Humans, Robots, Teaming, and the Future of Work

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Introduction

Whether it's digital agents or physical robots, semi-autonomous intelligent systems are poised to have a big impact on the way organizations get work done. But are organizations prepared for the challenges of incorporating these systems into their operations?

There's no question that intelligent systems offer substantial benefits to organizations across industries. They can amplify the value of human workers: Robots can go places that are difficult, dangerous, or impossible for people to go; they can do some things more effectively, and free up human workers to perform more cognitively demanding tasks. But when organizations aren't prepared to effectively incorporate the technology into their operations, these opportunities are missed or delayed.

Based on observation of early adopters, we argue that getting ready to incorporate semi-autonomous intelligent robots into the workplace is best thought of as more than a matter of adopting this technology; it's **part of a bigger transformation in the nature of teams and of teaming**, driven by a number of factors, including maturation of digital collaboration technologies and visualization technologies, as well evolving demands of modern work processes. We believe that future of work will increasingly involve **cross-disciplinary** teams of **digitally-connected workers** that **operate seamlessly across locations**, and **some of them will be robots.**

In other words, the configuration of the teams is going to change, and the inclusion of robotic teammates is just one of those complications: As high-tech communication / collaboration channels become the context in which work gets done, successful collaboration depends on mastery of both the new collaboration channels and new team dynamics. The digital collaboration affordances available in cyberspace are different than the ones available in physical space. At the same time, increasing autonomy makes robotic agents (both virtual and physical) begin to feel less like tools that we use, and more like teammates – albeit teammates with very different affordances and capabilities compared to human teammates.

The successful workers of the future must be skilled at using the available channels to coordinate effectively with both their human and robotic teammates to carry out various tasks. The most successful organizations will be those that put together the right interdisciplinary teams – including both human and robot teammates - and then give those teams the right collaboration affordances, *and* help them build the skills needed to use those affordances.

Toward best practices for Human-Robot Teaming

The best practices for introducing, building, and training a workforce capable of successful human-robot teaming (HRT) are only now being discovered. To work toward codifying such practices, researchers from the University of California, Santa Cruz – Leila Takayama and Kevin Weatherwax (with research sponsorship from Accenture) – conducted a series of interviews with an early wave of expert HRT practioners: People who work with flying robots, service robots, telepresence robots, and deep sea robots all offered their insights. These interviews provide real-life examples of challenges and solutions related to HRT. Our aim in the rest of this paper is to distill insights that cut across individual interviews and domains, and to distill an initial set of general recommendations for developing more effective human-robot teams.

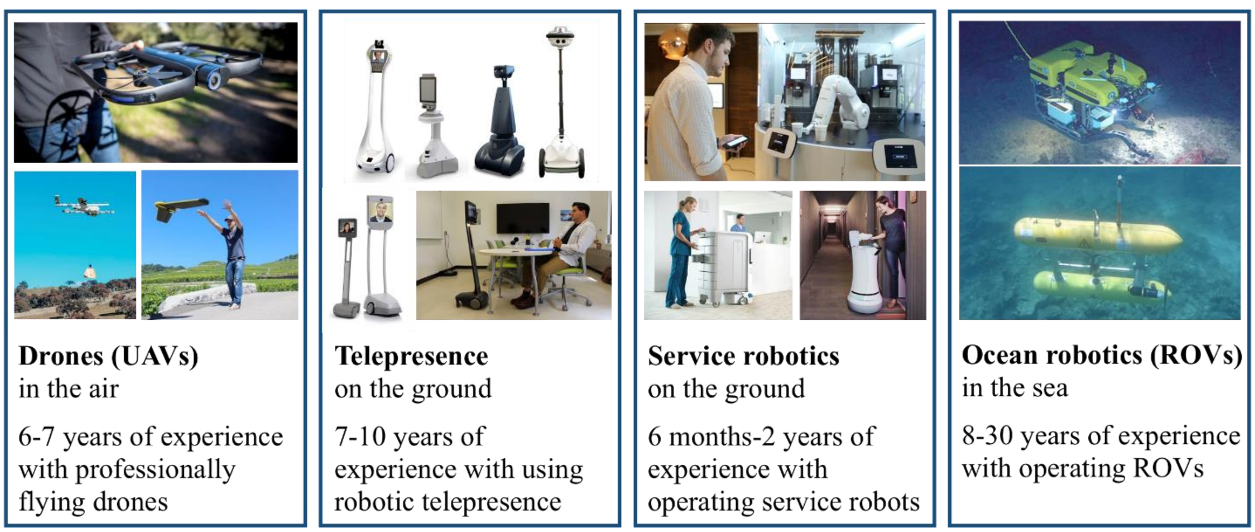

Figure 1. Interviewed robotic professionals had varying amounts of expertise with different types of robotic systems.

Semi-structured interviews with nine professionals partnering with robots for their daily work allowed us to explore the perspectives of those working successfully with robotic systems. This includes both human teleoperated systems and autonomous ones such as underwater and telepresence robots as well as drone and service robots.

Insights and Recommendations

We identified several insights for human-robot teaming.

- Human-robot teams are more effective when the **human teammates participate in the integration and customization of new robotic systems**.
- Human workers need **strong communication and coordination skills** for working with increasingly diverse teammates, especially when the team is distributed across locations.
- **Informal training and mentorship** have been critical to developing robot operation skills.
- The most effective human-robot teammates today may be those who have been **digitally connected for years**.

These insights are instructive and point to recommendations for organizations that are looking to incorporate robotic systems into their workforce.

Recommendation 1: Include robot operators and their human team-mates directly in the integration and customization of robotic systems

Toyota automobile manufacturing lines actively encourage on-the-line employees to provide feedback toward the adoption of new technologies and improvements to their existing operational procedures (Takeuchi, 2009). Similarly, we observed that more effective human-robot work teams also incorporated employee perspectives and recommendations into the integration and customization of robotic systems. Without those viewpoints, valuable insights and opportunities to improve human-robot interactions are lost.

> *The engineers go through and program all of the interfaces and they write all the codes but they… don't actually sit down and pilot all of the robots so a lot of the nuances and a lot of the interactions get lost between the cracks. (Service Robot Operator B)*

Almost all of the robot operators we interviewed provided some feedback and design recommendations to the engineering teams that were building robotic systems, but the engineering teams were not always close enough to the operations to absorb all the nuances of the requirements. Having experience with using these robotic systems on a daily basis enables robot operators to provide grounded feedback to the team that is designing and deploying the robots. In some teams, this was done via a software development ticketing system and seating the operations team close to the engineering team. In other teams, this even involved the ad hoc formation of sub-project teams of an operator and an engineer, who worked together to add new sensors to the robot, enabling the operators to more effectively fly the robot. Sometimes it was possible for in-house engineering teams to make the requested changes, but sometimes it required calling in outside contractors for design and engineering support.

By including the operators in the integration and and customization of their robotic systems, work teams are better prepared to develop more effective human-robot work processes. This empowers employees to take ownership of decisions about when and how to incorporate robotic systems in their work processes. It also enables organizations to take advantage of the on-the-ground experiences and expertise of their employees to more effectively leverage the strengths of robotic teammates.

Recommendation 2: Select and train for strong spatial/cognitive and communication/coordination skills

Economic analyses of how robots are reshaping the workforce typically base their analyses along the dimensions of current human workforce abilities (e.g., manual dexterity, repairing skills), drawing from resources like US Dept of Labor’s O*net database (Bakhshi, Downing, Osborne, & Schneider, 2017). These analyses identify jobs that are susceptible to automation and predict a devaluation of the skills and abilities associated with those jobs. However, the jobs of people working with robot teammates have yet to be detailed. Moreover, current robot experts shared experiences that run counter to the typical predictions about how automation will reshape work. Specifically, they reported heavy reliance on sets of core skills and abilities for *collaboration* with robots.

Our experts described relying on specific (and somewhat surprising) core skills for success in their work. These core skills included: **spatial cognitive skills** to understand where and how partner systems are physically located, oriented, and moving; and **communication and coordination skills** to interact with the surrounding environment and entities with/through a non-human form or counterpart. Though the required skills varied depending on domain and hardware, all of our interviewees had a set of core skills to successfully work with, or alongside, their partner robotic system(s). In the majority of situations, robot operators are part of a *team* of other domain experts; they are rarely solitary operators.

Spatial Cognitive Skills

> *That's the difference between a good pilot and a not so good pilot... there's that 3-D quality, especially working with the arms... You are watching your sonar, you are watching where the vehicle is in relation to the ship, you are watching your tether, where your tether is being pulled on... You're watching the diagnostics to just make sure there isn't something going wrong... it's a learning process and some people can just process that stuff better than others. (Romotely Operated Vehicle Captain/Pilot B)*

In order to track and control a robotic system, operators have to shift their perspective. Although most described feeling that the experience working with a system itself yields expertise in core skills, Remotely Operated Vehicle (ROV) pilots also noted that "being a natural," which translated largely to one's spatial cognitive abilities, was an important aspect of control. When pressed on this point, one ROV pilot captain framed it as being able to split your consciousness, embodying the robot's physical body while staying cognizant of important information in your own personal space.

Some interviewees felt these perceptual shifting abilities could be trained with practice. This is similar to the more dominant view in sports performance science: While task-specific differences exist as a result of individual expertise, there are no significant differences in cognitive abilities in expert groups (Van Leeuwen, de Groot, Happee, & de Winter, 2017).

Communication and Coordination Skills

> *We're on this boat half the year with each other, you know, it's like being on a basketball court with people. …so… if you don't get along with your team... (ROV Pilot A)*

Inter and intra-personal communication and coordination skills are essential for human-robot teams and highlight how we understand the use of robotics in the workplace: shifting from tools to collaborators. Experts leveraged their interpersonal abilities to assist both human and robot teammates in performing their jobs. Depending on the domain, this could take the form of interacting with bystanders and customers localized near the robot (e.g., food service robot, health service robot) or interfacing more directly with human team members controlling different aspects of both the robot and task at hand.

Drone pilots acted as safety supervisors and models for engineers while the food service robot operator and service pilots relied on engineering staff to intervene in instances of exceptional breakdowns. ROV pilots work in *rotating two-person teams* to fly and operate the arms while also communicating remotely with the ship's captain. Service robot pilots reported taking strides to behave in ways that would provide people with positive experiences and views of their robots. This meant "reading" social situations unfolding around their robot and using their individual judgment to determine the best approach. Interpreting social cues are an especially important aspect of navigating the complexities of human society.

Robot operators need to employ their communication skills to get the harder parts of the work done, e.g., coordinating and negotiating with other project subteams, or easing new customers into trying out a new robotic service. There is a dire need for human teammates to provide the skills that the robots do *not* already have. For example, robot operators should not need to calculate the transfer functions to switch from Cartesian to Quaternion spaces; that is what the robotic systems can do more efficiently and reliably than people. Instead, operators bring high level skills such as critical and strategic thinking, creativity and empathy ensuring that all participants coordinate tasks that range from highy cognitive to physically remedial together effectively.

For robot operators, what also matters are spatial cognitive, and communication skills that complement the robotic system's skills and enable the person to effectively make sense of the world from the robot's perspective, so that they can perform collaborative tasks together.

Recommendation 3: Promote mentorship and apprenticeship within human-robot work teams

Today, there are some formal training programs being developed to prepare robot operators for jobs in spaces such as autonmous underwater vehicle operation (AUV; flying underwater) and unmanned aerial vehicle (UAV) piloting (flying in the sky). These programs tend to use more autonomous systems (e.g., Sensefly eBee UAVs) that put less of a burden upon human operators. While this might decrease the learning curve, we also know that there are real risks associated with operators become complacent when teamed with imperfect automation (Metzger & Parasuraman, 2001); spending too much time using automation without practicing manual control (Haslbeck & Hoermann, 2016) can leave pilots unprepared to operate effectively when they do need to take over manually. It’s critical to develop the skills necessary to take over control at a lower level when needed (e.g., when the position holding algorithms fail to perform as intended). To develop robot operating skills, it is also necessary to provide mentorship and informal learning opportunities, especially for newer employees.

For most of our expert robot operators, we saw a much heavier use of informal learning through mentorship as opposed to formal training through official certification programs. They practiced with an experienced robot operator until they had achieved sufficient ability, which eventually transitioned into a peer relationship. This was particularly important for operators developing piloting skills as it allowed them to gradually push the limits of their piloting abilities, observe expert practices in many different situations, and develop the technical skills necessary for the job by assisting in maintenance and repair of the robotic systems.

> *It was a Buddy Box setup... somebody who is very good at flying holds that transmitter and when they hold the switch you get control and you learn to fly and if you get in trouble they let go of the switch and they take over and fix it. (Drone Pilot B)*

Through informal networks of shared knowledge and experience (Cox, 2005), people develop a shared repository of skill, ability, and knowledge (Wenger, 1999). The most widely reported case study of such informal learning groups is a workplace ethnography of photocopier maintenance workers (Orr, 2016), which provided early insights into how groups of people can develop novel and adaptive methods for working with complex machines. Indeed, in the present study similar strategies of situated learning were reported among the robot operators.

> *It's very important to keep a team on a system... For many years, in the offshore oil industry, especially as these companies got bigger, and there's more and more vehicles, and all them were supposed to be the same... the idea was you could send any group of guys and they could work on it and that's true maybe right in the beginning. But as you tweak this, you do this, somebody fixes this differently, wiring is changed and all of a sudden they started failing offshore a lot and they couldn't keep these vehicles running because they never had the same team. (ROV Captain/Pilot B)*

These informal communities of practice (Lave & Wenger, 1991) have often been connected to developing and supporting specialized expertise alongside specific artifacts, including systems as complex as airplanes (Davenport & Hall, 2002). Our ROV pilot participants often described their robotic partner systems explicitly as a “sixth member” of their five-person team.

Recommendation 4: Start initial robotic system deployments with more digitally connected workers

It's using these analog controls, you're translating your hands into these different controllers, and that translates to some action on the screen.(ROV Pilot A)

Robot operators expressed how acquiring an understanding of how something will move becomes second nature and facilitates a flow state for work. Across domains, participants who practice direct control described how experience leads to the partner systems becoming "smooth," that things "slow down," and a "natural" feeling permeates their movements.

> *I've been gaming all my life, too. Of course, all the pilots I know are huge gaming nerds... because... you're just decoupling from your body. Right, just your mind is connected to the vehicle remote and when you're playing these games like that, well, you're kind of doing the same thing. And it's a lot of controls... you're translating your hands into these different controllers, and that translates to some action on the screen. And it's very, very similar. So if you've been playing games your whole life, like I am, it really is no different. (ROV Pilot A)*

Being digitally connected for years may result in the development of a skillset that easily translates to interacting with robotics. As with piloting skills, it may be that exceptional spatial cognitive ability is partly the result of honing those skills through gaming. There are big opportunities in leveraging gaming experience for future robot operators. The professional aerial drone pilots reported heavy use of flight simulators. The other expert robot operators also consistently mentioned video games for enhancing or priming their spatial cognitive abilities used to operate their robots, especially in the service robotics and deep sea domains.

One ROV pilot we spoke with felt that his experience gaming was so integral to his success as a pilot that he will get “in the zone” before a work shift by playing action and motion intensive games (e.g., Grand Theft Auto V). These types of games have been the subject of a great deal of research, which has found that games may improve performance on spatial cognitive tasks, hand eye coordination, object recognition, object tracking, and identifying relevant information in a heavily information saturated space (Spence & Feng, 2010). Indeed, the US Army funded the early days of the video gaming industry in hopes that the games would entice and begin to train future soldiers (Huntemann & Payne, 2009). Playing online multi-player video games, generally requires communication and coordination with many different players (in different physical locations) to achieve in-game goals. This experience translates well into the kinds of collaboration required for successful human-robot teams.

The extensive practice of video gaming amongst these expert robot operators points toward opportunities in the gaming space to better prepare future robot operators, developing the skills needed for future roles in human-robot teams.

1:1 Human-robot interaction

Being able to take on the perspective of a body that is not your own is a skill that these robot operators seem to share. One aspect for the design of both gaming and robot operation user interfaces is the use of first-person vs. third-person perspectives when controlling characters in a game. This is a common distinction found in first-person shooter (FPS) video game design. The first-person robot operators (e.g., ROV pilot A) would even play first-person racing games to get "in the zone" before work shifts, which is probably not a coincidence. In contrast, drone operators (e.g., UAV pilot A) flew aircraft from a third person perspective and could quite readily put themselves in the headspace of the aircraft, which is not easy for more people to do. This is critically important for remotely operated robots (i.e., when the robot operator is located in a different physical space than the robot), which are becoming increasingly pervasive across many industries, including hospitality, hospital services, oil and gas, etc.

1:N Human-robot teams

Operating fleets of robots (as opposed to individual robots) remains a long-term goal and also a major challenge for human-robot teams. Doing this effectively at larger scales remains a major challenge for large-scale human-robot team performance. Once again, game designers have already developed many different configurations and user interfaces for enabling people to command fleets of autonomous agents in real-time strategy games, which could be leveraged for larger-scale human-robot teams.

N:N Human-robot teams

Just as one person might control many robots, sometimes it takes teams of people to operate the robot(s). There are interaction design and team dynamic lessons to be learned from multiplayer online battle arena (MOBA) games in which players coordinate in cooperative groups.

Moreover, there is research which has found players of these types of games have high spatial cognitive and task planning skills (Bonny & Castaneda 2017).

Although the experts in our study were quite adept at operating their robotic systems, it became clear that they had remarkable piloting skills that we are unlikely to see in a broader population of workers. The user interfaces that they worked with were quite specialized and had evolved over time, but there is clearly an opportunity for overhauling the interaction design for robots in the workplace. We observed a wide variety of graphical and physical user interfaces in this study, most of which were designed by engineering teams for engineering teams.

For those organizations that have the design capabilities to customize user interfaces for their own purposes, it's time to put those powerful robotic systems into the hands of broader populations of workers. We have even seen robot operations teams buy third-party software licenses for user interfaces to replace the unusable interfaces provided by the robotics companies. Similarly, we are seeing the US military buying videogame controllers to replace their existing robot operation controllers.

There was once a time when computers were only usable by engineers. With the development of graphical user interfaces (SRI NLS and Xerox Star), spreadsheets (VisiCalc), and personal computers (Apple Lisa), we witnessed a massive shift toward computers being used in workplaces everywhere. While having user experience (UX) teams involved in product development is standard practice in consumer and enterprise computer products, it is not yet a common practice in robotics companies. This is the time to create that new norm, especially because the cognitive load involved in operating a robot in real time can be quite taxing. UX design that reduces the load is therefore one relatively accessible opportunity. Some interaction design opportunities include:

- Using video-game controllers (as we are seeing done by the US Army) or other familiar controls and interfaces
- Offering multiple perspectives upon the robotic system (first-person and third-person perspectives) to improve the operator's situation awareness
- Consolidating multiple sensor streams into unified displays that make the information easier to digest via the use of aggregate data visualizations and intelligent metrics over the multiple displays of raw sensor data that operators today often contend with.
- Providing only the truly urgent alerts to operators during intense operating activity to free up visual space, remove distraction and reduce cognitive load. In addition this allows for suggested actionable next steps to address those alerts. This involves the use of AI scheduling algorithms to order and display information efficiently. Messages that are less urgent can be logged for review during times when there is less intense pressure on the operator.

- Supporting hand-offs between shifts of human workers by making logs of recent activity readily available and easy to digest, perhaps with the aid of pre-processing by intelligent analytics systems pointing out key issues and patterns.

In the longer-term, there is more research and design work to be done, including:

- Developing taxonomies of the professional roles and job descriptions that will be required to effectively build human-robot teams for specific industries and settings
- Conducting need-finding research to prioritize important use cases, opportunities, and pain points for robot operators who possess the complementary skills that robotic systems cannot provide (e.g., customer service, bedside manner)
- Iterative user testing, design, and development of more effective user interfaces for robot operators to use on-the-job, e.g., fleet management systems, dispatch systems, robot sysadmin systems

Future of Work: Human-Robot Teams

Ever since our very first imaginings of robots in Čapek's 1920 play, *Rossum's Universal Robots*, we have dreamt of robots doing work for us. This dream might be a nightmare to some, with fears of jobs being automated away. But the reality of the future of robotics in the workplace is that robots will rarely replace human workers. Instead, robotic systems work *with* people – and we are moving toward a future where those robotic systems might be more autonomous, more capable, and more like teammates than just machinery.

There has been a good deal of work in expressive robotics attempting to harness a robot's ability to transmit, or mimic, nonverbal cues for facilitating human robot interactions (Breazeal, 2001; Mutlu et al., 2009; Trovato, et al., 2012). However, robots are far from being able to read, interpret, and act on the vast amount of incredibly subtle information transmitted via nonverbal cues in humans (Sidner, 2016). Until that time comes, successful human-robot teams, particularly public-facing and service-related platforms, will require the expertise of socially competent human teammates.

As we move toward a future of work that includes increasingly autonomous robotic teammates, it will be important for organizations to **empower employees to participate in the customization and integration of new robotic systems** into existing workflows, and support employees in developing **more flexible communication and coordination skills**, recognize and **promote mentorship and apprenticeship** within work teams, and **start initial robot deployments amongst digitally connected workers** with an eye toward re-designing robot user interfaces to support a broader population of workers.

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