Key components of effective remote engineering work: Factors learned in school and on the job - Study motivation, design, and preliminary results

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***Abstract*— This Research Work-in-Progress Paper focuses on the change in collaboration practices within engineering and design (E&D) teams caused by COVID. A mixed-methods research approach was used. A survey designed to examine the long-term educational impact of an in-depth mechatronics graduate-level course sequence on its alumni was supplemented with Likert-scale and open-ended questions asking participants about the impact of COVID on their work mode and work satisfaction. The survey was administered in September 2021 and served as a filter to determine an interview sample. A literature review identifies leadership as an important factor in increasing team collaboration efficiency among virtual E&D teams. We identified and interviewed nine of the alumni who are currently leading E&D teams. Our goal is to identify skills those leaders acquired during their course experience that were particularly valuable for navigating the transition to remote collaboration. Furthermore, skills that have been critical for successful collaboration but were not learned during the course will also be identified. We then aim to derive practical implications for E&D course teaching teams on how to better prepare future E&D team leaders for remote collaboration. This Work-in-Progress paper focuses on our study motivation, design and preliminary results.**

Keywords*— *virtual teams; mixed-methods research; leadership; collaboration; team dynamics; remote work; mechatronics; alumni

I. Introduction

At its peak, the global COVID pandemic forced more than 50% of US employees to work remotely from home [1]. Especially for engineering and design (E&D) teams, this has caused major disruption in common collaboration aspects like information sharing and decision making, but also on how hardware prototyping was mastered. Management and leadership are identified as important factors for increasing team efficiency among virtual E&D teams [2]. However, there is little empirical research on which specific skills this transition to remote work demands from current E&D team leaders and to what extent current E&D courses in universities are structured to help students develop these skills.

We seek to answer the question: ***How can educators better prepare future E&D team leaders for remote collaboration?***

Using mixed-methods research, we aim to identify skills current E&D team leaders acquired during "ME 218: Smart Product Design", an in-depth mechatronics graduate-level course sequence at Stanford University, that turned out to be particularly valuable for navigating through the transition to remote collaboration. Furthermore, skills that have been critical for successful collaboration but were not learned in ME 218 will also be identified. Ultimately, we aim to give practical implications for E&D course teaching teams on how to better prepare future E&D team leaders for remote collaboration. This Work-in-Progress paper focuses on our study motivation, design, as well as some preliminary results, and it is largely based on the master's thesis of Lamprecht [3].

II. Collaboration Within E&D Teams

Our paper is guided by Patel, Pettitt, and Wilson's collaboration framework [2]. In 2012 they developed the CoSpaces Collaborative Working Model (CCWM), which serves as a descriptive human factors model of collaboration focused on E&D teams. Patel, Pettitt, and Wilson argue that collaboration "involves two or more people engaged in interaction with each other, within a single episode or series of episodes, working towards common goals." [2].

The CCWM evolved out of the European Integrated Project, CoSpaces, and the factors determining it were examined through extensive literature research and empirical work with partner user companies in the aerospace, automotive, and construction sectors. The model identifies seven main factors involved in collaboration each entailing several subfactors. We used parts of their model to develop our interview protocol [2].

When discussing all the subfactors in detail, Patel, Pettitt, and Wilson distinguish between distributed and co-located teams. As this work focuses on *remote* E&D teams, we distilled the subfactors which mostly influence distributed teams. Based on the literature research Patel, Pettitt and Wilson conducted for each subfactor, we identified eight of them as being particularly important for distributed teams.

Patel, Pettitt, and Wilson state that collaboration *(1) technology tools* are essential for virtual distributed teams, and they distinguish between tools for pure collaboration and those

that are task-related. *(2) Informal networks* facilitate the effectiveness of daily work and are more difficult to establish in distributed teams. *(3) Communication* helps synchronize mutual beliefs, maintain shared awareness, and foster *(4) common ground*. All these aspects are relevant to enhancing team effectiveness and easier to establish for co-located teams than for distributed teams. Computer-mediated communication can lower boundaries for all team members to share ideas within the *(5) decision-making* or brainstorming phase. Distributed collaboration needs careful support to ensure that weaker *(6) relationships* and a lack of familiarity between team members do not reduce team commitment. In reference to that, distributed working can make it difficult to develop *(7) trust* among colleagues, and the expression of power influences the level of trust among teams. Support from *(8) Management and Leadership* is thus key to improving team effectiveness [2].

These subfactors form the backbone of the semi-structured interview protocol. To ensure the importance of the identified factors, we cross-verified them by reviewing team and virtual team collaboration literature [4–8].

III. A Leader's Lens

The rationale behind focusing on team leaders to interview is primarily rooted in literature and was developed in an iterative process. Patel, Pettitt, and Wilson stress the importance of leadership in their framework [2]. Furthermore, team effectiveness and specifically virtual team effectiveness literature identify leadership as one of the main leverage points for increasing team effectiveness [4–8]. For example, Gilson et al. state that leadership plays a central role in virtual team functioning, particularly as leaders influence how a team deals with obstacles and ultimately adapts in the face of such challenges. Virtual team leaders are thus critically important when abating the impact of conflict [4]. With this information, we then looked at the study population. As soon as we could identify a representative sample of alumni currently leading and directing E&D teams, we decided to take the leader's lens [3].

IV. Research Questions

We seek to answer the overall research question: ***How can educators better prepare future E&D team leaders for remote collaboration?*** To begin to address this broad question, we focused on three specific research sub-questions in this study:

RQ1: What collaboration-related factors play the most important role in remote collaboration within E&D teams?

RQ2: What changes occurred to these factors comparing the pre-COVID situation with the COVID situation?

RQ3: Which skills did E&D team leaders acquire during their ME 218 experience that turned out to be particularly valuable for navigating through the transition to remote collaboration, and which ones have been critical for successful collaboration but were not learned in ME 218?

These questions are part of a larger effort to constantly improve project-based E&D classes in order to prepare students as best as possible for their future careers. Our work contributes to the existing engineering education literature on professional development in remote teamwork and collaboration practices by providing insights and recommendations to engineering educators on which E&D team collaboration and leadership skills are needed for success in new workspaces shaped by COVID. This study's findings will strengthen the foundation for future mechatronics courses that want to emphasize team collaboration and leadership. Furthermore, our findings will be useful to practicing engineers whose work involves collaboration in remote settings [3].

V. Methods

The study design begins with survey-collected quantitative and qualitative data. Quantitative data are represented by Likert-scale questions, and qualitative data by open-ended questions. These survey data were used to identify interviewees. The main data-collection are then semi-structured interviews [3]. According to Borrego, Douglas, and Amelink this work can thus be classified as an embedded mixed-methods approach with a focus on qualitative data [9].

A. Quantitative Study

We were opportunistic in designing this study. To a survey designed to examine the long-term educational impact of ME 218 on its alumni we added Likert-scale and open-ended questions asking participants about the impact of COVID on their work mode and work satisfaction. The survey was administered in September 2021 to 1735 alumni who graduated from Stanford University's ME 218 module between 1987 and 2018. This cohort was a rich target for selecting interviewees to understand E&D engineers transitioning to remote work, as the course attracts many students interested in careers focused in integrated design of systems involving software and hardware. The online survey was emailed to the participants and hosted on Qualtrics. A response rate of 28.9% could be recorded, leading to an effective sample size of 503. The cleaning and subsequent analysis of the data were conducted using R [3].

B. Qualitative Study

A semi-structured interview strategy was developed according to Gioia, Corley, and Hamilton.

a) Sampling Approach: This study employs theoretical sampling as recommended by Eisenhardt for a multiple case study research [10]. Several survey components were utilized to determine the recruitment criteria for the interviewees. The procedure of narrowing down the survey population to an interview sample size of 26 is described in Figure 1.

The following criteria were applied to the survey data when conducting the manual screening to ensure a diverse and heterogeneous interview sample.

1) The answers given to the open-ended COVID question – a particular focus was given to individuals who mentioned collaboration, leadership, or team aspects.
2) An equal distribution of participants who got influenced (strongly) negative vs. (strongly) positive in their overall work satisfaction
3) An equal gender distribution
4) A diverse ethnicity distribution
5) A diverse organizational role distribution.

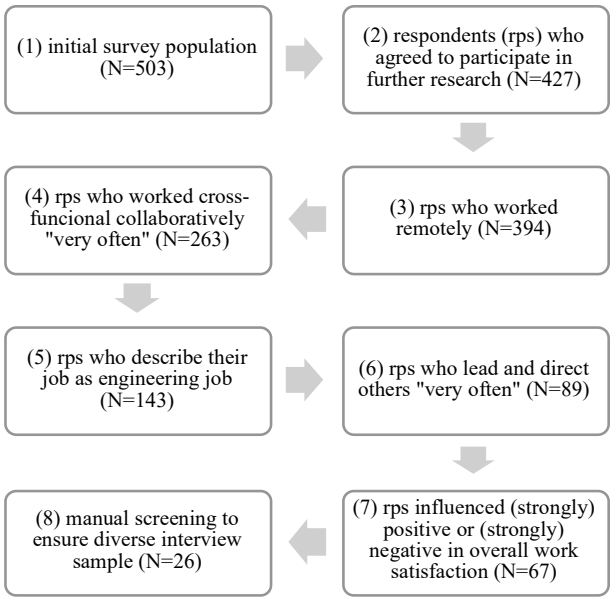

Fig. 1. Sampling Approach *(source: Lamprecht [3])*

The following criteria were applied to the survey data when conducting the manual screening to ensure a diverse and heterogeneous interview sample.

1) The answers given to the open-ended COVID question – a particular focus was given to those individuals who mentioned collaboration, leadership, or team aspects in their answers.
2) An equal distribution of participants who got influenced (strongly) negative vs. (strongly) positive in their overall work satisfaction
3) An equal gender distribution
4) A diverse ethnicity distribution
5) A diverse organizational role distribution

The recruiting phase was split into two batches to test the response rate and ensure that all interviewees willing to participate in this research study could be interviewed. Firstly, an initial subsample of 14 participants was contacted via email, and seven agreed to be interviewed. As only one of these seven individuals was female, we decided to focus on females only in the second batch and were able to recruit two more. In total, we reached out to 17 individuals, and nine agreed to be interviewed, leading to an overall response rate of 52.9 percent [3].

Table 1 compares the interview sample characteristics regarding the recruiting criteria against the overall survey population.

We tried to achieve a higher female ratio to get a wider variety of viewpoints and thus more generalizable results. Furthermore, interviewees who were (strongly) negatively impacted by COVID offered more promising answers to the open-ended survey questions. Overall, Table 1 stresses the heterogeneity of the interviewed sample regarding the defined recruitment criteria [3].

TABLE I. COMPARISON OF RECRUITMENT CRITERIA

Answer Options	***Interview Sample***	***Survey Population***
Gender		
male	66.7%	79.9%
female	33.3%	18.9%
I prefer not to answer	0.0%	0.0%
Ethnicity		
American Indian or Alaska Native	0.0%	0.2%
Asian or Asian American	22.2%	30.2%
Black or African American	0.0%	3.2%
Hispanic or Latino/a	22.2%	8.3%
Native Hawaiian or Pacific Islander	0.0%	0.4%
White	44.4%	57.7%
Other:	11.1%	1.2%
I prefer not to answer	0.0%	3.8%
NA	0.0%	0.6%
Job Role		
Employee for a medium- or large-size business	44.4%	49.1%
Founder/co-founder of your own for-profit organization	11.1%	11.9%
Employee for a small business or start-up company	33.3%	23.5%
Faculty member or educational professional in a college or university	0.0%	6.4%
Employee for the government, military, or public agency (excluding a school or college/university)	11.1%	4.0%
Employee for a non-profit organization (excluding a school or college/university)	0.0%	1.8%
Founder/co-founder of your own non-profit organization	0.0%	0.4%
Teacher or educational professional in a K-12 school	0.0%	0.2%
NA	0.0%	2.8%
COVID Impact		
strongly negative	11.1%	3.4%
negative	55.6%	36.4%
neutral	0.0%	29.4%
positive	11.1%	22.5%
strongly positive	22.2%	5.6%
NA	0.0%	2.8%

b) Interview Protocol: In line with Edmondson and Mcmanus, we aimed for a methodological fit of research question, prior work, research design, and theoretical contribution [11]. As Gioia, Corley, and Hamilton suggest, "the heart of [this study] is the semi-structured interview." [12]. It serves "to obtain both retrospective and real-time accounts by those people experiencing the phenomenon of theoretical interest." [12]. The identified subfactors relevant for remote E&D team collaboration derived from Patel, Pettitt, and Wilson's CCWM [2] build the backbone of the semi-structured interview protocol, which is split into four sections.

Section one focused on the interviewee's role and the team they are currently working with. The goal was to get a sense of how the subject understands their job role so the interviewer can 'walk in their shoes'. Another aspect was to make sure they were referring to the remote setting and to double-check with the indication made in the survey on how often the interviewee leads and directs others. Lastly, it was important to understand how close the team was already (i.e., already friends vs. newly formed) to put answers to questions related to, e.g., team cohesiveness, into perspective [3].

In Section two, collaboration was the main theme. Here we tried to dig deeper into the interviewee's role as a leader and what challenges they faced during COVID concerning the collaboration factors that are particularly important for remote E&D teams. A particular emphasis was put on the interviewee's before/after perspective to identify what changes occurred to these factors when comparing the pre-COVID situation with the COVID situation and thus answer research sub-question 2 [3].

Section three was designed as a reflection session. We asked more open-ended questions about the changes in the interviewee's leadership style due to the pandemic and wanted the interviewee to reflect on aspects like autonomy given to team members, distributed leadership, or leader-like behavior of colleagues [3].

The last part of the protocol focused on learning experiences resulting from the ME 218 course sequence that were particularly helpful for the interviewee in navigating through COVID regarding team collaboration. Furthermore, we also tried to figure out elements that have been critical for successful collaboration but were not learned in ME 218 [3].

The protocol was intensively revised and tested with members of the Designing Education Lab and leaders of E&D teams before conducting the first interview. Depending on the interviewee's answers, some questions had to be passed; otherwise, the interview would have exceeded 60 minutes [3].

VI. Preliminary Results and Work-In-Progress

Based on the survey, more than 90% of the survey participants were working at least partly remotely. Looking at the explicit workplace, the largest proportion, i.e., 86.7% of respondents, were working from home. When asked how the pandemic influenced their overall work satisfaction, 29.4% of the respondents reported no influence, while 36.4% were negatively and 3.4% strongly negatively influenced. 22.5% reported a positive influence on their work satisfaction, and 5.6% a strong positive influence. These insights served as an important factor in whom to recruit for the interviews [3].

Nine semi-structured interviews lasting on average 60 minutes were completed and have been transcribed using the software otter.ai. Currently, qualitative content analysis (QCA) is being conducted using NVIVO. We aim to uncover overarching themes and highlight key course elements contributing to developing E&D team collaboration and leadership skills. We are using an inductive coding approach and are following the open coding recommendations of Corbin and Strauss [13]. As Gioia, Corley, and Hamilton suggest, we are aware that the research questions of this study might be further refined throughout the coding process [12].

Looking at RQ1 and RQ2, preliminary QCA confirms the factors *technology tools, communication, informal networks, common ground, team relationships, and management and leadership* as being important for remote collaboration within E&D teams. Furthermore, 34 entailing sub-factors are uncovered. The interviews did not confirm the factors of *trust* and *decision-making* [3].

In addition to that, two new factors emerged from the interview data. Firstly, the factor *meeting structures and work frameworks* describes how leaders adapted their meeting structures and collaboration frameworks over the pandemic. Secondly, due to the focus of this paper, the topic of *remote hardware work* was very present throughout the interviews. Informants here describe how they worked on hardware in the remote setting, the logistical burden caused by it, and the best practices in translating this process into the digital world. Both new themes state an addition to the framework of Patel, Pettitt, and Wilson [2, 3].

Some very preliminary findings for RQ3 suggest that documenting one's work, managing time and project, working interdisciplinary, handing off work between teams, and clearly communicating are skills that were developed during the course experience and turned out to help navigate through the pandemic. Experiences the alumni would have found helpful include remote and virtual team collaboration, learning how to present results in a concise form, and dealing with more “real-world” project definitions (i.e., not having a clear project definition beforehand). These findings are part of the 1st order codes described by Gioia, Corley, and Hamilton [12]. Our next steps are to derive 2nd order schemes and aggregate dimensions to develop a final data structure out of which we plan to derive practical implications for E&D course teaching teams on how to better prepare future E&D team leaders for remote collaboration.

VII. Conclusion and Limitations

This Work-in-Progress paper shows our mixed-methods approach to identifying skills for E&D team leaders that were particularly valuable for navigating the transition to remote collaboration. The qualitative study is based on nine interviews. A semi-structured interview protocol was developed based on the CCWM of Patel, Pettitt, and Wilson [2], out of which eight factors were identified as particularly important for remote E&D team collaboration. Work-in-Progress comprises QCA, confirming six of these eight factors and uncovering two newly emerged themes. Implications for E&D course teaching teams will be derived and presented at the conference, together with detailed findings.

We recognize that the findings from this work come from a specific group of alumni and are not necessarily generalizable to all remote engineering work. The focus of ME 218 on team collaboration is unique and could have provided the interviewees with an unfair advantage regarding managing collaboration. We are excited to expand this exploration to more diverse populations of E&D course alumni.

References

[1] Brynjolfsson E, Horton J, Ozimek A et al. (2020) COVID and Remote Work: An Early Look at US Data. National Bureau of Economic Research, Cambridge, MA

[2] Patel H, Pettitt M, Wilson JR (2012) Factors of collaborative working: a framework for a collaboration model. Appl Ergon 43:1–26

[3] Lamprecht J (2022) Key components of effective remote engineering work: A leader's lens on the impact of COVID on team collaboration. Master's Thesis (unpublished), Stanford University; Technical University of Munich

[4] Gilson LL, Maynard MT, Jones Young NC et al. (2015) Virtual Teams Research. Journal of Management 41:1313–1337

[5] Hoch JE, Kozlowski SWJ (2014) Leading virtual teams: hierarchical leadership, structural supports, and shared team leadership. J Appl Psychol 99:390–403. https://doi.org/10.1037/a0030264

[6] Joshi A, Lazarova MB, Liao H (2009) Getting Everyone on Board: The Role of Inspirational Leadership in Geographically Dispersed Teams. Organization Science 20:240–252. https://doi.org/10.1287/orsc.1080.0383

[7] Martins LL, Gilson LL, Maynard MT (2004) Virtual Teams: What Do We Know and Where Do We Go From Here? Journal of Management 30:805–835. https://doi.org/10.1016/j.jm.2004.05.002

[8] Powell A, Piccoli G, Ives B (2004) Virtual teams. SIGMIS Database 35:6–36. https://doi.org/10.1145/968464.968467

[9] Borrego M, Douglas EP, Amelink CT (2009) Quantitative, Qualitative, and Mixed Research Methods in Engineering Education. Journal of Engineering Education 98:53–66

[10] Eisenhardt KM (1989) Building Theories from Case Study Research. AMR 14:532–550

[11] Edmondson AC, Mcmanus SE (2007) Methodological fit in management field research. AMR 32:1246–1264

[12] Gioia DA, Corley KG, Hamilton AL (2013) Seeking Qualitative Rigor in Inductive Research. Organizational Research Methods 16:15–31

[13] Corbin J, Strauss A (2008) Basics of Qualitative Research (3rd ed.): Techniques and Procedures for Developing Grounded Theory. SAGE Publications, Inc, 2455 Teller Road, Thousand Oaks California 91320 United States