CONCEPTUAL FRAMEWORK TO STUDY TEAM COHESION IN HUMAN-ROBOT TEAMS

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ABSTRACT

Social Robots, part of current advanced technology, will be integrated into our daily lives across diverse use-case scenarios, including homes, hospitals, workplaces, and recreation. Though the area of Social Robotics has gained traction in recent years, the majority of the studies so far have studied single-human and single-robot interaction. In comparison, Social Robots are increasingly being placed in human teams, likely affecting team dynamics. On the other hand, Engineering teams work together to deliver outstanding results and the processes in these teams are social. We propose that Social robot can be added to engineering human team to enhance team cohesion and performance. Therefore, this paper presents a preliminary framework towards developing a conceptual framework to study team cohesion in Human-Robot Teams (HRTs) in engineering context, looks at different roles of social robot and how the responses, behaviours, emotions of social robots shape outcomes in the engineering team. The research specifically focuses on team cohesion because team cohesion is reportedly one of the most critical concepts in team dynamics. The paper outlines the research objectives, framework and concept workflow.

Keywords: Teamwork, Organizational processes, Research methodologies and methods, Artificial intelligence, Societal consequences

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1 INTRODUCTION

Advanced technologies like robots, voice assistants, and agents are becoming an integral part of the daily life of humans. Humans use voice assistants such as Alexa or Siri to access information and task management easily. In-home service robots, such as the robotic vacuum, Roomba, represent an area of home technology designed to help people with household chores. Industrial robots help industries in manufacturing and production. Also, robots are increasingly becoming a central part of teamwork (Robert and You, 2014). Robots with human teams are used in various disciplines like search and rescue, space exploration, and minimally invasive surgeries. Human-Robot Teams (HRTs) are multiple-member collaborative teams exhibiting task interdependencies (Wolf and Stock-Homburg, 2022) Robots which interact naturally with humans, work as partners and interact socially with humans to get tasks done are called Social Robots (Cagiltay *et al.*, 2020). The exploration of the social dynamics and how Social Robots integrate into HRTs as part of our daily lives is still nascent. The industrialised world is experiencing a shift from industrial to social robotics (Taipale *et al.*, 2015). The presence and uses of HRTs are growing, especially boosted in the face of the various restrictions imposed by the COVID-19 pandemic. An estimated 82% of business leaders already believed in 2018 that HRTs would be a daily reality within five years. A recent study survey with 596 U.S. employees (65% men, mean age = 36.92 years, SD = 10.85 years) found that they could easily imagine working with a robot as a teammate (39%), team assistant (50%), or even team leader (34%)(Dell Technologies, 2018).

We are witnessing intuitive interaction and increasing acceptance of invisible actors daily– assistive interactive devices support team members in organisations. With increased human workload, assistive robots can reduce fatigue and free human cognitive resources from routine tasks. This will allow humans to focus on decision-making activities. Social Robots may also facilitate team building and thus create a friendly work environment. Similarly, Social Robots can be part of 'coordination teams'. Engineering teams work on design and manufacture of complex technical systems. There occurs constant agreements and disagreements among team members. Excitement and interest lies at the beginning of the project and with the time this graph may come down and team delivers project with certain outcome. Teams operate successfully when members are bonded together for a shared common goal. Cohesion is a force binding members together based upon attraction to each other or the group goals or tasks (Festinger, 1950). Cohesion phenomena are seen in Human-Human Teams (HHTs) in everyday life in all fields. As we see, technological advances, HRTs will become prominent in which Cohesion is an essential phenomenon.

This research focuses on making Social Robots more social through team cohesion phenomena and making them part of our daily lives in engineering context. We propose that a Social Robot can be added to engineering team, which elicits human interactions in team by its responses, behaviours and emotions. Despite the broad investigations of different interaction dynamics, addition of social robot in engineering teams has not been looked at, role of behaviours, emotions of social robot and how the behaviours, emotions social robots express and shape subsequent performance relevant outcomes in the engineering team. This study presents an initial exploration into the relationship between social dynamics specifically team cohesion and performance in engineering teams with the addition of social robot to human engineering team.

This paper is organised into four sections. Section two briefly provides the literature review of the research, describing related previous research on the subject. Section three provides the theoretical background for the research, describing important concepts of the subject. Section four talks about methodology used for framework. Section five presents the conceptual framework detailing the variables of interest and concept workflow. Section six concludes the paper with a short discussion of the proposed concept and the future work.

2 LITERATURE REVIEW

Team members collaborate with one another to develop ideas over time and eventually produce finished items. Hackman (1978) says the nature of their interaction has an impact on performance relevant outcomes such as the quality of final deliverables, the fulfilment of personal needs, or the willingness of a team to work together in the future. Researchers interested in uncovering the relationship between social aspects of designing in teams and performance have looked at a large

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variety of phenomena such question asking (Eris, 2004), gesturing activity (Tang, 1989), process changes (Frankenberger and Auer, 1997). Jung (2011) investigated the notion of Group Hedonic Balance, the balance between positive and negative affect expressed and experienced in a small group, as an indicator of performance in engineering teams. Negotiations play a crucial role in the interactions of engineering teams (Bucciarelli, 1988) and affective interaction dynamics influence their process and outcome (Curhan and Pentland, 2007). So, we can say there lies relationship between social aspects of designing in teams and performance. For an engineering team to deliver a project, Cohesion is required among team members.

The idea that Robots and agents could become part of groups and teams has developed from a promising vision into a reality (Hinds *et al.*, 2004). Increased use of robots is seen in small teamwork settings in the industry (Takayama and Go, 2012) and larger group settings at conferences (Neustaedter *et al.*, 2016). Fully autonomous systems are employed as part of groups and teams by performing delivery tasks in hospitals by working closely alongside people (Ljungblad *et al.*, 2012). Recent advances in Artificial Intelligence and conversational agents have led to an increase in the placement of robotic systems in groups across domestic such as Amazon Echo, Jibo, Google Home and work settings. So, we can say that Social robots can be part of engineering teams by promoting cohesion in team.

3 THEORETICAL BACKGROUND

Many facets of collaborative teamwork exist. The three main threads of a team include how time affects the team's process, how group norms evolve and become actual, and how information is acquired and shared within teams. Teams need many factors for their success and team performance. One of the factors is Cohesion. In HHTs, it is proven that Cohesion results in improving team performance. Now our goal is to improve/enhance cohesion in HRTs in engineering context.

3.1 Group development

What makes the teams deliver outstanding results? Theories of group development explain how a group's structure and interactions change repeatedly throughout time. The educational psychologist Tuckman (1965) explained a five-stage model of group development: Forming (the orientation stage, during which members of the newly formed group disclose themselves and exchange information), storming (a stage where disagreement and disunity are prevalent), norming (called the structure stage where the group establishes rules, roles, and unity), performing (performance stage) and adjourning (dissolution stage). The third stage norming talks about Cohesion which is an important phenomenon for teamwork. Establishing norms and rules forms better unity, and the group becomes a more intense experience for its members. These stages are similar to humans' maturity from infancy to old age. The dynamics of the group stabilise, the relationships among the members deepen, and the group gains expertise as it traverses the difficulties it must overcome at each stage. Outcome of engineering team is expressed in terms of team performance and satisfaction of team members. Technical knowledge, expertise, and interactional content are frequently sought as determinants of engineering team performance. Bucciarelli (1988) says the practice of designing in teams is inherently social.

3.2 Group dynamics and cohesion concept

There are many important group dynamics concepts such as cohesion, inclusion and identity in a group, structure and norms of group, formation, leadership, decision making, conflict, and intragroup relations. A cohesive group is an intense group which affects members, the group’s dynamics, and performance in many ways. Group cohesion is believed to be group dynamics' most theoretically important concept. The concept of group cohesion provides insight into various processes that occur in groups, including productivity, members’ satisfaction, formation, stability, influence, and conflict. Strong interpersonal bonds and a shared commitment to the group and its goals are the sources of cohesion. Cohesive, but the unity is the result of very different group processes. Cohesion represents a commitment to the team and the task (Forsyth, 2014).

Teams offer many benefits, but in large part, these benefits will be realised only in cohesive teams. As cohesion is important to the team and organisational performance, accurate measurement is essential. However, several issues complicate effective measurement. First, cohesion is an umbrella term used in many domains. Second, because cohesion has team and individual components, operationalising,

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measuring, and analysing cohesion at different levels is often difficult. Third, cohesion is thought to emerge over time (Salas *et al.*, 2015).
Cohesion is analysed in many directions, such as Conceptualization/definition (Unidimensional, Multidimensional); Dimensionality of measurement (Task cohesion, social cohesion); Operationalization/focus of measurement (Attitudes, Behaviors); Level of measurement (individual level, team level); Level of analysis (Individual level, team level) (Salas *et al.*, 2015). Big data, Sociometric badges, Physiological metrics, Content analysis, and External observer are the innovative techniques that facilitate the collection and analysis of cohesion data in complex team settings (Salas *et al.*, 2015). From the teams perspective, cohesion is considered as a multidimensional construct, and task and social cohesion are prioritised when measuring cohesion. Cohesion is multilevel since it operates consistently at the team level.
Cohesion makes successful groups, but groups that succeed also show more cohesiveness. Cohesion is a quality that develops in a group and that is measured by asking the group's members to rate the group's groupness on two levels (individual and group) in two categories (task and social). It has mainly been researched in the context of established groups (sports teams, therapy groups, work groups, military groups) and about performance.

3.3 Social robots in engineering teams

A social robot is one that exhibits social behaviour (functions) in a given environment and has an appearance(form) that openly communicates its desire to be sociable with any user. Social Robot contains a robot and a social interface. The aspects that have been created to make a user perceive a robot as having social attributes are all included in a social interface (Hegel *et al.*, 2009). Single Human and Single Robot interaction has been studied extensively in laboratory settings. But groups and teams of human and robot interaction have limited understanding in complex social settings. As robots increasingly become members of collaborative HRTs, robots could improve team performance by positively shaping team social dynamics, i.e., by team cohesion. Social robot can enhance engineering team interactions by its behaviours and emotions (Figure 1). Social robot interacts with humans through verbal and non-verbal channels and expresses emotions. Social robot can participate in the conversations and discussions right from the stage of Ideation and concept generation, research analysis, prototyping and testing, design development and refinement. Intervention of social robot in engineering team will also result in mental well-being and to maintain confidence levels of humans. Social Robot can help in Brainstorming with humans and can play various roles such as teammate, assistant, collaborator etc. Coordination, communication and collaboration enhances when social robot is in team, this will result in overall enhancement of team cohesion.
Our area of interest lies in a single robot and engineering teams. Our research focuses on interdisciplinary areas combining robotics, design, behavioural science, and artificial intelligence. To our knowledge, there is no notable conceptual framework for enhancing team cohesion in HRTs till now. Our approach is based on applying HHTs behavioural theories and concepts of social and organisational psychology related to team cohesion to HRTs. This helps us better understand the interaction of ongoing group processes in HRTs.

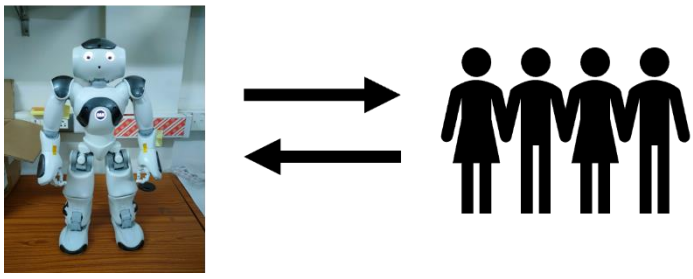

Figure 1. Illustration of social robot and engineering team

HHTs undergo team processes and bring outcomes, and involves various behavioural theories in these team processes. Research shows that HHTs are the bases for HRT research. Rather than one unifying theory, multiple behavioural theories can provide underlying mechanisms for HRI. Social identity theory (SIT) (Tajfel & Turner ,1979) defines that aspect of a person's self-concept that results from his awareness of his participation in a social group (or groups) and the emotional value associated with

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that membership. Self-Categorization Theory (SCT) (Abrams and Hogg, 1990) says why people tend to categorise themselves on a group-level rather than on an individual level because distinguishing successfully between groups enhances self-esteem and threatened self-esteem benefits from and motivates intergroup bias. Following upon these two theories in Human-Robot Teams, how robots and humans categorise and identify themselves in a team, such that the goal of the team is to enhance Cohesion.

4 METHODOLOGY

Our central research area is how to use Social Robots in human teams in engineering context, as there is a lot of scope for replacing or augmenting HHTs with HRTs. To address this need, our study aims to identify the roles, use cases for Social Robots, focusing on interactions in different organizations. HRTs consist of multiple robots, and their human-human and human-robot collaboration operators should be examined to understand better how these teams achieve their goals in synergistic ways. We propose a framework for HRTs that includes characteristics of an organisation's inputs, processes and team outcomes (Figure 2). Size and composition of HRT matter for changes in team cohesion. Feedback loops are considered for improving output in every new interaction. Robot and human role in a team can change depending on the context considered. From this we understand that Social Robot behaviour positively shapes team dynamics, it not influences HRI (Human-Robot Interaction) but also influences HHI (Human-Human Interaction). Thus, the Input-Process-Output framework involves multi-level concepts in HRTs.

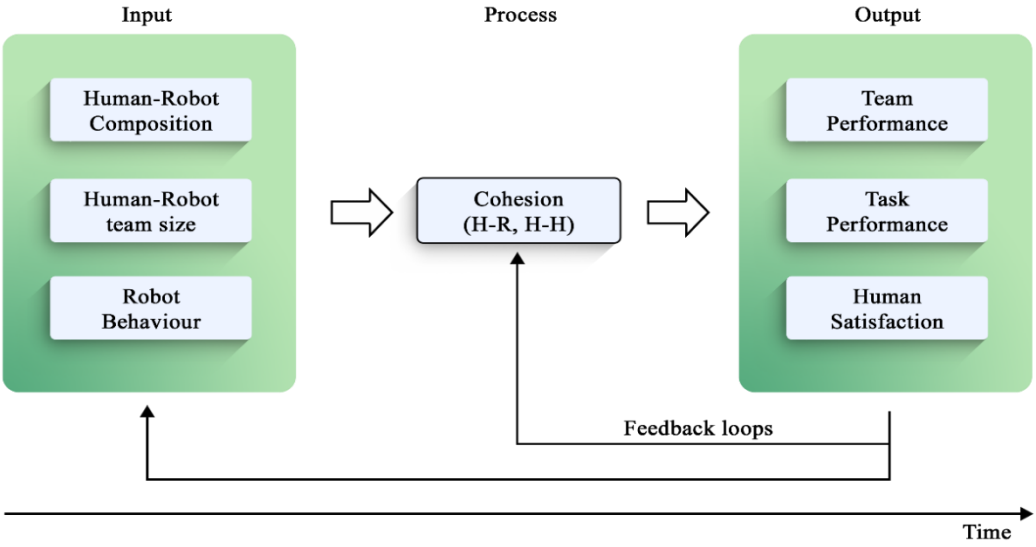

Figure 2. Input-process-output framework for human-robot team

Extending HHTs behavioural theories, such as SIT and SCT, that explain and support social behaviour to HRTs. The research seeks to make new theoretical and methodological contributions towards understanding HRTs. Therefore, it targets Key Performance Indicators (KPIs) like Team cohesion and task performance compared to HHTs and exhibiting socially supportive behaviour. The transactions between human-human and human-robot are assessed using the Transactive Memory Systems (TMS) approach. Information is encoded, stored and retrieved across distributed systems such as team members and robots (Singh and Mirzaeifar, 2020). Social learning modes like personal interaction, task observations, and interaction observations are involved in HRTs that form team mental models and their relation to team performance (Singh, 2009).

Our Research is based on theoretical arguments, thought experiments, and experimental observations. To know how the structure of a human-robot group can be engineered to enable the exploration of specific group behavior and dynamics, we hypothesize that adding a Social Robot to human engineering teams increases Team Cohesion. We also hypothesise that robot behavior which shows enhancement of Team Cohesion will yield good results both for team member satisfaction and overall

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task and team performance. So, how does a Social Robot increase Team cohesion? This is done by emotion and behaviour modelling of Social Robot in engineering context.

5 CONCEPTUAL FRAMEWORK

Successful teams have trust between team members and allow the team to learn from mistakes, take risks, and entertain diverse ideas. Strohkorb Sebo *et al.* (2018) said that robots' vulnerable behavior has "ripple effects" on their human team members' expressions of trust-related behaviour. The robot can act as an emotion regulator for a team and positively influence conflict dynamics, i.e., aid conflict regulation. This ability of robots in a team to aid teamwork extends the range of more task-oriented team processes that robots typically support (Jung *et al.*, 2015). When considering ingroup-outgroup in HRTs, verbal support from a robot can increase the participation of marginalised or outsider team members (Sebo *et al.*, 2020). Verbal support from a robot positively shaped psychological safety and inclusion, and verbal support from the robot inhibited the verbal backchannels that ingroup members directed toward outgroup members (Sebo *et al.*, 2020). The number and type of robots observed by humans had an interactive effect on responses toward robots, leading to more positive and negative responses for groups for some robot types (Fraune *et al.*, 2015). A recent paper by Abrams and der Pütten (2020) proposed the I-C-E framework to distinguish between Ingroup Identification, Cohesion and Entitativity in developing an understanding of a robot's positioning within a group from an individual or group-level perspective. We can say from the literature that factors contributing to Cohesion in the team are trust, psychological safety, inclusion of teammates, collaboration, coordination, communication, conflict resolve enhances by addition of social robot to engineering teams (Figure 3).

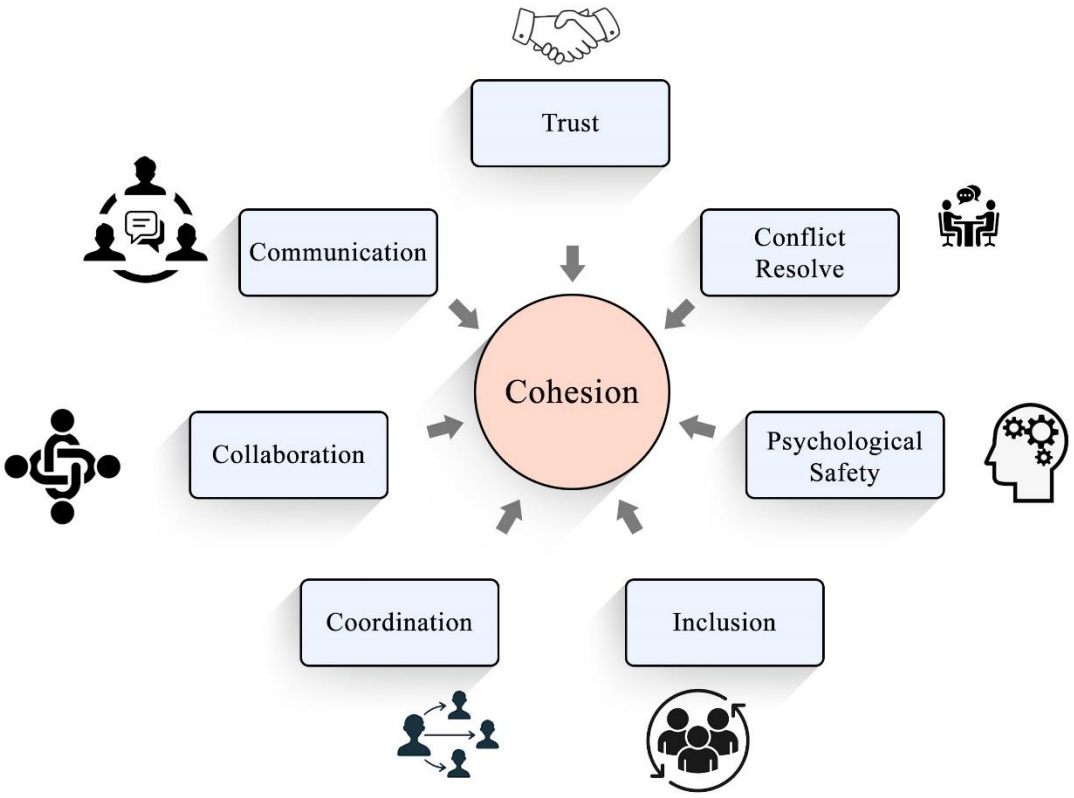

Figure 3. Factors contributing to cohesion in the team

Teams define design requirements, develop design concepts, create detailed design drawings in any engineering project- Social robot can take part in all these steps. One such scenario illustrating example of having a social robot in a engineering team is Design of a simply supported beam. Here, we consider robot's role as a teammate, which discusses with team about determining the load, calculating the span, allowable stress, bending moment, shear stress, cross-sectional area and gives suggestions to the team. Social robot socializes, have team and task mental model, and gives updates

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to the team continuously based upon the model trained. This timely reaction ensures that no crucial brainstorming points are overlooked. By the use of AI, social robot responses correct information and real-time sensing helps robot behave and express emotions according to situation. We expect social robot by its behaviour and emotion promotes coordination, communication, collaboration in the team. In addition to this, social robot does increase trust among team members, psychological safety of team, inclusion of team members and easily resolves conflict among team members. These all result in cohesion enhancement by a social robot in the team. Social robot keeps energy of team high by its behaviours, assisting continuously on design problem. Social robot by its behaviour not only influences Human-Robot Interaction but also influences Human-Human interaction which is mainly required in engineering teams for working on projects. Through the cohesion, it results in satisfaction of the team and improvement in team performance. In a newly formed team or sophisticated discussion team, humans may be hesitant to state their opinion on given design problem, social robot by its gesturing and backchanneling enable humans to express their opinions and feel at ease. Otherwise, if a human is asked by other teammate, he may feel less at ease in that team environment. Social robot adds advantage to this situation.

The proposed solution to enhance Team Cohesion is response, emotion and behaviour modelling of robots in engineering context for seamless interaction between social robot and human team. Social Robots can influence group interactions through their nonverbal and verbal behaviors. A robot's use of nonverbal behaviors (e.g., gaze, proxemics, gestures) can socially cue group members to produce desired responses. Additionally, robots are capable of expressing emotion, showing emotional indicators, recognising human emotions, empathising with members, and verbally influencing the affective status, or mood, of a group and its members as well as personality traits including collaboration, competition, trustworthiness, and warmth. Overall concept workflow is shown in Figure 4.

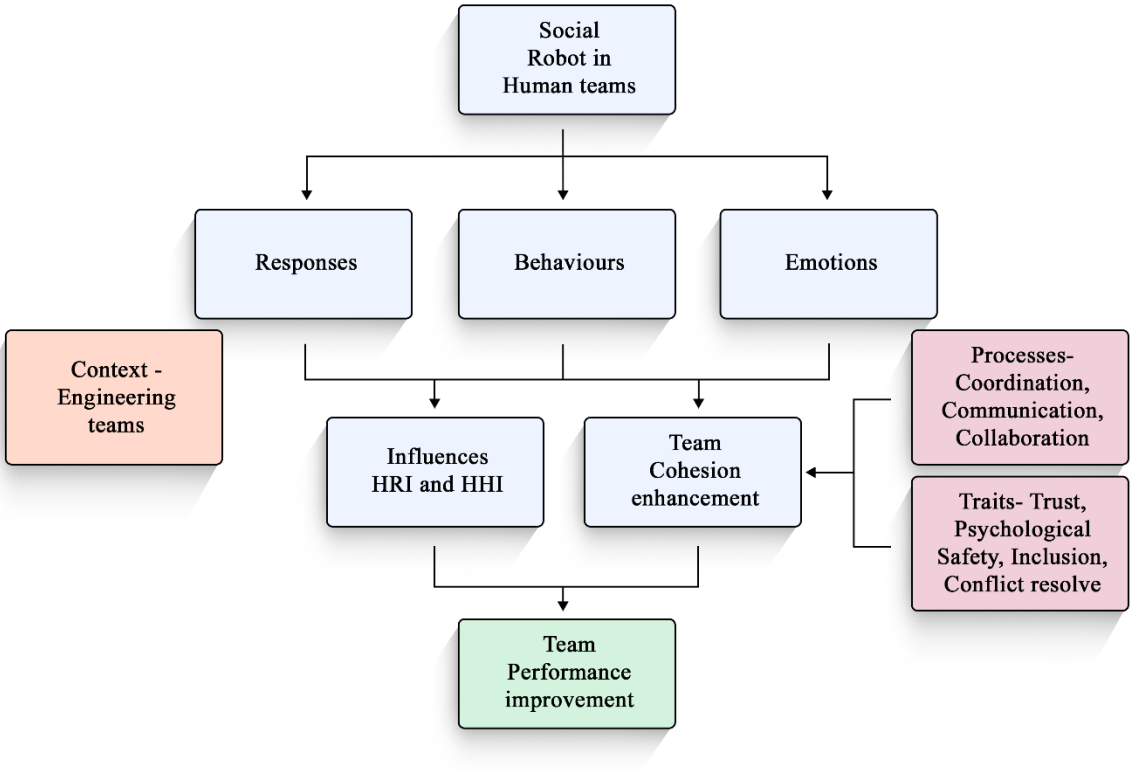

Figure 4. Concept workflow

These all justify that there are chances of enhancing Team Cohesion and Performance by addition of social robot to engineering team. It also results in seamless interaction between humans and robots. As the robot lacks the Mental Model of Team members, AI will help the robot to learn from humans through observations in the team for real-time sensing decision-making. Cohesion is generally assessed using questionnaires and surveys in HHTs during different stages of Team development. In HRTs, Cohesion can be assessed using behavioural and survey measures by performing Human-

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Subject experiments. Though there are many types of cohesion, Task and Social Cohesion are considered important for teamwork. Both Task and Social Cohesion are measured from insider member group perspectives at individual and group levels.

6 CONCLUSION

This research is a preliminary stage at understanding team dynamics and cohesion. Based on the literature review so far, we hypothesise that adding a Social Robot to human engineering team increases Team Cohesion. This is our initial step to develop a framework of cohesion enhancement in engineering teams. We expect the growth of social robots with various roles as a part of team in many use case scenarios such as business, design and manufacturing companies, consultancies etc. Future works include conducting Human-subjects experiment, how people are perceiving the social robot in the team, cohesion and team performance assessment. To check whether our framework can be generalized to different types of groups across a variety of contexts, effect of team size, formal leadership structure, type of engineering tasks e.g., maybe highly ambiguous tasks. For robots interacting with groups, it would be helpful if a robot could measure group cohesion through observing the real-time behavior of group members, so that the robot could adapt its actions based on the current cohesion of the group, rather than having to rely on an infrequently administered questionnaire.

Engineering team performance is seen as determinant of technical engineering skills. These skills however can only come to bear in the context of interactions. The ability to build those interactions by a Social Robot by regulating responses, behaviours and emotions of team members is therefore critical for building a team interaction context that is conducive for high engineering team performance. Responses, behaviours and emotions are not aesthetics, they are the drivers of high engineering team performance.

Future research aims to explore gaps in organisations where robots can work alongside humans to provide social support while enhancing team cohesion. The research will further explore the application of Social Robots in healthcare, education and industry to strengthen the virtuous circle of world economic growth. This research also aims to explore how humans and society can prepare for work-life context mediated by HRTs in daily life.

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