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Development of Perceptions of Technical and Ethical Expertise In Teams Over Time

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Abstract

This study considers a social network analysis conducted with design teams in an engineering education program at a major Midwestern university. We conducted a longitudinal social network analysis with two classes, which each contained 2-5 project teams, to explore changes in the way technical and ethical expertise are described and manifest in network structures across three consecutive semesters. Specifically, we examine how network structure and positions shift over time as different individuals become more or less central to the technical and ethical networks. This study extends previous work[1] by adding a third semester of data, which enabled us to identify trends and patterns in the social network responses over time. This study contributes to understanding teams and teamwork in engineering design courses, but places the focus on students' perceptions about their teams. Additionally, by comparing technical to ethical elements, we contribute to extant literature considering the perceived distinctions between engineering's professional skills and more technical abilities.

Keywords—Multidisciplinary teams; communication; design; engineering ethics; social network analysis

Introduction

The "social" and "technical" aspects of engineering design have been the subject of extensive research. Scholarship increasingly focuses on the need to integrate the two together in our understanding of design and engineering more generally, rather than reifying the "socio-technical divide."[2,3] In part, this requires increasing the recognition that these two aspects of design work are often in competition, but they are both important in shaping the everyday work of design. Indeed, a more thorough investigation into the team processes that comprise design work could help to illuminate the interaction between these two priorities, while also satisfying the call by Borrego et al. (2013)4 to better incorporate literature on team effectiveness and functioning from other literature. While sharing knowledge and having specialized skills are important for engineering projects, we envision expertise for this paper as a socially constructed and fluid concept that may change depending on the members of a team.[5] Thus, expertise is not viewed in a traditional sense as limited to senior engineers or even highly skilled novice engineers. Rather, expertise is viewed as a team-level resource, or a communicative achievement as members of a team evaluate one another and choose to incorporate or marginalize diverse skills, knowledge, and perceptions of their team members. From this view, we do not seek to examine expertise as a trait or as an earned label, but instead as a resource that is socially constructed by team members and incorporated into the everyday work of designing. This enables us to examine perceptions of expertise in a student design team, in which there are few if any true "experts" as they are traditionally conceptualized. The manifestation and incorporation of expertise is dependent upon the communication and perceptions of the team's members,[5] as well as the external factors such as design problem and setting. Thus, a better understanding of how students understand, identify, and incorporate different kinds of expertise into their design projects is needed. We present an evolutionary social network approach[6,7] to explore the reflexive relationship between team network structures and the communicative relations that emerge in design teams, probing the way technical and ethical expertise manifest and develop over time in student design teams.

Literature

Social and technical values in engineering design

Engineering design, education, and practice involve a myriad of considerations, including the integration of technical considerations with social, cultural, and ethical aspects.[2,3] Organizational globalization, virtual collaboration, cultural diversity, and the highly social nature of design work itself[8,10] are just a few factors that necessitate engineers' abilities to work cooperatively and learn to incorporate diverse perspectives, specializations, and values into the design process. The highly social nature of design work itself [2,8] requires novice engineering students to learn about, recognize, and practice the social sides of engineering, an effort advanced by many researchers and practitioners in recent years.[4,9,10,11,12] Yet much of the extant literature has failed to incorporate insights from organizational and team research outside of engineering education and related disciplines.[3]

This study focuses on the emergence of technical and ethical relations in design project teams. While technical coordination has long been a primary consideration for both scholars and practitioners,[3] there has been less definitive progress on integrating ethics into pedagogy and practice.[13,14] We adopt the "everyday ethics" view from science and technology studies (STS)[14,15] that views ethics as inherently interwoven throughout the design process and manifest in the micro-decisions and practices of design work. As a step toward developing more effective integration of technical and ethical considerations in student design work, this study explores how these two design considerations emerge as relational components of team-based design work. That is, we probe how perceptions of team members' technical and ethical competence may impact the social environment in which design work is achieved. We specifically considered the communicative environment in which the social processes of design are accomplished as multidisciplinary teams, which represent diverse skills, perspectives, and approaches to design through their diverse membership.

Communicative approach to ethics in design teams

We use a social network analysis to probe the development of technical and ethical relations in these teams. Social network analysis (SNA) is an approach that enables researchers to examine the relationships among members of a given system or group.[6] The network analysis approach enables researchers to visualize and analyze the informal communication patterns that underlie the formal organizational structure.[6] This paper focuses on preliminary SNA results of a longitudinal study as a portion of a larger study. In this study, we seek to address two guiding research questions: (RQ1) How do network densities change over time across technical and ethical relations? (RQ2): How does network centralization change over time across technical and ethical relations?

Methods

As part of a larger study, we collected social network surveys from students in a project-based multidisciplinary engineering education program at a major Midwestern university. In this program, students engage in real-world design projects and deliver solutions to community partners. The program emphasized ethics education in a number of ways: (1) it employs a human-centered approach to design, in which students are encouraged to continually return to the end user throughout the design process; (2) all students participate in a lecture on ethics that focuses professional ethics as it relates to a case study as well as their own projects, and (3) students were asked to reflect on ethics periodically throughout the semester as a component of the course. The authors chose this program for this study in part because of the emphasis on the role of the end user throughout the design process, and the emphasis on ethics education in this program, to probe if students in such a program interact distinctly with regard to ethical versus technical concerns related to design. We focused on two classes, which are comprised of project teams consisting of 3 to 9 students each. Each class shared a common theme, advisor, and teaching assistants, but project teams worked mostly independently with limited collaboration with other teams in their class. We chose to conduct the analysis at the class level in order to account for the full environment of resources in which each project team was embedded, which enabled us to capture information about how advisors, teaching assistants, and other members of the class were utilized (or not) in participants' perceptions about who served as resources for technical and ethical expertise.

We gathered social network surveys from 139 participants. Because social network analysis requires a high level of participation from the teams being studied, we offered incentives and gained no less than 90% participation for each class. Consistent with our institutional review board approval, we obtained informed consent twice each semester from each participant. Confidentiality was assured, and pseudonyms and alterations of certain project details are used to protect participants' identities. Surveys were distributed through an online survey system each semester, and were only available to members of the research team. During the first semester, data were collected at the end of the semester (T1). After this data collection, the researchers noted the students' evolving perceptions over the course of the semester, so an additional data point was added for the remainder of the study. For the second and third semesters, data were collected once at mid-semester (T2 and T4, respectively) and once at the end of the semester (T3 and T5, respectively). These data were used to generate binary matrices of complete networks, which were analyzed to determine the following network measures. Two structural characteristics were measured, network density and network centralization.

Social network analysis

We used two items to probe technical and ethical relations: "I can rely on this person to have the technical competence needed to get the task done," and "I would go to this person if I had serious ethical concerns about the project." These items were adapted from Chua, Ingram, and Morris (2008)[16] to reflect the engineering design project context. Students were presented with a roster of their class members and asked to identify each member to whom they felt these statements applied by marking a 1 to indicate the presence of that relationship, or a 0 to indicate its absence. These responses were developed into matrices and analyzed using SIENA[17] network analysis software, which allows researchers to examine network evolution over time. We probed participants' understandings of and meanings associated with both technical competence and ethical concerns in the interviews, which will be discussed in a later paper.

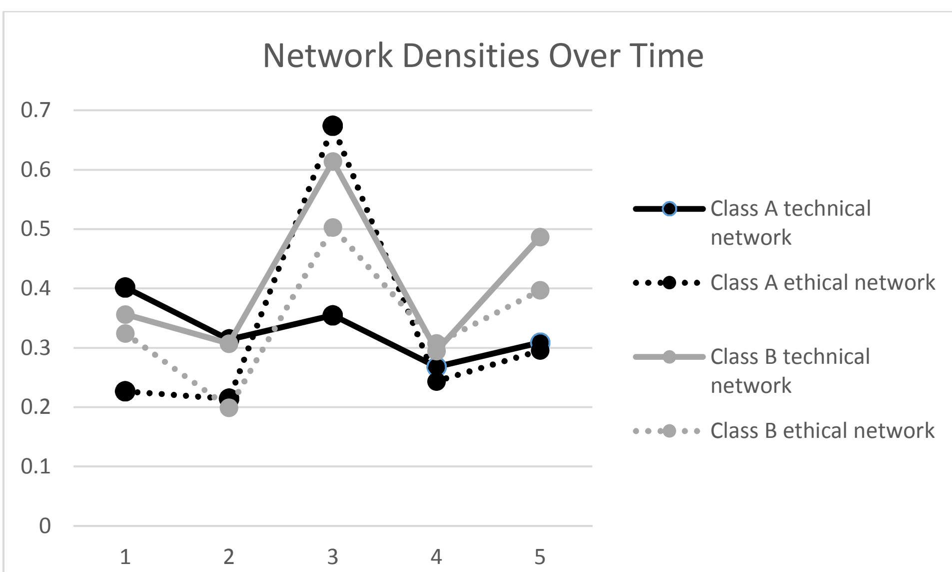
We considered two measurements for social network analysis: network density, and network centralization. *Network density* reflects the ratio of ties that exist in a given network to the total ties possible in that network.[6] Density scores range from 0 to 1, with 1 indicating complete connection among all members. Density measures suggest how interconnected a group of people may be; for this study, the degree to which team members identified one another as ethical or technical resources. Examining the density of a network and comparing density across different networks gives insight into how much members of that network interact with one another around a specific construct, such as work-related talk or levels of trust.[18] *Network centralization* reflects the variability in degree centrality of all the actors in the network.[6] Degree centrality measures the degree to which a network relies on one or a few members, or if its relations are more evenly distributed across all or most actors. Higher network centralization scores indicate the presence of a small number of actors with much higher degree centrality scores than the rest, meaning that a few actors in the team are the most prominent and influential in a given network. Centralization also ranges from 0 to 1, with 1 indicating one actor with significantly higher degree centrality than all the rest in a network.

Results

Density

SNA analysis revealed patterns that suggest ways students organized around technical versus ethical considerations. The first research question asked how network densities changed over time for technical and ethical relations. Network density scores varied in similar patterns across the two classes. To compare these densities across groups with the same members, we applied Snijders and Borgatti's (1999)[17] bootstrap-assisted paired samples t-test to technical and ethical networks for each class at each observation. The changes in density scores are shown below in Figure 1.

Figure 1: Comparing Densities



Across observations, both technical and ethical network densities exhibited similar trends. They dropped slightly between observations 1 and 2, and then rose significantly during observation 3, only to drop again between observation 3 and 4, and rise again between 4 and 5. Thus, densities in both relational networks were lower at the mid-semester point, and rose by the end of the semester. This trend offers insight into the impact of the project-based class structure in which students join and leave between semesters. Additionally, analysis revealed that densities between the technical and ethical networks were statistically significantly different for six of the ten time points for the two classes, suggesting that there is a difference in how participants identified class members for the two relations.

While differences in density cannot be interpreted fully on their own, the patterns of difference and the existence of statistically significant difference suggest several insights about the social dynamics surrounding technical and ethical expertise as these students move through the design process. First, that there is in most cases a meaningful difference in densities between the technical and ethical networks suggests that these two resources are being incorporated distinctly into students' design work. In most cases, densities for the ethical networks were lower. This suggests that students are more willing, better equipped, or perhaps have more confidence in their teammates' technical expertise than ethical expertise. We will consider possible reasons for this in the next section, and further research is needed to fully examine the importance and meaning of this finding. Yet this evidence suggests that students do, on some fundamental level, perceive technical competence and ethical competence as distinct, and they seem to incorporate ethical expertise in lower degrees than technical. Figures 2, 3, 4, and 5 illustrate how these differences looked across one observation for one class (tracing the technical and ethical network for Class A for two observations). We chose pseudonyms that used the same first initial and last name for members of the same project teams, to help visualize the team-level relations within each class. In the figures below, one can see that some project teams cluster together, while others have more connections across the class. Nodes that are larger and closer to the center of the graph represent individuals with higher degree centrality, indicating that more members of the class included them in their survey responses for each item. The more densely clustered and central nodes surrounded by smaller and more sparsely connected nodes represent highly centralized networks.

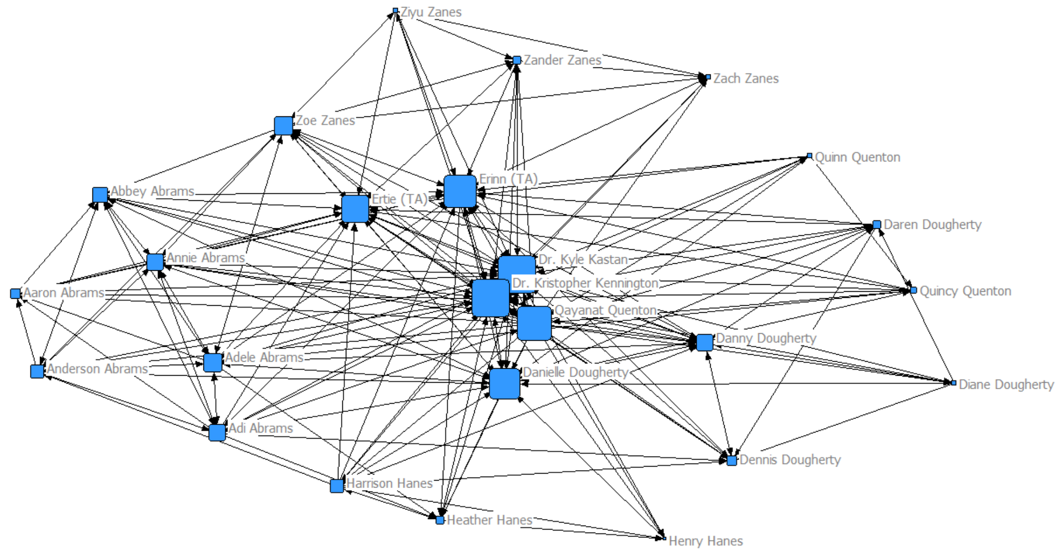


Figure 2: Technical network for Class A in Observation 1.

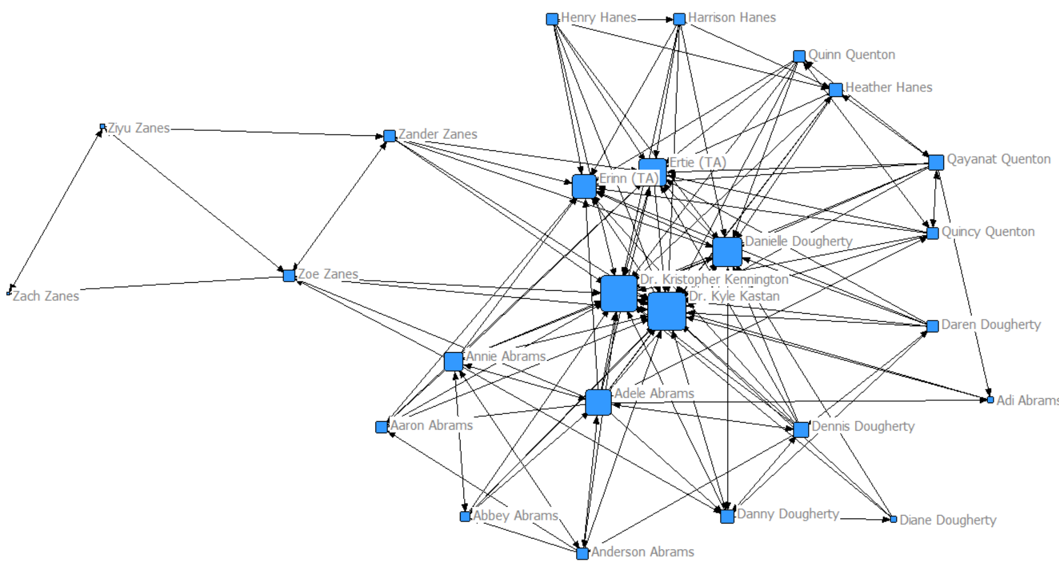


Figure 3: Ethical network for Class A in Observation 1.

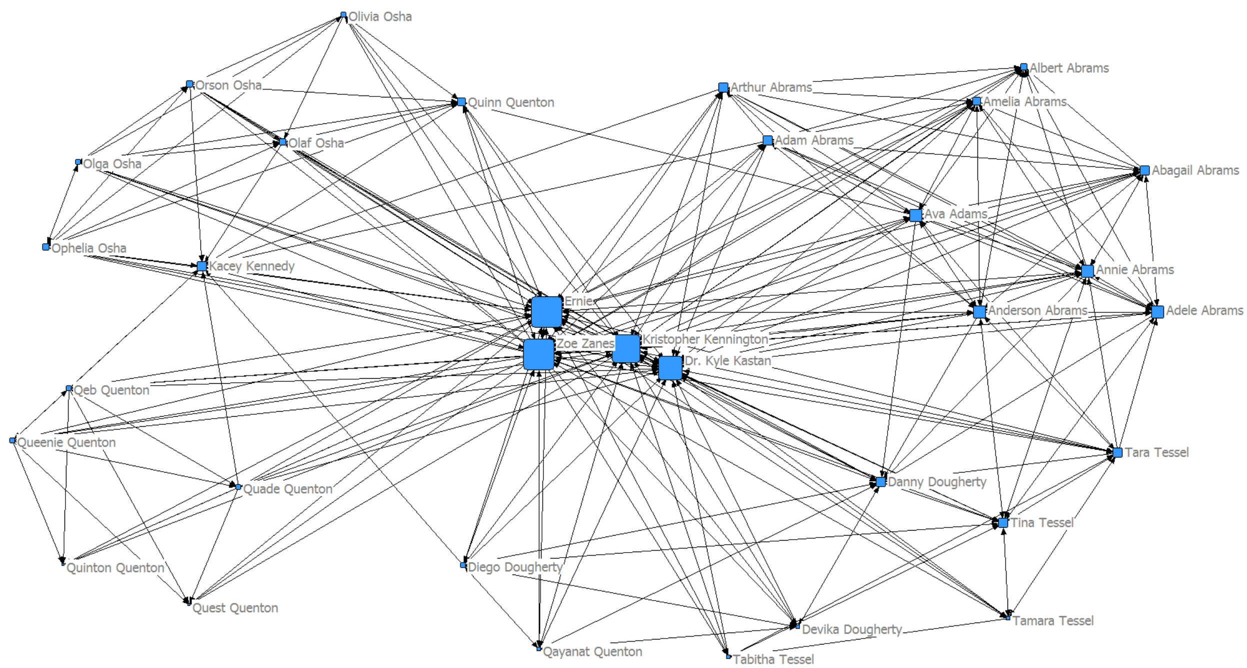


Figure 4: Technical network for Class A in Observation 5.

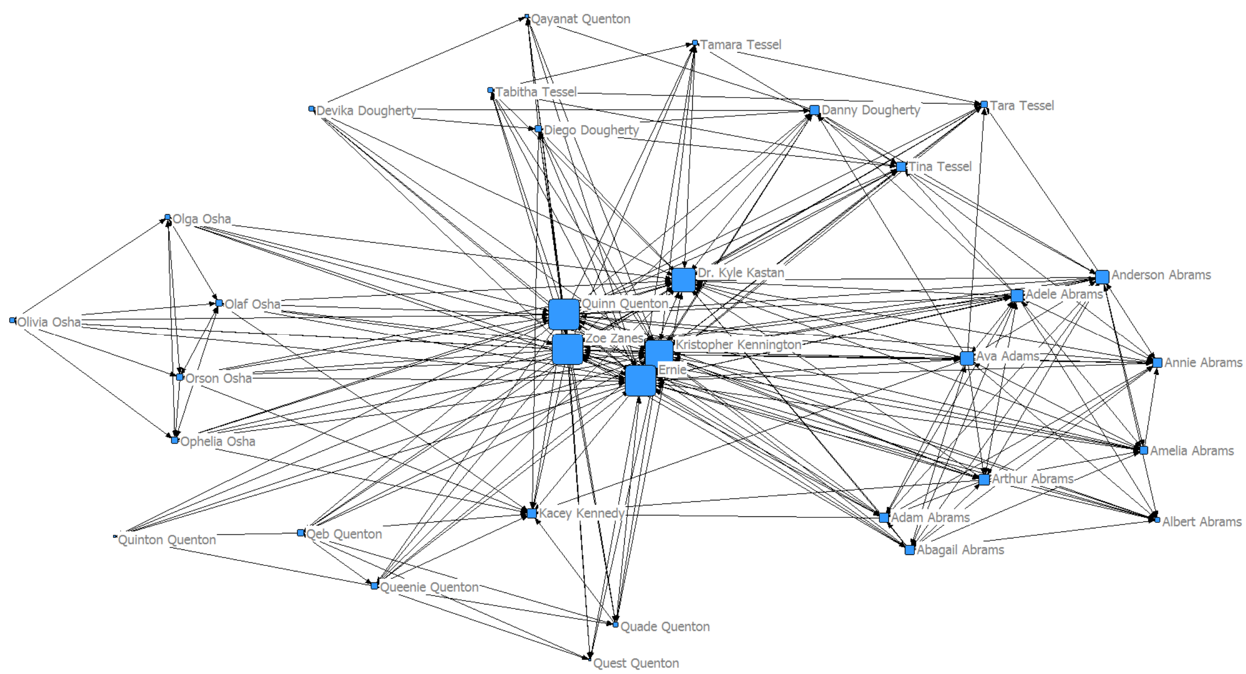
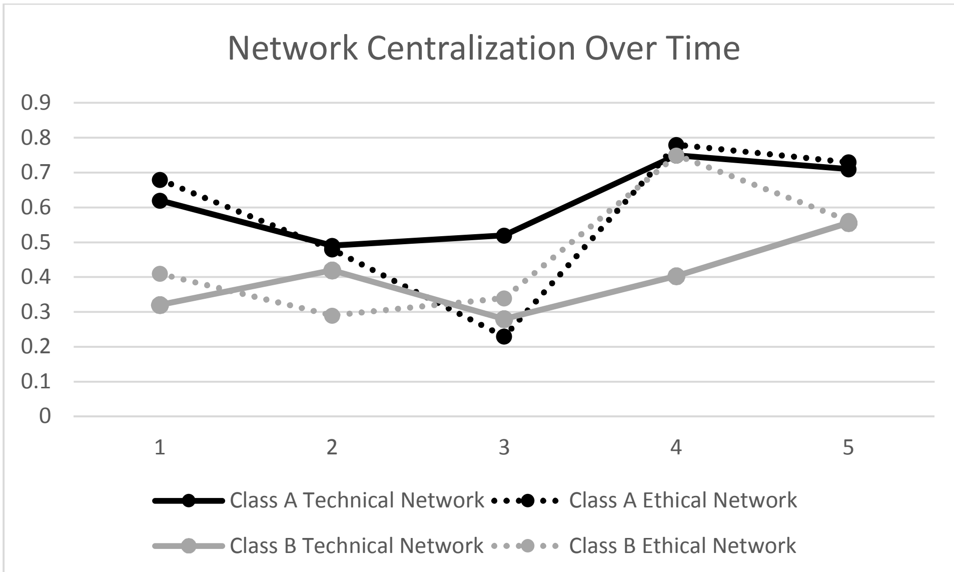


Figure 5: Ethical network for Class A in Observation 5.

Centralization

The second research question asked how network centralization changed over time for technical and ethical relations. The centralization scores for each respective semester are shown in Figure 6 below.

Figure 6. Comparing Centralization



Centralization scores were highly variable. Generally, centralization scores were lower in Class B than Class A, suggesting that overall, centrality scores for actors in Class B were more evenly distributed rather than having just a few actors with high degree centrality scores. Higher centralization may be associated with a team's performance. For example, Balkundi and Harrison (2006)[20] found that when analyzing the results of 37 studies, leader centrality in a team's instrumental network was positively associated with task performance and resource advantages for the team. Past scholarship has also explored leader centrality specifically in the engineering design context, finding that leadership position in engineering design teams has a significant impact on team creativity and team interactions.[21] In the current study, advisors and team design leads generally had the highest degree centrality scores, which supports these past findings. However, the variance between the two teams in terms of centralization suggests that they may operate differently, with Team A more reliant upon advisors and formalized positions of authority. Additionally, in both classes, ethical networks were often more highly centralized than technical networks. This suggests that students were more likely to identify one or a few people as highly ethically expert, while perceptions of technical expertise were somewhat more evenly distributed throughout the class.

Discussion

This study builds upon ongoing efforts to incorporate ethics into engineering education. By incorporating research from the team communication and ethics fields, we are able to provide insight into how engineering design teams function, and how technical and ethical considerations may be handled in the social enactment of design work. Extensive research in the field of group communication supports the trend we found for network density. Groups encounter phases, which often start with conflict and uncertainty as group members get to know one another, establish and sometimes compete for roles, and struggle to come to a shared understanding of the project and its goals.[19] While in this program, some students remained with their projects for multiple semesters and even years, extant research suggests that this may not ease the conflict and uncertainty that marks the start of a team. Rather, the presence of long-term members may exacerbate those tensions. Returning members must negotiate the adjustment to new team members, new skills and challenges, and new interpersonal dynamics. Concurrently, returning members must struggle to adapt from the group's previous norms (eg. how decisions are made; whose voices are listened to and who is systematically marginalized; how leadership is enacted) to the new norms that will be created as the new group works together.

Given this prior research, it is not surprising that density would exhibit this pattern across semesters. Density has been linked in past research to group dynamics, group performance, and the social processes of teams. For example, in a meta-analysis of 37 studies of teams in natural settings, Balkundi and Harrison (2006)[20] found that teams with highly dense interpersonal ties are able to attain their goals and are more committed to staying together. From the extant literature, it seems that more highly dense networks may have higher levels of information sharing and potentially engage in more collaboration, both of which contribute to successful completion of tasks. However, there has been no extensive research to show how the specific issues of technical and ethical expertise may shift and change over the course of a class design project. Indeed, there exist no standards by which to categorize densities as high, moderate, or low; this study is only able to describe the differences between densities, and whether a statistically significant difference exists between given densities. Yet there is a great volume of past literature that suggests that density is associated with the type of network (eg. distinct trends for a technical network versus an ethical network).

While density and centralization measures each offer limited insight into these teams, combining the two may provide some insight about the inner social workings of these teams. In cases where density was lower, in the ethical networks, the network centralization was often higher. This may suggest that students identified fewer team members as ethically expert, because they associated ethical expertise with only a small number of individuals on those teams. It may be unsurprising that those rated most often by team members as ethically expert were figures of authority, from advisors to design leads. Yet there were also outliers in this trend, with students lower in seniority and with no formal position sometimes taking a high rank in the ethical network. While future work is needed to probe this, our initial findings suggest that advisors and team leaders play imporant roles in technical and ethical elements of the team's design work.

Taken together, the findings from this study suggest that there are social processes that change over time in project-based design classes that may help us to better understand how student designers from a multitude of disciplines, class levels, and ethnicities work together to accomplish the task of design. By utilizing extant research in team communication processes, these findings offer several practical implications for engineering educators that help build upon past scholarship seeking to improve integration of ethics into enginnering education. First, our findings suggest that there *is* a difference in the way students perceive ethical and technical resources on their teams. Ethical expertise is less of a prominent resource for the teams in this study, suggesting that students are more willing or even able to identify and seek help on technical matters than ethical. While the importance of advisors (who may be considered “true” experts, from the traditional approach) is not surprising, design teams must be able to incorporate ethics into their everyday work, rather than seeking it out from an external source. Something about the way ethics is currently incorporated into these projects fails to integrate it into the everyday, and limits it to external authority figures rather than as an inherent part of design work. While the cause of this difference requires further analysis, these findings suggest that engineering educators should strive to teach students to rely on one another in both technical and ethical matters. Additionally, engineering educators may take steps to solidify the interrelated nature of these two priorities in design work, as they seem to play a role in the way student teams work together to accomplish design tasks. Second, engineering educators should be aware of the changing nature of these relations in student teams that span multiple semesters. One possible approach to utilizing this finding is to leverage returning members by tasking them with introducing the ethical components of their work to new members. Another approach may involve asking teams to intentionally reflect on challenges of starting a new collaborative effort, which might speed up the increasing density over the semester. These efforts could further the “micro-insertion” method[12] of incorporating ethics into engineering courses, by applying them to team-based design work.

Conclusion

This study contributes to our understanding of the social and communication processes that affect students’ engagement in design work. Through a communicative approach involving social network analysis, we provide insight into the team social processes that facilitate, hinder, or otherwise affect the ability of teams to fully recognize and integrate ethical considerations with technical design concerns. This study allows us to better understand the relationships and resources that facilitate design work within diverse design teams. The findings offer potential to help students improve their work and interactions, and to help engineering educators develop their ability to design effective pedagogical practices that help teams learn to value and incorporate the many competing values that characterize design work. By utilizing a social network approach, we are able to identify patterns of communication *in practice* that may be unclear or obscured in everyday design work, and to identify the key members of teams as they work to integrate technical and ethical considerations.

Acknowledgements

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