

A Novel Method for Measuring, Visualizing, and Monitoring E-Collaboration

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ABSTRACT

With its roots in the 1960s, e-collaboration has dramatically evolved and expanded over the past decades and became a globally adopted practice of teamwork. On the other hand, despite the development of e-collaboration technologies, the lack of true collaboration remains one of the main reasons for teamwork failures. However, traditional approaches to improving collaboration due to time-consuming, complicated, and expensive procedures do not meet the modern setup's requirements. This paper presents a new fast, simple, and low-cost method to improve e-collaboration through active engagement measures by analyzing data logs. The authors designed and ran a feedback system to mirror the participants' engagement during a collaborative engineering design course. The results of two case studies, including nine teams, suggest meaningful positive impacts of the method. The presented approach is applicable in upgrading e-collaboration platforms and further investigation on improving web-based collaborative learning and teamwork through monitoring dashboards and feedback systems.

KEYWORDS

Active Engagement, Collaborative Design, E-Collaboration, Feedback, Teamwork

1. INTRODUCTION AND RATIONALE

E-collaboration refers to utilizing electronic technologies in collaborative activities (Kock, 2005). Following an exceptional evolution in just a few decades, e-collaboration is a common and widespread practice nowadays. Rutkowski et al (2002) believe that e-collaboration is more than only a technological trade-off for traditional *face*-to-face collaboration. By focusing on the communicative dimensions of e-collaboration over a period of four years, Rutkowski and others developed a project with hundreds of participants from different national backgrounds working during six weeks of collaborative work. They used different interventions including IT setups and interviews based on which they concluded that: First, the evolution of e-collaboration is transforming the nature of teamwork, its functionality, and its productivity. Second, geographical distances between team members or time

DOI: 10.4018/IJeC.317223

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zones, no longer form a barrier to remote collaborations. Third, the fast spread of information and decentralized communication enables both problem solving and creativity. Further, it is necessary for the organizational structures to support e-interactions as a central element to efficient online teamwork. In addition, after removing the basic technical barriers, the main challenges in collaboration to deal with are organizational and social issues. Since Rutkowski et al's study, technical barriers have been significantly minimized and e-collaboration technology has continued to advance, however, as the study concluded, organizational and social challenges related to collaboration appear to remain central factors in teamwork failures. In this study, we intend to deal with technical methods that can help us to overcome the challenges of poor e-collaboration. For this purpose, in this section, we will first discuss the history of e-collaboration evolution, its current scope, and existing challenges, then we expand the concept and our solution in the next sections.

The idea and history of e-collaboration date back decades ago. Christopher Allen (2004) has traced its evolution from the very beginning till the 2000s; we have re-shaped and summarized Allen's work in Table 1, to portray the evolution of the e-collaboration basis, and then discussed the current status. We will next touch on evidence suggesting that technological development has not necessarily ended up with the same improvement in collaboration quality.

Zhang et al. as cited in (Jones, 2012), more elaborated the evolution of collaboration digital technologies by dividing them in two main categories; 1) Asynchronous tools, and 2) Synchronous. Each of these categories has subdivisions as follows:

1. Asynchronous tools
 - Communication tools (including: Email, Newsgroups, Microblogs)
 - Information Sharing tools (including: Blogs, Discussion, Forums, Wikis, Online, Documents, File sharing)
 - Group Calendar tools
 - Social Networking Tools
 - Integrated Systems
2. Synchronous
 - Whiteboarding
 - Video Conferencing
 - Instant Messaging (Chat)
 - Short Message Service (SMS)

The path that collaboration technology has taken towards digitization has been very fast and impressive. However, looking at its evolution in Table 1 and the mentioned categorizations, it seems that developers' attention of e-collaboration has been more on technology and removing technical barriers than fostering collaboration essence. Over hundreds of thousands of years, if not millions, humans have been engaged in collaborative activities in different ways. As cited in (Sewell, 2001), Lipnack and Stamps's (1994) by pointing to the collaborative nature of work in early human times argue that after the Industrial Revolution we have forgotten how and why we used to collaborate and work in teams: to achieve goals that bind mutually dependent small groups of people. Mentioning the prehistoric examples of hunter-gathering or farming, they argue that modern forms of cooperation have led us to refuse teams. We argue that the fast shift of traditional collaboration style to digitalized e-collaboration in the last two-four decades has even exacerbated this gap.

To understand the current situation of e-collaboration technologies and updated statistics, we searched for the latest valid surveys. In a recent article, Boskamp (2022) by citing Forbes, Fortune, Deloitte, Harvard Business Review, and some other widely known magazines/publications, broke down their data and illustrated remarkable statistics of work collaboration and the role of digital technologies in collaborative works. According to the article, over 50% of U.S. workers report relying on collaboration in their work, while 75% rate collaboration as a critical aspect. At the same time,

Table 1. Tracing the evolution of E-collaboration

Year	Authors/Inventors	Names/Brands	Application/Capabilities	Highlights/Notes
1940's	Vannevar Bush	Memex	To store books, records, and communications, as an enlarged intimate supplement to the memory	The idea was way before its time and never caught on.
1960's	ARPA and J.C.R. Licklider	ARPANET	To use computer as a remote communication device to collaborate in teams	ARPA or Advanced Research Projects Agency formed by the US as a response to the USSR launching Sputnik.
	Doug Englebart And ARPA at SRI	Initially: NLS (oNLine System) Later: Office Augmentation	Integrating psychology and organizational development with the advances in computing technology in order to augmenting human intellect	Doug inspired by V. Bush's idea, but it seems that later on, the term 'augmentation' replaced with 'automation', and the idea was lost
1970's	IBM	Office Automation	To broaden the scope of IBM's 'word processing' products to all aspects of the office.	Ideas of collaboration got lost in the plan of process and automation
	IBM, AT&T, Annenberg Trust, NSF and the New Jersey Commission of Science and Technology	Electronic Information Exchange System (EIES)	The first major implementation of a collaborative platform, including: threaded-replies, polling, anonymous messages, etc.	While there were references from that time to terms such as 'computer-mediated communications', 'decision support system', and 'collective intelligence', none of these was broadly adopted.
1980's	Peter and Trudy Johnson-Lenz	Groupware (1)	Person-to-person collaboration that is facilitated by computer.	Outside of the EIES community, 'groupware' was not widely adopted.
	MIT's Irene Greif and DEC's Paul Cashman	Computer-Supported Collaborative Work (CSCW)	To develop new theories and technologies that can aid in the coordination of work groups.	In general, CSCW has never been truly adopted by anyone other than academics.
1990's 1990's	Robert Johansen	Groupware (2)	Computer support for business teams. A distinction between time and place for different types of collaboration was a unique contribution of the idea.	Emerging of Lotus Notes, Microsoft Exchange Server, and Outlook
	Ted Nelson and Phil Salin	Xanadu and AMIX	The origin of social software: The abilities of working with links and filtering, supporting collaborative development of modelling, games, and simulations.	The 'social software' term did not take off in that period. While Wiki was created in 1995, inventors did not define it as social software initially.
2000's 2000's	Clay Shirky	Social Software Summit	Evolution of Social Software Tries to converge existing technologies to support e-collaboration	Social software is re-defined as "software that supports group interaction" Web 2.0 created a network of cloud-based applications that enabled more collaboration, community-building, and other types of interaction.

56% of employers utilize online collaboration techs. Furthermore, Fortune Business Insights (FBI, 2022) reported that the market for team collaboration technologies will be valued at \$40.79 billion by 2028, which shows more than a 230% rise, compared with 2021. These data and the evolution

of e-collaboration in the last 60 years are stunning, however, despite the impressive development of e-collaboration technologies, in terms of collaboration quality, there are significant gaps to cover (Hihn et al., 2011; Ho et al., 2019; Rometty, 2006). Based on the Boskamp work, lack of collaboration is cited as the leading cause of workplace failure by 86% of employees in leadership positions.

In summary, e-collaboration technology has grown rapidly and is now part of the daily lives of a significant number of teams across the world. Meanwhile, the quality of collaboration has a lot of room for improvement. The main objective of this study is to address the challenge of poor collaboration in teams that have a serious dependence on digital technologies for teamwork. We believe that, due to accessibility to recorded history logs and computerized procedures, e-collaboration provides a great potential to analyze team activities and suggest effective methods to improve them.

In this study, we investigate two engineering teams in two different case studies, as examples of complex e-collaboration. Collaborative design teams usually consist of engineers from different disciplines who work together to solve complex problems, where e-collaboration plays a significant role. Later, we will further discuss why we think log data, which is a record of e-activities provides a substantial possibility to improve collaborative work.

This paper continues with the following sections: Section 2 expands the literature review and finishes with the hypothesis. Section 3 presents the study's design and research methodology. Section 4 reports the case studies, results, and analysis of the studies. In section 5 we discussed our findings and limitations. Finally, in the last section, we conclude and talk about future studies.

2. LITERATURE REVIEW

Founded on the research literature, this section follows the following order: (A) We explore the definition of collaboration, different research perspectives, and its elements, framework and, constructs. (B) Then, reviewing some of the studies on improving collaboration in general. (C) We discuss studies that specifically focus on online collaborative activities and the application of the data log in e-collaboration analysis. (D) Next, briefly reviewing feedback systems. (E) After that, we move on with a summary and the hypotheses of this study.

2.1 Definitions and Constructs

Wood and Gray (1991) suggest a notable definition of collaboration derived from a synthesis of conclusions from nine studies on the subject;

“Collaboration occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain.”

They further highlight six elements in their definition: **First**, Stakeholders of a Problem Domain; referring to the groups with common and/or different interests. **Second**, Autonomy; meaning that stakeholders are independent decision makers. **Third**, Interactive Process; indicating the involvement of all stakeholders in a change-oriented relationship. **Fourth**, Shared Rules, Norms, and Structures; referring to implicit or explicit agreements to govern the interaction process. **Fifth**, Action or Decision; showing that to reach the objectives the contributor must intend to “act or decide”, regardless success or failure in obtaining the objectives. **Sixth**, Domain Orientation; directing to the need that participants' processes, decisions, and actions must be oriented toward to the problem domain that brought them together. Thomson et al. later expanded Wood and Gray's definition and redefined it as follows (Thomson et al., 2007):

“Collaboration is a process in which autonomous or semi-autonomous actors interact through formal and informal negotiation, jointly creating rules and structures governing their relationships and ways to act or decide on the issues that brought them together; it is a process involving shared norms and mutually beneficial interactions.”

Rooted in a learning approach, Lai (2011) believes that collaboration is the “mutual engagement of participants in a coordinated effort to solve a problem together.” Lai further explains different perspectives and research paradigms in collaborative learning: The “effect” paradigm focuses more on outcomes than collaborative process itself, comparing group performance to individual efficiency. In the “conditions” paradigm individual characteristics, group heterogeneity and size, and task features are considered as moderators of the effectiveness of collaboration on learning. The “interactions” paradigm attempts to identify mediating mechanisms between outcomes and collaboration, developed as an answer to the complexities associated with the previous paradigm. And the “computer supported” paradigm attempts to determine whether the theoretical basis of face-to-face collaboration can be realized in computer-mediated interactions.

Griffiths et al (2021) conducted a systematic review to map a conceptual framework of collaboration in the educational setting. To build a universal model, the review aims to identify the common constructs throughout different definitions of collaboration. Then authors developed the “building blocks” framework and identified the necessary steps to come into the position of true collaboration. The model underlines the iterative nature of the collaborative process and the significance of re-evaluating the basic elements of a collaborative development. Figure 1 shows the building blocks and Table 2 illustrates the definition for each term in the framework.

Figure 1. Building blocks of collaboration (Griffiths et al, 2020)

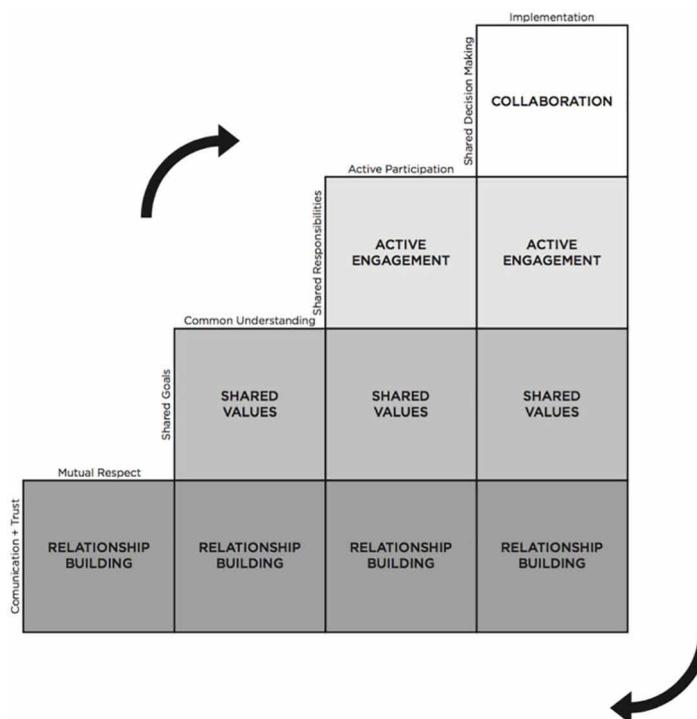


Table 2. Concepts and constructs of collaboration based on Griffiths et al work

Terms	Definition
Shared decision making	Members have the chance to provide input, and there is balance in the process of decision-making
Active participation	Team members equally contribute and accept a specific role; includes, shared problem solving, cooperation, and actively engaged in the process
Shared responsibility	Practical usage of capabilities, the establishment of roles, equivalent contribution, and productive use of members strengths
Shared goals	Mutually determined goals by the team in order to carry-out mutual outcomes that the team agreed-upon
Common understanding	Members of the team communicate and understand each other
Open communication	Open, honest and transparent sharing of ideas that leads avoiding unnecessary conflicts
Trust	Trust is acquired when time, effort, and energy are committed to the development of a functioning system of communication.
Mutual respect	To value skills, competence, and knowledge of others

2.2 Improving Collaboration

Over recent decades, a large body of research from engineering to healthcare investigated the importance and demand for improving collaboration. Depending on the discipline and context different approaches are being occupied to improving collaboration. For example, Willey & Freeman (2006) conducted a study in the field of engineering education to improve teamwork and engagement. They examined the benefits of self and peer assessment together throughout a multistage collaborative project. A confidential online tool was used to gather 180 participants receive self and peer-evaluation grading. The findings suggest that the method improved participants' engagement, collaboration, and satisfaction. Yin et al. (2011) in order to investigate how to measure and improve collaborative design performance, adopted a questionnaire survey and in-depth focus group interviews after critical literature reviews. They developed a design performance measurement (DPM) matrix that measures team members' performances in a collaborative design work through five DPM indicators and 25 DPM criteria. Indicators are innovation, efficiency, collaboration, effectiveness, and management skill. Their findings suggest that decision-making efficiency is the key DPM criterion for collaborative design efficiency. Clear team objectives for collaboration, the decision-making ability of managers, and competitive advantage in innovation are the next important criteria. Yin et al. believe that DPM is a useful tool for improving collaborative design performance. Alharthi et al. (2018) investigated the effect of cognitive styles in collaborative gaming activities. Players took part in the mixed methods user-study that were classified based on a cognitive style elicitation instrument. The analysis revealed that cognitive styles had an effect on performance; the mental load could result in different team collaboration (Alharthi et al., 2018). Hebert et al. (2014) in a social work context examined whether intensive inter-agency collaboration facilitated an effective collaboration for maltreated children in a pilot study of intensive family intervention. This qualitative study evaluated inter-agency collaboration through a semi-structured group interview format and thematic analysis. According to the analysis, the collaborative model is strongly endorsed. The authors indicated that the observed change may have been a result of the pilot program's unique structure and functioning, which encouraged high levels of team communication, strong client engagement, availability, and intensive treatment of mental health problems in children and parents. In a healthcare setting, Sandahl et al. (2013) conducted a study to investigate how simulator-based medical team training can improve inter-professional collaboration within an intensive care unit (ICU). During their case study over a period of two years, 135 members of the general ICU staff in a hospital received inter-professional team training. The findings showed

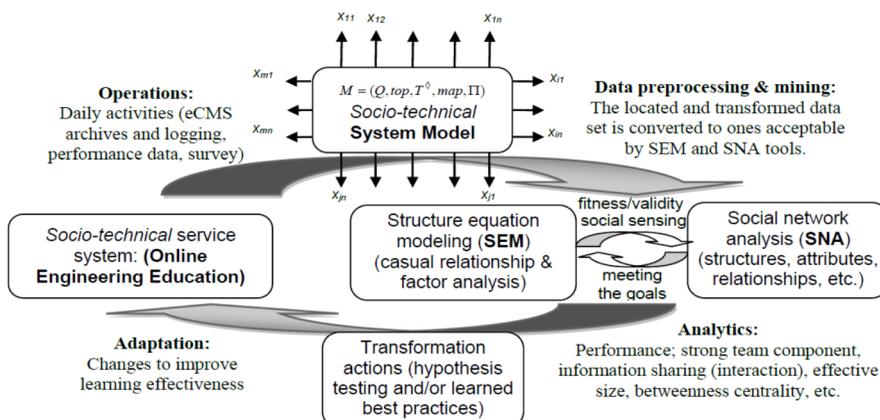
that the training sessions (three times a week) was effective to improve the participants' understanding of fundamentals of collaboration. However, the findings indicate that the observed improvements is not sustainable without everyday use of the learned behaviours in work. In addition, there are other threats to sustainability such as overtime for staff, budget cuts, and poor communication.

2.3 Improving E-Collaboration, and Using Data-Log

Qiu (2019) in an online engineering education setting looked for a solution to facilitate learning engagement. Compared with the empirical studies of conducting hypothesis tests, Qiu worked on a practical, systematic, and model-driven approach to assessing and enhancing collaborative practices. After exploring the proposed framework through two tests (Pilot and confirming) the results suggest the approach is helpful to improve collaborative practices for retaining effective engagement in the online engineering education setting. Figure 2 shows an overview of Qiu's systemic approach. Online education is modelled as a socio-technical service system. Data collection on teaching/learning activities is the first step, the pre-processing, and mining. The next step includes analysing processed data using Structure Equation Modelling (SEM) and Social Network Analysis (SNA) tools to identify best practices and know transformative operations for improvement. The framework also relies on daily survey data in the Operations stage. According to Qiu, the proposed systemic approach should be applied in an iterative and evolutionary mode, in order to continuously and adaptively leveraging collaborative learning in an online engineering education setting.

Belanger et al. (2022) studied difficulties of engineering design teamwork in the e-collaboration settings. They report that the rapid shift from co-located to distance collaboration during the pandemic caused dramatic challenges to many engineering students. With the aims to explore challenges of e-collaboration in engineering design teams, the authors observed teamwork difficulties through three datasets. (A) By collecting data through survey responses during in-class idea generation activities; (B) reflection essays about their team project at the final stage of the semester; and (C), individual reflections on the discussion panel during the whole semester. The study results show significant positive correlations between teamwork experience (e.g., perceived contribution, efficiency, and communication) and the number text-based idea generation, and significant negative correlations between teamwork experience and the number of ideas generated in a blend mode of sketches and text. These findings were unlike the classic findings that sketches improve performance. Moreover, the online environment intensified existing team challenges more than it formed new challenges. The e-collaboration challenges also dropped dramatically over time then remained steady. The challenges and their variable patterns indicate a great potential to improve web-based collaborative design.

Figure 2. Qiu's approach to leveraging engagement in online collaborative learning (Qiu, 2019)

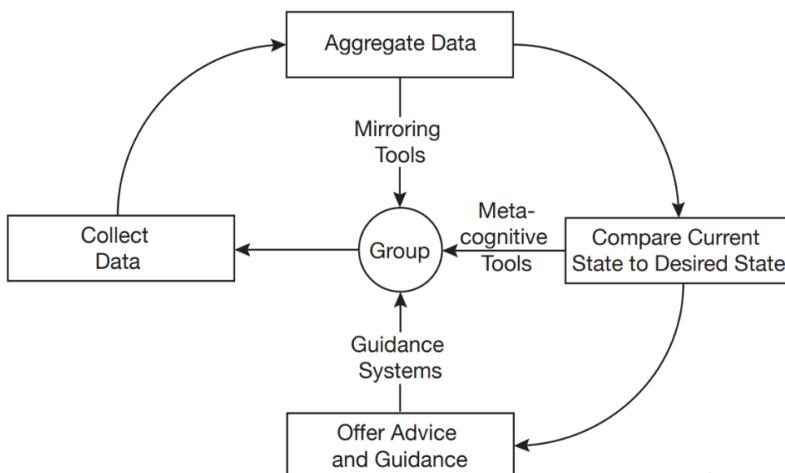


In a conceptual model of collaboration by Martinez et al. (2021), authors argue that the use of log data to identify key indicators of collaboration and teamwork has enabled new ways of predicting outcomes and personalizing feedback on a real-time basis. In their paper, by citing different publications, they provide many examples: for instance, Reimann, Yacef, & Kay, (2011) used log data to understand the way of groups working in synchronous/asynchronous settings, Perera, Kay, Koprinska, Yacef, & Zaïane, (2008) used data log to characterize effective collaboration, Rosé et al., (2008), applied log data in argumentation, and Kay, Maisonneuve, Yacef, & Zaïane, (2006), used log data in teamwork. Schwind and Wegmann (2008), also in the field of software development networks, used socio-technical network analysis as an approach to data driven collaboration measurement. They extracted data from three sources; code classes, e-mail traffics, and versioning data derived from databases. Fan et al (2017) to address a gap in how specific collaboration process patterns affect teamwork performance in collaboration management, developed a Collaboration Process Pattern approach to analyse teamwork performance by mining collaboration system logs in software programming teams. The authors indicate that the research is novel in three ways. (1) It is fact-driven because the result is based on teamwork tracking logs. (2) The developed pattern mining approach is based on graph and sequence mining. (3) They used time-dependent regression, and the approach derives business insights from real-world collaboration data. The study showed that the effects of collaboration patterns differ based on the types of tasks. According to the authors, the findings are helpful in prioritizing the limited attention of managers on certain tasks for intervention.

2.4 Feedback Systems

Sarah Tausch (2016) studied the effect of feedback systems on improving collaboration and shows that providing feedback on collaboration to teams, especially through a computer-mediated system, enhances problem-solving (Tausch, 2016). She employed group mirrors techniques (also known as social mirrors) to produce feedback on collaborative works in the group processes. Tausch by referring to Jermann et al. (2001) draws a distinction between three different feedback systems; 1) mirroring techniques, 2) metacognitive tools, and 3) guiding systems (Figure 3). A mirroring system reflects the existing state to the group using the aggregated data. A metacognitive tool by comparing the current state with the desired situation goes a step further, and a guiding system directs the team by providing advice.

Figure 3. Mirroring, meta-cognitive and guiding systems according to Jermann et al. (2001) and Streng et al. (2009), as cited in (Tausch, 2016)



While literature on process feedback is less extensive than outcome feedback, evidence support the idea that process feedback can be as effective as outcome feedback to enhance performance (Earley et al., 1990; Geister et al., 2006; McLeod et al., 1992; Paulson Gjerde et al., 2017). Geister et al. (2006) to address the challenge of feedback deficit about team processes in virtual teamwork, provided feedback through an Online-Feedback-System (OFS). A longitudinal study of 52 teams was conducted, where motivation, interconnection aspects, and task-related aspects were observed. The results suggest that compared with the control groups that did not use the OFS, teams that used the OFS showed improved performance. Moreover, results indicate primary motivation as a moderating variable on the improvement prompted by the OFS. The less motivated team members were positively affected by OFS in both motivation and satisfaction. Furthermore, interpersonal trust was a mediating factor for less motivated team members.

2.5 Summary, and Forming the Hypothesis

It seems that there is no single and common definition of collaboration and opinions cover different characteristics depending on the context and discipline. However, **engagement** is a common element in all above-mentioned definitions. As discussed, according to Wood and Gray's (1991) definition, engagement occurs in the interaction process as a change-oriented relationship. Thomson et al. (2007) believe that all actors **interact** throughout all the stages of collaboration. The definition given by Lai (2011) is fundamentally based on "**mutual engagement**". And Griffiths et al. (2020) used the term **Active Engagement** and showed that a collaborative engagement consists of two steps; Active Participation and Shared Responsibility.

Although the definitions of collaboration, its process, and development are not the same across different opinions, the need to improve collaboration is a widely accepted view. However, in the proposed methods often there is a need for surveys, training or the presence of an agent. The fully data-driven approach by Fan et al (2017) is different and not relied on the traditional time consuming or costly method, however, the proposed method by Fan et al, designed for software programming teams.

We believe that e-collaboration technologies have not sufficiently addressed the issue of poor collaboration. And this case needs more exploration, the more data and research we have in this field, the better future technologies can help us in enhancing collaboration.

Based on the discussed topics, this paper proposes and examines three main hypotheses:

1. Active Engagement is meaningfully correlated with collaboration.
2. Active Engagement is automatically measurable through analysing log data in e-collaboration activities.
3. Visualized results from log analysis (hypothesis 2) is useful in preparing team performance reports and creating a computer-mediated feedback system.
4. Using the process feedback in hypothesis (3) significantly changes the pattern of engagement and outcomes.

Later, we apply and redefine these assumptions according to the case studies.

3. RESEARCH DESIGN AND METHODOLOGY

In an iterative process, followed by forming the research questions and hypothesis, all the stages started with observing design teams, then a literature review. When the question and initial hypothesis are formed, a descriptive study was conducted (study I). Next, the second round continued with a prescriptive/comparative study (study II). Figure 4 shows the procedure and setup of the two studies.

For example, the first case study ignited with the observation of a technology planning and road-mapping course. Four teams of engineers were working on a different complex engineering project and the deliverable was a collection of well-documented designs and research on a Wiki-based page. The entire process was held online. We started to track the activities in the online meeting rooms

and then search for clues through the data logs. A clear inequality of contributions was observable. However, instructors do not pay any attention to the engagement level of the participant; instead, they provide detailed technical feedback on outcomes after each review. We started digging the literature to design a study. Next, we conducted a pilot study (Study I). After reiterating the literature search, we reported the initial results. From this point, the process repeated for study (II). More detail on study I and II are provided in the next section.

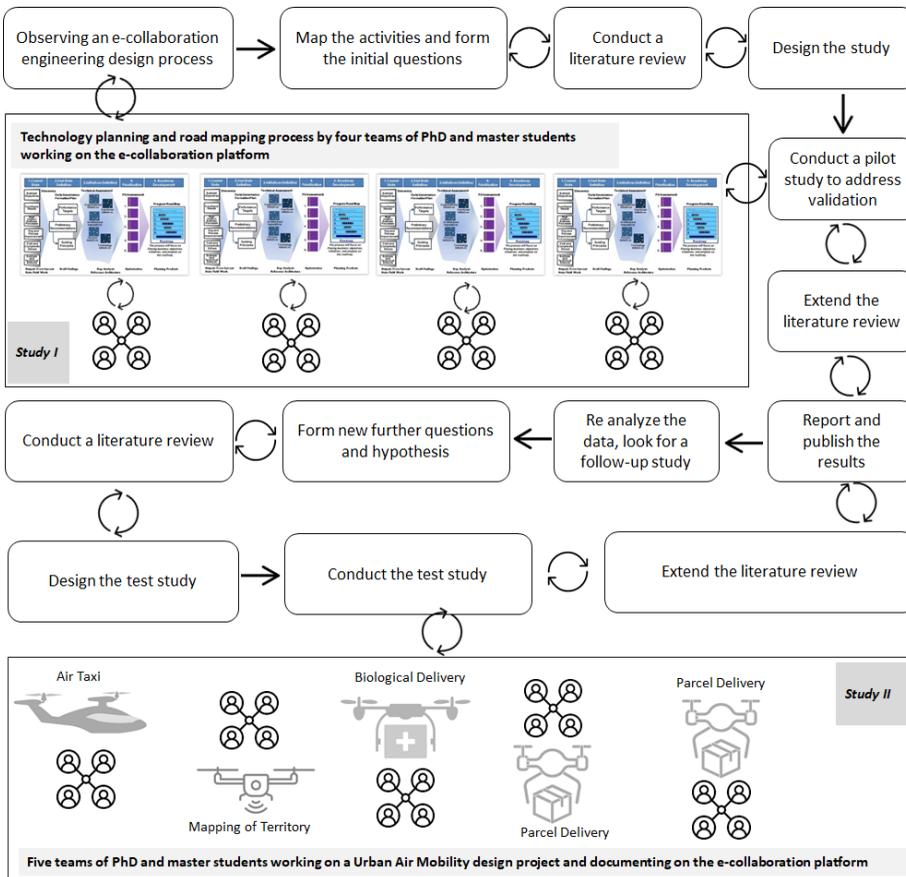
4. CASE STUDIES

In line with the objectives of this study, two case studies have been conducted. The first study presents a design to analyse engagement in web-based collaboration and using the results in a feedback system. When the design completed, we applied it in a pilot study and through a questionnaire gathered the opinion of team members. The first study submitted at a conference, was accepted, and is in the press to publish (The study will be cited here after the final acceptance). A summary of the study is reported in the study I section.

4.1. Study I

We used an input, process, output model (Farshad & Fortin, 2023) to design a system that is able to utilize log-data of e-collaboration and map the engagement level of team members (Figure 5,

Figure 4. Research design



represents the system schema). Inputs are time and data elements based on frequency, volume, and synchrony. Active Participation (AP) and Shared Responsibility (SR) which are crucial building blocks of collaboration (as described in the literature review) are calculated. In the next step, a visual quantitate report is available as the process feedback. We are expecting a higher level of collaboration and better teamwork results after applying the system.

In the system presented in Figure 5, Active Participation (AP) is extracted from these inputs; (a) data volume (bytes), (b) time spent (days with a recorded activity), (c) revision (number of times the log recorded any edit). Shared Responsibility (SR) is extracted from these inputs; (d) the number of tasks that jointly worked with another team member, (e) the number of times that (e) is repeated, (f) the number of people with the (e) process. All the units are in percentage. Active Engagement (AE) is calculated from the average of ‘a’ to ‘f’ by taking into account the respective weights (more details available at; authors (2023)).

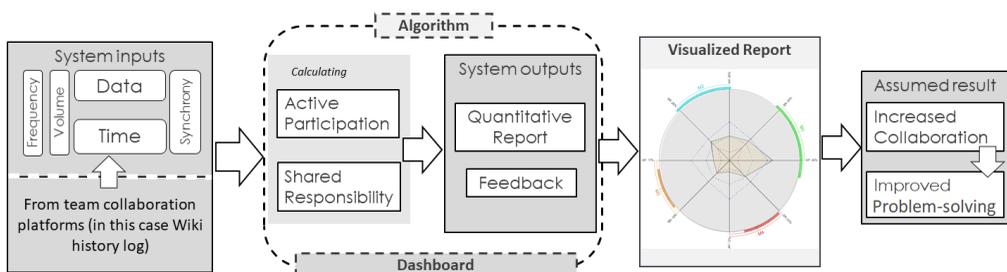
To examine the validity of the method, we designed case study I, where, we had access to the history log of four teams of engineering students in a technology planning and road-mapping course while documenting all the project activities on a Wiki page as the e-collaborating platform for delivering the project requirements. The participants had to deliver documentation of technology planning and road mapping (TPR). The stages of TPR included the following tasks:

- Defining the project’s scope
- Explaining technology vision and the existing state of the art
- Creating a timeline
- System modelling
- Doing the relevant literature review
- Exploring the relevant patent databases
- Presenting technical feasibility
- Preparing financial valuation and market research
- Applying risk and uncertainty analysis
- Listing and citing the scientific references

After gathering the data from projects’ history logs and applying the method, we prepared a report and sent them to all team members via email. The definitions, procedure, and graphs were presented to all the teams beforehand. Figure 6 is an example graph of the mapped data after analysing. In the end,

We used a questionnaire survey and asked the participants to rate the accuracy of the report. According to the results, 75% of participants believe that the accuracy of the report for showing the team engagement is 70 to 80%, but 25% believe that the accuracy is 30 to 40%. To answer the question of applicability of the report to improve team collaboration; 75% believed that the usefulness is higher than 50%, while others doubted a high usefulness.

Figure 5. System’s process, input, and output (Farshad & Fortin, 2023)



In a follow-up short group interview with volunteers (one from each team), we asked; what was the most unpleasant situation you observed while working in a team related to collaboration. All interview participants agreed that a heterogeneous engagement in the tasks was a challenge for the team.

To answer the question what would you suggest to improve the feedback report? It was jointly suggested to use only one scale instead of two (meaning that instead of SR and AP, only use Active Engagement (AE) in the graph)

The drawback of the model is that it could not completely cover all the teamwork, because teams normally relay in more than one platform for teamwork (e.g. communication, configuration management, coding, search, etc.). However, the aim of the study was not to measure the entire collaboration; instead, we tried to investigate the possibility of facilitating the measurement on a specific portion of the collaborative work in one hand, and the correlation of active engagement with the general collaboration on the other hand. Having that said, if we could do the first step successfully and find meaningful correlations, then we can expand the system outside of the one specific platform. To give an example, Figure 7 represents a team of four members working on N different e-collaboration platforms, different patterns of engagement and different levels of importance are associated with each. Members can agree on the weights (W) first, then the performance is determined for each platform. Finally, to define the overall level of engagement, equations 1 and 2 respectively calculate the total activity of each member, and the whole team's performance.

Through an Application Programming Interface (API), it is possible to integrate and unite all the platform results. One of the problematic issues could be analysing data from communication platforms because of the natural language complexity; machine-learning technique might be able to address.

4.2. Study II

This study was conducted to test the effectiveness of mirroring AE to teams as process feedback. During an eight weeks project-based Systems Engineering course, 25 students from 14 different disciplines and 8 countries were equally distributed in five teams according to their expertise, nationality, and gender (Table 4). While the structure of the teams was not set randomly, and they were designed to match a normal distribution. The studied groups were determined randomly. Two teams (teams 1

Figure 6. A schema design of the visualized results of the team contributions analysis

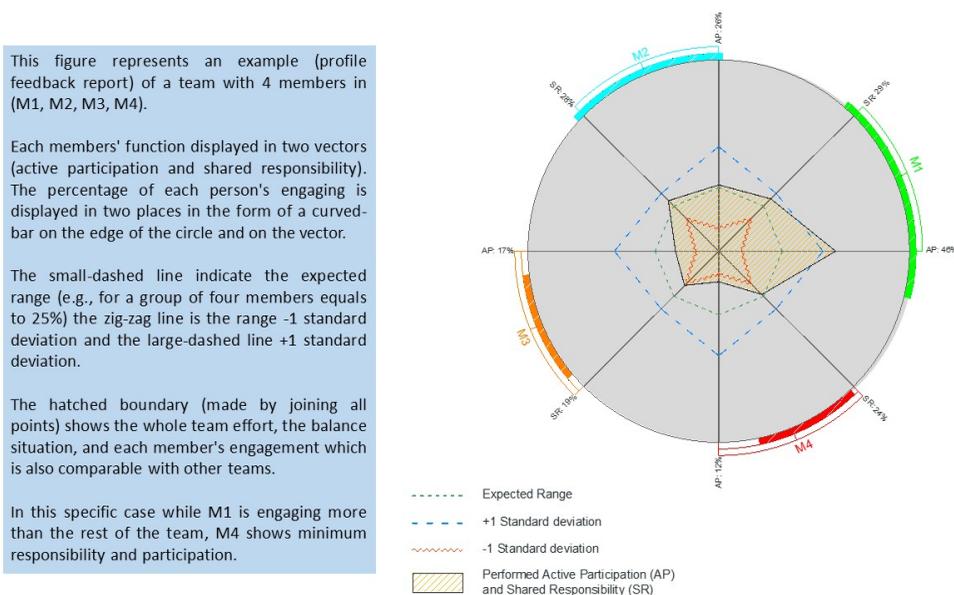
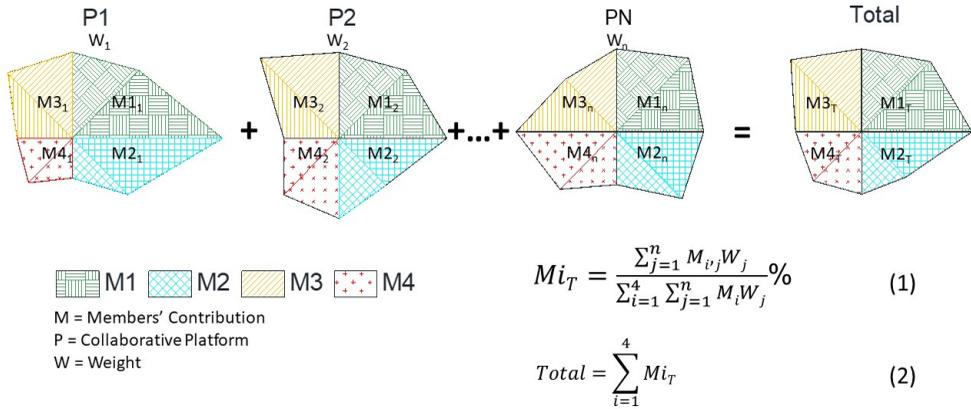


Figure 7. An example of four team members working in N number of collaborative platforms (Farshad & Fortin, 2023)



and 2) were randomly assigned to the test group and the other teams were considered as the control group. Two participants dropped the course in the first week in the control group (teams 3 and 5) which made these teams continue with four members.

The projects are defined as an Urban Air Mobility development mission including five projects (Air ambulance, Parcel delivery, Mapping of territory, Air taxi, and Biological delivery). Teams optionally selected a project, and there was no limitation to selecting a duplicated topic. In order to fulfil the requirements, they had to follow the System Engineering methodology (V-Model) as outlined in INCOSE System Engineering Handbook (Haskins et al., 2006) and deliver the requirements in two stages (Table 3) including a working physical prototype.

All teams were provided with an Unmanned Aerial Vehicle (UAV) prototype that was modifiable to meet the projects' objectives. On PDR and CDR days, teams presented their project and five domain experts graded the presentations.

The main hypothesis of this study defined as follows:

1. The pattern of engagement of groups is not significantly different in the first weeks.
2. Teams who receives process feedback (test group) show significantly improved patterns of engagement (more balance and less inequality) compared with the control group.
3. Improvement in engagement leads to better results (higher grades in system design)

Table 3. Project deliverables and review stages

First Stage (Week 4) Preliminary Design Review (PDR)	Second Stage (Week 8) Critical Design Review (CDR)
<ul style="list-style-type: none"> • Mission Objective(s) • Concept of Operation (by sketching) • Stakeholder Analysis (Value network) • Stakeholders Expectations • System Requirements • System Model (IDEF0) • System Architecture • Risk analysis • Prototyping plan • Schedule (Gantt chart) 	<ul style="list-style-type: none"> • Improved PDR (according to the feedback) • Assembly Integration and Test (AIT) plan • Validation and Verification (V&V) plan • The results of AIT and V&V • A working prototype

Table 4. Participants and teams

No.	Master Degree	Bachelor Degree	Gender	Country	Team
1	Engineering Systems	Quantum physics and nanoelectronics	F	Russia	1
2	Aerospace Engineering	Embedded systems	M	Russia	
3	Engineering Systems	Electronic Systems Engineering	M	Syria	
4	Engineering Systems	Robotics	M	Russia	
5	Engineering Systems	Applied math and physics	M	Moldova	
6	Engineering Systems	Computer Science	M	Russia	2
7	Engineering Systems	Robotics	M	Russia	
8	Aerospace Engineering	Mechanical engineering	M	Kazakhstan	
9	Engineering Systems	Nuclear physics and cosmophysics	M	Russia	
10	Engineering Systems	Aerocraft Engineering	F	Russia	
11	Engineering Systems	Radio Engineering	F	Russia	3
12	Engineering Systems	Robotics and Mechatronics	M	Uzbekistan	
13	Engineering Systems	Aerospace Engineering	F	Turkey	
14	Engineering Systems	Robotics	M	Russia	
15	Engineering Systems	Aerospace Engineering	M	Russia	4
16	Engineering Systems	Machinery Automation	M	Russia	
17	Engineering Systems	Autonomous control systems	M	Russia	
18	Aerospace Engineering	Mechanical Engineering	M	Italy	
19	Aerospace Engineering	Aerophysics and Space Research	M	Russia	
20	Engineering Systems	Aerospace Research	M	Russia	5
21	Aerospace Engineering	Aerospace Engineering	M	Turkey	
22	Engineering Systems	Industrial Automation	M	Russia	
23	Engineering Systems	Aerospace Engineering	F	USA	

As a process feedback, during the project, the experiment group (test group) received a weekly report and statistics of their engagement level (Figure 8). The control group has not received any process feedback. Both groups received the same outcome feedback in PDR and CDR days.

4.2.1. Results

Table 5 shows teams, groups (Test or Control), project names and Preliminary Design Review (PDR), as well as Critical Design Review (CDR) results.

Figure 8 represents all teams Engagement change rate during the entire time on a bi-weekly basis. Teams 1 and 2 (Test Group) received these reports as the process feedback along with feedback report on PDR and during the course, while team 3, 4, and 5 (Control Group) had not received process feedback. In the chart, 'Mn' refers to team members (M: Member, n: from 1 to 5).

4.2.2. Data Analysis

The variable we used to compare was the distance change between the green-dashed line (+StD) and the red-dashed line (-StD) in the charts. As the samples in this study are small (only two teams in the test group represented by only two values) and this is the minimum data required to show a meaningful

Table 5. Teams' performance over time

Team	Group	Project	PDR	CDR
1	Test	Air Taxi	10	13
2		Parcel Delivery	9.5	11.5
3	Control	Parcel Delivery	10.5	12
4		Mapping of Territory	9.5	11.5
5		Biological Delivery	11	11.5

difference; we used the one-sample t-test (equation 1) (Student, 1908) method for statistical analysis. With this approach, the whole class is considered as the population based on the first two weeks' statistics of engagement (Five teams). Then the differences between the groups and the population were analyzed independently for each group through the t-test over time. Table 6 shows the data, and Table 7 summarized the t-test result.

$$T = (\bar{X} - \mu) / S / \sqrt{n} \tag{1}$$

In equation (1) \bar{X} is the sample mean, μ represents the population mean, S is the standard deviation (equation 2) of the sample and n is the number of sample observations.

$$S = \sqrt{\frac{\sum(X - \bar{X})^2}{n - 1}} \tag{2}$$

In equation (2) X is each value from the population, \bar{X} is the sample mean, and n is total number of values.

Based on the analysis; hypothesis (1) of study II is accepted; no significant differences between the test and control group were observed in the first stage of the experiment (Week 2). However, the analysis shows a significant difference between test and control group in following weeks (e.g., in week 4 t-test of Test group is 0.03 significantly lower than 0.34 t-test of Control group) with this hypothesis (2) accepted. At the same time, the control group shows no significant change in the entire process. Comparing the weeks reveals that the maximum change occurred in the sixth week, while in the eighth week the teams show a tendency to return to the starting point, both in the test and control groups.

While the average CDR grade (Table 5) of the test group is higher than the control group (12.75 > 11.34), the difference does not appear as significant in the statistical analysis. However, as the PDR grade was in the Pass/Fail format, we could not compare the changes. With this, we cannot completely accept hypothesis (3)

5. DISCUSSION

To improve e-collaboration we suggested a data-driven approach combined with a feedback system that is a classic method. The feasibility of the designed method, its validity, and its effectiveness have been examined in two case studies. The results of the first study show that data logs are a rich source of information to analyze and interpret collaborative activities. In addition, data logs are suitable in programming and machine language, at the same time, produced reports from logs can be on a real-

Figure 8. Radar charts of Active Engagement change over time

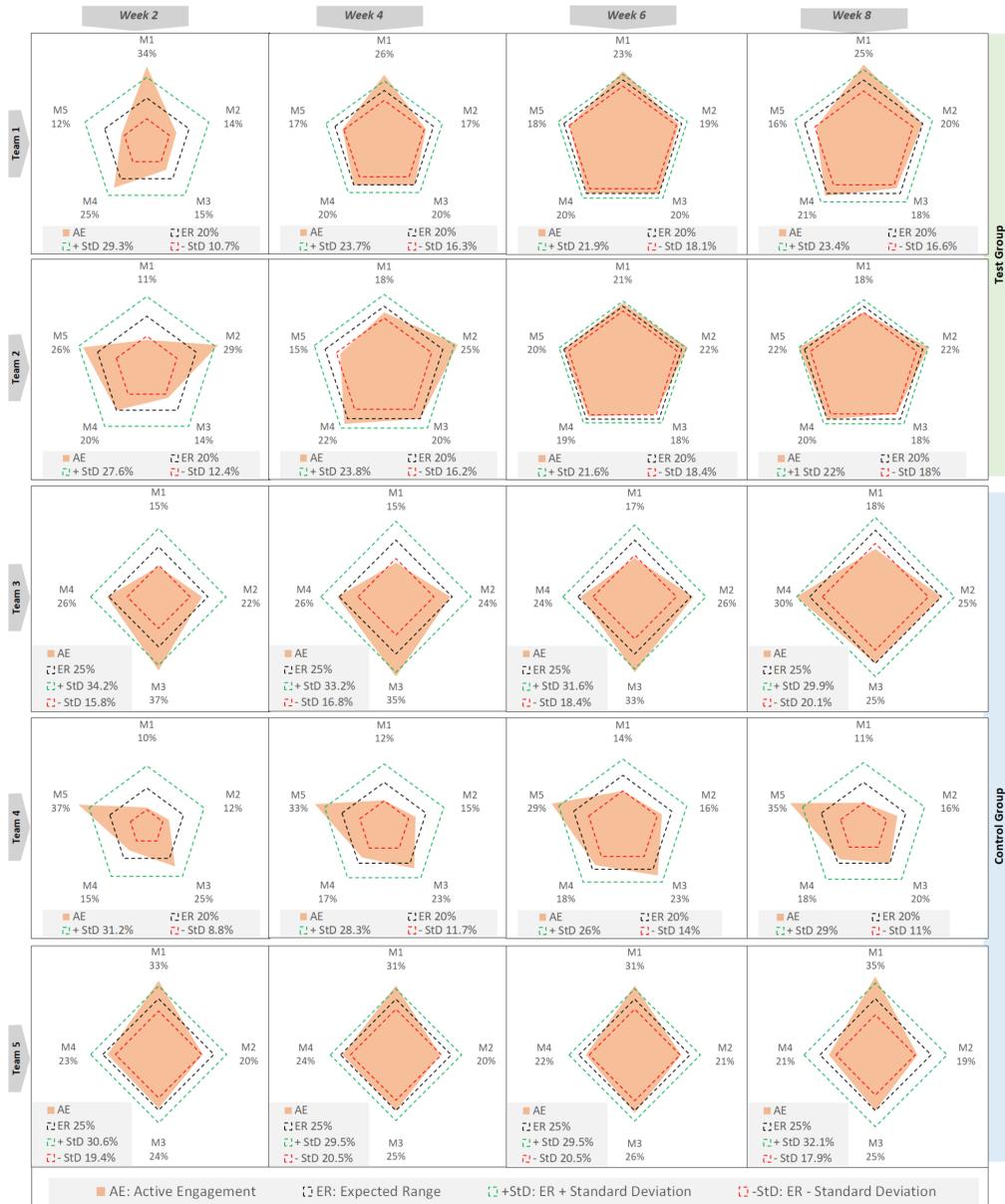


Table 6. Distance between +StD and -StD over time in teams

Group	Team	Week 2	Week 4	Week 6	Week 8
Test	Team 1	0.186	0.073	0.037	0.068
	Team 2	0.153	0.076	0.032	0.040
Control	Team 3	0.184	0.164	0.132	0.099
	Team 4	0.224	0.166	0.121	0.181
	Team 5	0.112	0.091	0.091	0.142

Table 7. One-Sample T-Test results (T: Test Group, C: Control, Sig: Significance)

Time	Week 2		Week 2 Vs. Week 4		Week 2 Vs. Week 6		Week 2 Vs. Week 8	
Group	T	C	T	C	T	C	T	C
t-test sig	0.95	0.96	0.03	0.34	0.015	0.168	0.033	0.462

time basis, fact-driven, and fast. These results are in line with previous research on online collaboration and data-driven approaches (Fan et al., 2017; Iglesias-Pradas et al., 2015). The second study illustrates two different aspects. (1) A process feedback system can be designed by relying on the log data; this finding is novel. (2) Process feedback reinforces outcome feedback, and the participants reconsider their contribution and engagement. The positive effect of process feedback has been shown in previous investigations to improve group information elaboration and learning in virtual teams (Peñarroja et al., 2015). However, it is the first time that active engagement analysis through log-data is used in a process feedback study on e-collaboration. Although more studies are needed to expand and support the results, the developers of e-collaboration need to pay more attention to the improvement of the collaboration itself in addition to the technical improvement and provide users with tools to analyze teamwork and the level of members' engagement. This point is essential to managers to have a map of design teams' awareness, as well as in project-based learnings.

This study has some limitations; for instance, the number of participants were small, we tried to mitigate this problem through careful data collection and double-check all the analyses. The other point is the studies conducted in an educational setting. At the same time, the projects were engineering activities and strictly followed a particular structure, these limits the generalization of the results. Clearly, collaboration and team dynamics go beyond data input and time spent at the computer in virtual teams. Accordingly, the context of work, as well as the engagement itself, are equally important. This might be a limitation that is problematic to address. However, it sheds a light on another question; how does the context work reflect in the active engagement?

6. CONCLUSION AND FUTURE WORK

While the dramatic and fast shift from co-located teamwork to e-collaboration facilitates remote work, managers consider poor collaboration as one of the main reasons for teamwork failures. Classic methods of improving collaboration do not completely cover the digitalized environment, and the current studies to address the challenge are limited. The suffering from poor collaboration along with the massive market size is an opportunity for e-collaboration developers to re-imagine improving the essence of collaboration through providing analysis tools in addition to upgrading the technology. In this study, we suggested a new data-driven approach combined with feedback systems to improve e-collaboration. The results of two case studies showed that using data logs in a visualized process feedback system is technically feasible, and positively contributes to a more balanced engagement in teams. This means that team-monitoring dashboards in e-collaboration applications can benefit from the presented method.

Future studies can expand this investigation from several perspectives: first, using gamified process feedback instead of graphs and statistics. Second, digging into the conversation engagement through Natural Language Processing. Further, to repeat the research in the real-world environment outside of academia. Moreover, the relationship between the amounts of work that may be done beyond direct engagement in the background with engagement itself is a case to be investigated. Finally, during the process feedback, personal satisfaction with team engagement can be a measure to see how it changes with the feedback and with the level of engagements.

ACKNOWLEDGMENT

Authors would like to thank students and judges who participated in this study.

The authors of this publication declare there are no competing interests.

This research was supported by Skolkovo Institute of Science and Technology.

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