

# Robots in the Wild: A Time for More Robust Theories of Human-Robot Interaction

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Human-robot interaction (HRI) research to date has been dominated by laboratory studies, largely examining a single human interacting with a single robot. This research has helped establish a fundamental understanding about people as they interact with robots, how specific design choices affect interactions with robots, and how novel mechanisms or computational tools can be used to improve HRI. The predominant focus of this growing body of work, however, stands in stark contrast to the complex social contexts in which robots are increasingly placed. Developments in machine learning and tele-robotics, as well as compliant and social robotics, have occasioned more robots in closer proximity and even direct contact with people. Robots, especially mobile autonomous robots, are now deployed across work contexts and “sociable robots” such as Jibo, Cozmo, Kuri, and M.A.X. are increasingly becoming staples of household technology. These robots interact with people in everyday contexts across a wide range of tasks and situations, yet our research reflects a time when studies of HRI were possible almost exclusively only in laboratory settings. As a result, we have a limited understanding of how people will respond to robots in complex social settings and how robots will affect social dynamics in situ. In particular, our theories reflect an oversimplified view of HRI. The time is ripe for studies that tackle HRI in these complex settings and build generalizable theories about what to expect of HRI in the wild.

Although there is much to be learned in controlled laboratory settings and they should continue to be a mainstay of HRI studies, we argue that more HRI researchers need to venture into the

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workplace, the home, and into public settings where people are and will increasingly engage with robots. Further, we call for more studies that examine the effect of robots in multi-person contexts such as work teams, families, or groups in public settings to understand a robot's influence beyond a single person directly interacting with it.

## 1 UNDERSTANDING THE CONTEXT WITHIN WHICH THE SOCIAL TAKES PLACE

Studies that have examined robots in context have provided vital information about how robots change the way that people work, how people from different professions interact with robots, and how activities surrounding interactions with robots affect people's behavior and their attitudes toward robots. Research on hospital delivery robots, for example, has demonstrated that how people respond to a robot depends on patient needs, work practices within a given unit [10], and job roles [20]. The introduction of robots can also alter work practices and occupations. In a study of two pharmacy delivery robots in the United Kingdom, for example, Barrett et al. [1] found that pharmacy technicians expanded their role by tending to the robot whereas pharmacy assistants lost control over their work tasks, which were increasingly dictated by the demands of the robot and the technicians [1]. Studies of science teams operating remote rovers also tell us that working with a robot can alter fundamental aspects of scientists' practices (e.g., Vertesi [22]) and that increased autonomy can lead to questions about how to interpret a robot's activities [21]. Longitudinal studies of the Robovie robot in shopping malls also show that people tend to approach a robot in groups and are more likely to act on the robot's advice about what stores to visit if they feel they have a relationship with it [7].

Overall, from studies of robots conducted in situ, we have gleaned important insights about how robots fit into and change the social structures at work, at home, and in public settings, and how people behave when robots are intertwined with their daily lives. Unfortunately, studies of robots in context are too few. As a result, we cannot predict with confidence the effects that a robot will have across a variety of complex social contexts. It is hard to know when existing findings from the lab will hold since they tell us little about how people will respond to robots embedded in the complex web of activities and social relationships that characterize our lives. In order to build a generalizable theory of HRI "in the wild," we need research that provides a principled understanding of what to expect with different types of robots, performing different types of tasks, in different types of social situations and cultures.

## 2 UNDERSTANDING A ROBOT'S IMPACT ON THE SOCIAL BEYOND THE INDIVIDUAL

A growing number of studies have also demonstrated that a robot can affect its social environment beyond the person who is interacting with it. Such influence can play out in multiple ways. We know that robots can take the role of a mediator and actively influence how two or more people relate to or interact with one another. Early studies of robots used in autism therapy, for example, show that robots can shape how children socially interact with others (for a review, see Scassellati et al. [14]). The work of Hoffman and colleagues also suggests that nonverbal fear expressions by a low anthropomorphic robot can have a moderating effect in diffusing tension in marital conflict [4]. Expanding the focus from dyads to groups, Short and colleagues showed that intergenerational interactions between older adults and their families could be shaped through a robot's behavior [19]. Finally, Mutlu and colleagues [11] studied groups of museum visitors and demonstrated that even subtle, nonverbal gaze cues are sufficient to impact entire groups by shaping social roles. However, even robots that are not intentionally designed with a moderating role can shape interpersonal interactions, for example, by shaping norms of social conduct through their behavior. Lee and colleagues, for example, documented "ripple effects" of a robot's behavior as it influenced how people interacted with each other and as it influenced the shared norms that people developed

regarding appropriate ways of interacting with the robot [8]. There is also evidence that a robot's mere presence can affect how people interact with each other [2, 12]. Dole [2], for example, showed that participants looked at a nutritionist more and perceived her as less warm when in the presence of a physically embodied social robot as compared to a tablet computer or a nonsocial robot [2]. Taken together, these studies provide strong evidence that robots can influence how people interact with others, the roles that people assume, and the norms that groups develop.

Despite this evidence for a robot's impact beyond the individual, findings are not yet integrated into theories about how robots will impact groups of people. Having a theory that extends beyond a single human and a single robot is important. Without it, we cannot predict how certain design choices will impact the social environment in which the robot is placed and the consequences of such an impact. One area in which our lack of theory is particularly apparent is robot-supported work in teams. Early attempts to theorize the impact of robots on teamwork exist [18, 24] but are far too few and limited in scope. We have little understanding about a robot's influence on processes that are core to a team—such as decision making, conflict, or coordination—despite decades of research on teams that establishes that such processes are crucial for the short- and long-term functioning and performance of teams. Developing a theory about a robot's impact on teamwork is pressing since despite initial doubts [3], the idea that robots will become an integral part of teams is increasingly viable. Autonomous robots already support work teams in offices [8], hospitals [10], manufacturing [13], and space exploration [22]. Especially given recent efforts to develop autonomous robots to support even high-stakes teamwork, such as surgery [16] and fire-fighting [5], we need to build a principled understanding about how robots are likely to affect group processes and dynamics. The performance of high-stakes teams and sometimes even their survival depends on a team's social functioning, as has been well established from studies such as Weick's analysis of the death of a team of firefighters due to a breakdown in team communication and social structure [23].

### 3 WHERE TO GO FROM HERE?

We believe that, as more of these robots permeate our workplaces, homes, and public settings, the time is right for more studies of autonomous mobile robots in the wild. Studies should include qualitative and quantitative approaches but optimally examine behaviors and interactions over long enough periods to see how robots are integrated into and change the context over time. Responses to and effects of robots are likely to be especially sensitive to professional practices, status structures, social identities, and cultural norms. In particular, how people and groups are affected by different levels of autonomy, methods of interaction (e.g., voice, text, etc.), and the role of the robot are likely to be highly dependent on context. We advocate for studies that examine design elements in multiple different contexts, including different types of workplaces, homes with different types of family structures, and a range of public settings. There are, of course, good reasons that field studies are less prevalent in HRI, including limited numbers of mobile autonomous robots deployed and in use, issues with the cost and reliability of robots, and the time and expense of conducting field studies. This is changing, though, as robots become more reliable and more commercially available.

We further call for more studies that explore a robot's influence on processes and dynamics of groups and the consequences of such influence as well as efforts to integrate findings into theory. As “much of the world's work is done by small groups (e.g., juries, work units, army squads, athletic teams),” [9, p. 621], and efforts are underway to support work with robots in a wide variety of areas, we think it is particularly timely to learn more about robots in work teams.

A focus on a robot's impact on group dynamics also opens novel opportunities for design, especially when it comes to robot-supported teamwork. Most existing research on human-robot

teamwork has been focusing on developing task-centric techniques that allow a robot to support a single human in accomplishing a task, for example, by supplying needed parts to complete an assembly [17]. Focusing on a robot's impact on group processes acknowledges that work is typically performed by more than one person and opens possibilities for robots to better support teamwork through more social roles. Studies by Jung et al. [6] and Sebo et al. [15], for example, show the potential for robots to shape processes such as conflict and trust in teams even though an impact on group performance has not yet been demonstrated [6, 15].

As HRI researchers, we have the opportunity to break new conceptual ground by conducting research on people and robots in the wild. With robots moving increasingly into our workplaces, homes, and public settings, more opportunities will arise to study people and robots in complex social settings characterized by multiple people, roles, tasks, goals, and dependencies. Comparative studies in these settings can help to explain variations in responses as a way of building theory. We also advocate for leveraging more theories from the social sciences and assembling interdisciplinary research teams that span robotics, design, and the behavioral sciences. Taking up this challenge, we argue, will lay the foundation for more robust, nuanced, and comprehensive theories of HRI.

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