excited about for this course?
[Open-ended]

Please tell us anything else you'd like us to know about yourself.
[Open-ended]

Do you live closer to North or South Campus?
Response options:

- North Campus
- South Campus

Thank you for completing this survey.

Appendix B: Research Pre-Course Survey

To begin, we would like to learn about some of your experiences before college. Your responses to the survey items below will not be viewed by your instructors, and data analyses will be performed by researchers from the Northwestern University's Center for Advancing Learning and Teaching. Please answer honestly and know that the information you share will not impact your standing in this course.

First, we would like to know what you think about working with others on group projects. For each statement below, indicate how true it is for you right now.

	Exactly true	Moderately true	Hardly true	Not at all true
I feel able to participate in a group project where the ideas of different group members are incorporated into a project.				
I feel able to encourage other group members to share their ideas about a group project.				
I feel able to talk about my ideas for a group project with other group members.				
I feel that at least some of my ideas have been incorporated into past group projects.				
I feel able to respond to any concerns expressed by group project members.				
	Exactly true	Moderately true	Hardly true	Not at all true
I can take full responsibility for the tasks assigned to me as part of a group project.				
I can determine how much I have contributed to a group project.				
I feel able to identify ways to divide group project work fairly among group members.				
I can break down the tasks, people, and timelines required to complete a group project.				
I feel able to discuss with other group members when tension or conflict is present				
Group projects allow students to complete more complex work than they could do by themselves.				
	Exactly true	Moderately true	Hardly true	Not at all true
I can determine how much others have contributed toward a group project.				
I can receive feedback about my ideas from others.				
I can incorporate others' feedback into my work.				
I feel able to share feedback with others about their work.				
I can listen respectfully to others' ideas.				

Now, we would like to know how easy or difficult it usually is for you to do the following activities that are often part of group projects. For each statement below, indicate how difficult or easy it is for you right now to do the following.

	Very easy	Moderately easy	A little difficult	Very difficult
Participate in a group project where the ideas of different group members are incorporated into a project				
Encourage other group members to share their ideas about a group project				
Talk about my ideas for a group project with other group members				
Feel that at least some of my ideas have been incorporated into past group projects				
Respond to any concerns expressed by group project members				
	Very easy	Moderately easy	A little difficult	Very difficult
Take full responsibility for the tasks assigned to me as part of a group project				
Determine how much I have contributed to a group project				
Understand that a group project allows me to complete more complex work than I could do by myself				
Identify ways to divide group project work fairly among group members				
Break down the tasks, people, and timelines required to complete a group project				
Discuss with other group members when tension or conflict is present				
	Very easy	Moderately easy	A little difficult	Very difficult
Determine how much others have contributed toward a group project				
Receive feedback about my ideas from others				
Incorporate others' feedback into my work				
Share feedback with others about their work				
Listen respectfully to others' ideas				

Thank you for your responses.

Appendix C: Research Post-Course Survey

First, we would like to know how you understand the following aspects related to the design process before and after the course you just completed. Your individual responses will not be viewed by your instructors, only by researchers in the Northwestern University's Center for Advancing Learning and Teaching.

For each statement below, indicate how true the following were before *and* after completing this DTC course.

	At the start of **this course, I could:**				***After*** **completing this course, I can:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true
Conduct research on user needs								
Explain the user needs that my design attempts to improve								
Determine the requirements of a design project								
Use findings from *primary* research (interviews, site visits, focus groups, surveys) to inform design requirements								
	At the start of **this course, I could:**				***After*** **completing this course, I can:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true
Use findings from *secondary* research (reports and studies that are already published) to inform design requirements								
Receive feedback *from students* during different phases of the design process								
Receive feedback *from my course instructors* during different phases of the design process								
Receive feedback *from clients* during different phases of the design process								

Please tell us about any obstacles you encountered related to learning about the design process in this course.
[Open-ended]

Next, this course also focused on communicating with different audiences. We would like to know how you understand the following before and after this course.

For each statement below, indicate how true the following were before *and* after completing this DTC course.

	***At the start of* this course, I could:**				***After* completing this course, I can:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true
Choose the most effective ways to communicate my ideas *to other students*								
Choose the most effective ways to communicate my ideas *to my instructors*								
Choose the most effective ways to communicate my ideas *to clients*								
Sketch my ideas to graphically communicate them to a specific audience								
Use evidence to justify my design decisions								
Use evidence to make design-related recommendations to others								

Please tell us about any obstacles you encountered related to learning about different ways of communicating in this course.
[Open-ended]

This course also involved working in teams. We would like to know how you understand the following before and after this course.

For each statement below, indicate how true the following were before *and* after completing this DTC course.

	***At the start of* this course, I could:**				***After* completing this course, I can:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true
Participate in a group project where the ideas of different group members are incorporated into a project								
Encourage other group members to share their ideas about a group project								
Talk about my ideas for a group project with other group members								
Feel that at least some of my ideas were incorporated into a group project								
Respond to any concerns expressed by group project members								
	***At the start of* this course, I could:**				***After* completing this course, I can:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true

Determine how much I have contributed to a group project								
Take full responsibility for the tasks assigned to me as part of a group project								
Understand that a group project allows me to complete more complex work than I could do by myself								
Break down the tasks, people, and timelines required to complete a group project								
Identify ways to divide group project work fairly among group members								
Discuss with other group members when tension or conflict is present								
	At the start of **this course, I could:**				***After*** **completing this course, I can:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true
Determine how much others have contributed to a group project								
Receive feedback about my ideas from others								
Incorporate others' feedback into my work								
Share feedback with others about their work								
Listen respectfully to others' ideas								

Please tell us about any obstacles you encountered related to the teamwork part of this course.
[Open-ended]

So that we can better understand how student teams function and improve this experience for other students, we would like to know about some of your team-based experiences in this course.

For each statement below, indicate how true the following were before *and* after completing this DTC course.

	At the start of this course**, I felt I could successfully do the work involved in this role:**				***After completing this course*****, I feel I can successfully do the work involved in this role:**			
	Exactly true	Moderately true	Hardly true	Not at all true	Exactly true	Moderately true	Hardly true	Not at all true
Design (problem definition, ideation, building, testing)								
Primary Research (conducting client interview, user observation, user testing)								
Secondary Research (using written sources, library consult, expert interviews)								

Project Management (guiding team priorities, tasks, deadlines)									

	During the last quarter, how much did you *want to be* in this team role:					**During the last quarter, how much *were you actually* in this team role:**				
	I wanted to *only* be in this role	I wanted to *mostly* be in this role	I wanted to be in this role *some of the time*	I wanted to spend *very little time* in this role	I wanted to spend *no time* in this role	I was *only* in this role	I was *mostly* in this role	I was in this role *some of the time*	I spent *very little time* in this role	I spent *no time* in this role
Design (problem definition, ideation, building, testing)										
Primary Research (conducting client interview, user observation, user testing)										
Secondary Research (using written sources, library consult, expert interviews)										
Project Management (guiding team priorities, tasks, deadlines)										

	How important do you think each of the following roles is in executing a successful design project?				
	Absolutely essential	Very important	Somewhat important	A little important	Not important at all
Design (problem definition, ideation, building, testing)					
Primary Research (conducting client interview, user observation, user testing)					
Secondary Research (using written sources, library consult, expert interviews)					
Project Management (guiding team priorities, tasks, deadlines)					

	How often did your team do the following?			
	Quite a bit	Some-times	Rarely	Not at all
Provide honest feedback to each other				
Share information with each other (examples include research and other resources related to the project)				
Create opportunities for each team member to participate in design activities (examples include problem definition, ideation, building, testing)				
Create opportunities for each team member to participate in research tasks				
Create opportunities for each team member to participate in report writing				

Use project management tools (examples include RAM charts and Gantt charts)				

Finally, please tell us a bit about yourself by answering the following questions. If you prefer not to answer something, you may select that response. The responses you share here will be kept confidential and will not be linked to any other identifying information.

What is your race and/or ethnicity? (*select <u>all</u> that apply*)

- American Indian or Alaska Native
- Asian
- Black or African American
- Hispanic or Latinx
- Native Hawaiian or Other Pacific Islander
- White
- Another option not listed (*please specify*):_____
- I prefer not to answer

What is your gender? (*select one response)*

- Man
- Woman
- Non-binary/Third gender
- Transgender
- Another option not listed (*please specify*): _____
- I prefer not to answer

Are you an international student at Northwestern University? (*an international student is someone who is enrolled at Northwestern University on a temporary visa; they are not an immigrant, refugee, or undocumented individual)*

- No
- Yes
- I prefer not to answer

Select <u>any</u> of the statements below that are true for you. *(select all that apply)*

- Neither of my parents completed a baccalaureate degree.
- I regularly resided with and received support from only one parent, and my supporting parent did not complete a baccalaureate degree.
- Before college, I did not regularly reside with or receive support from a natural or adoptive parent.
- My parent(s) and/or guardian(s) attended college but do not have a bachelor's degree (did not graduate).
- None of these statements are true for me.
- I prefer not to answer.

On average, how many hours per week did you spend on the following activities during the fall quarter?

	I spent no time doing this	More than 0 but less than 10 hours/week	More than 10 but less than 20 hours/week	More than 20 hours/week
Attending other classes				
Studying for classes/doing homework				
On-campus work				
Off-campus work				
Other *(please specify)*:				

What do you feel was your greatest contribution to your team's work and final deliverables?
[Open-ended]

The research team plans to invite some first-year students to take part in individual 45-minute interviews to learn more about their experiences working in teams during the class. This interview would take place during the winter quarter. **Are you interested in being contacted by the research team to take part in an interview?**

- No
- Yes

*[**If Yes**, ask for their preferred contact information (phone/email). Instructions will explain that students' contact information will not be included with their other survey responses and will only be used to invite them to the winter quarter interviews.]*

Appendix D: Explanation of the coding process for previous experience survey narrative

The anonymous narrative responses provided below are selected out of the aggregate of answers for students' self-reported amount of experience; the full set of narrative responses received are *not* included in this appendix. Total counts of coded interpretations of narrative responses are provided following the tables of sample responses. Additionally, the total counts are provided for responses to the follow-up question regarding the student's self-perceived amount of knowledge, which was structured as a forced-choice question.

Skill category: Managing a team of my peers as we work on a group project (project management)

Free response question: *Your instructors would like to understand any experiences with the following and how much you know about them. (Write any experience as well as what part of each activity you found easiest or most difficult, or write "I do not yet have experience with this.")*

Responses were coded over five categories.

- *When responses were "I do not have experience in this" → no experience*
- *Passive observation of really only listed one experience → a little experience*
- *One to two actual doing it themselves experiences→ some experience*
- *Three to four separate contexts or anything above and beyond standard high school projects w/ some reflection or insight into process and what they learned→ considerable experience*
- *Five or more separate contexts and something above and beyond standard high school projects with significant reflection/insight into process and what they learned → a great deal of experience*

Sample responses	How they were coded
I was part of a one-semester engineering class in high school which required one person in a small group to assume the role of leader and to delegate tasks to the other members of the group. The role was randomly assigned so I was not chosen as the manager, but I was able to observe how the manager went about doing his job.	a little experience
My only experience with this would be two major projects that I had to complete at the end of my math classes in high school. I found that the easiest part of managing a team of peers was delegating different tasks to each person. However, I felt that the most difficult part was ensuring that each person was pulling their weight when it came to their assigned tasks	some experience
I was part of a team that organized several community service events in my community through a class at school my senior year. The hardest part was making sure each person/groups parts all fit together smoothly. The easiest part was being to listen to everyone's ideas and see what parts work well together.	considerable experience
I have participated in several small group projects throughout high school but notably I took part in a service learning project for my health occupations course which spanned over a semester. For this project we were supposed to choose an organization we	a great deal of experience

wanted to contribute to and had an ultimate goal of raising $500, volunteering, and raising awareness/advertising for the organization. Going into the project (where the members were assigned by the teacher) I was surprised to find that I needed to take on a leadership role within the group because of others' lack of initiative. Throughout the months working on this project I learned new skills and areas to improve in order to be an effective leader, such as using clear communication as well as maintaining an organized and well delegated agenda. Many things I learned were as a result of looking back after the completion of the project and realizing which things went wrong and how I could have contributed in order to resolve certain conflicts. As a generally quiet/non-assertive person the most difficult thing I experienced throughout the project was trying to effectively communicate with my sometimes unresponsive group members.	

Skill category: Gathering information for a research project by interviewing or observing people (primary research)

Free response question: *Your instructors would like to understand any experiences with the following and how much you know about them. (Write any experience as well as what part of each activity you found easiest or most difficult, or write "I do not yet have experience with this.")*

There was less spread in the responses, less variability in the amount of experience that people had; therefore coding was applied only over three categories

- *When responses were "I do not have experience in this" → no experience*
- *One to three experiences, mix of passive and active involvement → some experience*
- *Four or more separate experiences and something above and beyond standard high school projects with significant reflection/insight into process and what they learned → a great deal of experience*

Sample responses	**How they were coded**
I had a project in marine biology where, in groups, we picked any real world problem and had to try and find a solution and implement that solution, which for me involved contacting many people to gather information on the topic of plastic packaging in shipping boxes, which we had to sort through to come up with a solution for it.	some experience
In my sophomore year of high school my history class participated in a competition called National History Day. It involved an extensive multimedia research project, and one of the things my partner and I did was interview women who were knowledgeable on our topic: Equal Pay in America. What was difficult about this project was the sheer volume of information we had with such a short amount of time to work with. We had to sift through our findings and decide what was important, what we should delve deeper into, and what wasn't worth it.	a great deal of experience

Skill category: Gathering information for a research project by finding and selecting material from written sources (secondary research)

Free response question: *Your instructors would like to understand any experiences with the following and how much you know about them. (Write any experience as well as what part of*

each activity you found easiest or most difficult, or write "I do not yet have experience with this.")

There was less spread in the responses, less variability in the amount of experience that people had; therefore coding was applied only over 3 categories

- *When responses were "I do not have experience in this" → no experience*
- *One to three experiences, mix of passive and active involvement → some experience*
- *Four or more separate experiences and something above and beyond standard high school projects with significant reflection/insight into process and what they learned → a great deal of experience*

Sample responses	**How they were coded**
Through the AP capstone seminar class, we were required to do extensive independent research. This is also true for research projects in English and history classes as well. In each of these cases, we were held to a high standard in selecting sources.	some experience
I have had ample experience with gathering information from written sources to write research papers. Being a part of an IB program I had to write a small research paper (approximately 2000 words) known as an internal assessment for every one of my classes. I also had to write a longer research paper (4000+ words) in which written sources were my primary means of gathering information.	a great deal of experience

Skill category: Building something in order to solve a problem or perform a function; this can include working with tools and physical materials and/or building a virtual object, as in programming (training, building, & testing).

Free response question: *Your instructors would like to understand any experiences with the following and how much you know about them. (Write any experience as well as what part of each activity you found easiest or most difficult, or write "I do not yet have experience with this.")*

- *When responses were "I do not have experience in this" → no experience*
- *Responses included only computer science/programming experiences → programming*
- *Responses included only work with physical objects/building → physical objects*
- *Responses included work that either involved physical objects and programming (i.e. robotics club) or multiple experiences that fit one category or the other → programming and physical objects*

For experience in training-building-testing, responses were coded for whether students had experience in "building physical objects," "computer coding," "both," or "neither/no experience." In addition, students' self-reported confidence was gathered for each role using scaled response questions, ranging from "I do not know anything about this", "I'm not sure whether I know enough about this," "I do not know enough about this to fully understand it," "I know enough about this however I want to know more about this," and "I know a lot about this."

For the design course itself, experience building and testing physical objects is most relevant preparation; only 47% of students' narrative analysis indicated preparation in this area. For the training/building and testing category in particular, student access to such experiences may be dependent upon the strength and resources of their high schools' STEM program.

Sample responses	**How they were coded**
I participated in an academic competition called TEAMS that had a build portion, in which we were required to build something out of limited materials, such as an air filter that would trap the most glitter when blown through out of materials such as cardboard and tape.	physical objects
I've written a computer program once for a math project, and I found that it was easiest to outline my code and write the basic tasks for the program, but that it was hardest to write the small things needed to give the program better UI or more specific functionality.	programming
I have minor experience with physical building -- I took a design engineering class in high school, and used PTC Pro Desktop, but I don't think I took away anything from it. The class was dominated by guys who already knew how to build things, so I didn't have the chance to learn much from my groups. I did a woodshop class, too, in junior high... but I don't feel confident at all about building. I've done several programming projects, however (CS major), and a bit of modeling. I feel more confident about that aspect of the question.	programming and physical objects