Women and Men Collaborating with Robots on Assembly Lines:
Designing a Novel Evaluation Scenario for Collocated Human-Robot Teamwork

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ABSTRACT
This paper presents an original scenario design specifically created for exploring gender-related issues surrounding collaborative human-robot teams on assembly lines. Our methodology is grounded squarely in the need for increased gender work in human-robot interaction. As with most research in social human-robot interaction, investigating and exploring gender issues relies heavily on an evaluation methodology and scenario that aims to maximize ecological validity, so that the lab results can generalize to a real-world social scenario. In this paper, we present our discussion on study elements required for ecological validity in our context, present an original study design that meets these criteria, and present initial pilot results that reflect on our approach and study design.

Author Keywords
Human-robot interaction; Evaluation methodology; Gender studies

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces – Theory and methods

INTRODUCTION
Gender studies is a field of inquiry that uses a person's sex or gender identity as a primary means of inquiry. Far from being simply an academic curiosity, gender studies is an important element of science and technology studies, as ignoring gender-related issues can have far-reaching implications and impacts on technology development and acceptance [21]. This can even impact safety and result in deaths, as with the example of women being injured more often in car accidents, largely attributable to the tests and dummies being used assuming a male driver [18]. More subtle examples include the original microwave initially failing as intended (as a male bachelor technology) and being re-shaped by gender roles in the home [15], and studies that show how a large factor in the failure of smart-homes as a product has been the lack of considering women's needs, interests and concerns [2].

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Figure 1. A participant shaking hands with a robot co-worker after finishing an assembly-line task.

Concerns over gender issues are of particular urgency to the field of human-robot interaction: there is a chronic under-representation of women in science and technology [23,25], the very people who make and design robots. Thus, although women and men will equally be technology users, men are currently predominantly the technology makers; women are often excluded in the design, development, and testing of new robotic technologies. This increases the likelihood of problems, failures, and even safety issues, relating to a limited gender-balanced approach to designing these new technologies. While the ultimate solution is to improve the gender balance in the people making technology, the short term solution is to raise awareness and to explicitly integrate gender studies into research. This problem has been identified in the field [21], but there is still only limited gender work in human-computer interaction, and even less in human-robot interaction.

Robots are no longer isolated to research labs or relegated to being curiosities at technology fairs. Robots are starting to emerge as practical tools in museums, schools, and work places. They are also in the military, and used in search and rescue. Of particular note is the current boom in assembly line robots that – unlike assembly line robots of the past – work alongside people. These robots work as team members, handing items back and forth with people, as both the robot and the person perform specialized tasks collaboratively. In all of these cases, the person working with the robot is just as likely to be female as male, emphasizing the need for improved understanding of the role a person's gender plays in human-robot interaction.

The issue of gender is particularly important for the field of social human-robot interaction; the study of how robots can be social actors (e.g., as team mates or colleagues), or how they can use human-like social language (facial expressions, gestures, voice tone, gaze, etc.) to communicate, or interpret similar things from people [22]. Unlike many traditional interactive technologies such as the desktop PC, subtle differences can have large impacts, for example, an incorrect voice tone sounding sarcastic, using strange gaze (such as looking past someone or at one's shoes) impacting trust, and so forth. When such social issues are central to interaction, gender inevitably plays an integral element in how the interaction unfolds, as gender is a key social construct. Currently, we have only limited knowledge of what role gender plays in social human-robot interaction.

Our research explores the issue of how a person's sex impacts how they interact with a robot in a professional work scenario; specifically, working collaboratively with a robot as a team member. A particular challenge with social human-robot interaction is creating an experimental design which validly represents the task being studied, to create as authentic a social experience as possible. With a poor experimental design it becomes challenging to generalize any results to a real-world human-robot interaction instance. In addition to having a convincing story and practical task, a valid experimental design should strive toward a more complete social experience (socially situated holistic experience [22]) which includes an accurate array of representative social interactions and not be limited to a narrow context for a specific research question. We present the development of such a scenario in this paper.

In this paper we detail our process for developing a novel experimental scenario design for studying gender effects in human-robot collaborative teams on assembly lines. We explain the criteria we developed for improving the validity of our scenario, detail the actual scenario design, and provide initial insight into the effectiveness of the scenario from the results of a pilot study.

RELATED WORK

The idea of robots being collaborative team workers – instead of isolated automation machines performing repetitive tasks – is well established in the field of human-robot interaction. However, this work (including ours) takes place in laboratory scenarios (e.g., [1,9,11,14,20]), which limits ecological validity, and we are unaware of work that has looked at collaborative robots in real assembly lines. Research has broadly aimed at improving workflow and simplifying how people and robots can communicate and work together, for example, by managing team work under high time pressure, [19] or developing new ways to communicate back and forth [1,8]. Other work has looked at ensuring worker safety [8,14,19,20] (as malfunctioning robots can be quite dangerous). While we do not yet enter actual assembly lines, we explicitly aim to improve ecological validity within the limits of a laboratory study.

Enabling robots to use and understand social human communication techniques (i.e., social human-robot interaction) has been identified as a powerful mechanism for improving interaction, for example, by a robot using gaze cues [12], or human-like object handoff strategies [10]. However, the question of participant gender is generally relegated to a secondary analysis question and is not the core target of inquiry. Further, study designs generally are quite targeted and narrow to specific research questions, and do not offer the broader contextual validity we require in our exploratory work. There do exist more encompassing methodologies for evaluation in human-robot interaction (e.g., [22]), but these are aimed toward highlighting avenues of inquiry and questions to ask, and do not provide specific scenario designs for high ecological validity and broad-based exploration.

Gender has been explored extensively in sociological science and technology studies, for example, looking at technology acceptance in workplaces [13] or how gender has impacted technology development and acceptance [17]. This background serves as a solid foundation for gender work in human-robot interaction (e.g., as detailed in [21]).

Gender studies is only recently starting to emerge as a theme of inquiry in human-robot interaction and human-computer interaction more broadly [16], and targeted work is very limited. This line of research has investigated gendered differences in, for example, problem solving strategies for software use [4], or methods of processing 3D graphics (e.g., wide or narrow views [5]). More recently, some have investigated possible gendered nuances of language used in user studies [3] (e.g., participant or user).

There is much less gender work in human-robot interaction. One recent work indicated how a robot's gender (not the user's) may elicit stereotypes, such as a female-looking robot being more appropriate for traditionally female tasks (such as house work [7]). Another example highlighted how women and men may talk about robots differently despite sharing opinions, for example, that women may talk more about how robots may impact their personal life while men may talk more about society in general [21]. For the most part, however, gender investigation in human-robot interaction appears as afterthoughts or minor components of studies that target other questions. For example, optimal approaching behavior of a robot may be different for women and men [6], or women and men may have different requirements for assistive robots [24].

CRITERIA FOR AN ASSEMBLY LINE SCENARIO

Our goal is to develop an assembly line (i.e., production line) scenario that simultaneously maintains a high level of ecological validity (within the constraints of a laboratory setting) while enabling for a broad base of exploration of gender related issues. This is a challenging balance, as each time a new scenario element is introduced to enable exploration from a new angle, we must ensure that the new pieces do not diminish the validity or believability of the scenario.

Building Believability and Ecological Validity

We have to accept that it will be clear to participants for any lab study that they are engaging in a laboratory experiment and not real work – in fact, many ethics protocols will require this to be disclosed. However, it is critical that the task they are performing feels like simulated real work, and not a make-work or toy example such as sorting colored balls.

Gender issues are squarely embedded in the social elements of interaction and so it is important to help participants to treat the interaction as naturally as possible. Placing a participant in an obviously mock scenario (such as placing playing cards, or having a tiny robot pretend to lift a heavy object) can have strong implications on how they interact, and thus, the validity of gendered findings. For example, there may be differences in how men and women approach tasks that feel like make-work, which would be a confound of a study. By convincing the participant that they are doing real work, such as soldering, product assembly, packing, or inspection, these issues can be minimized as much as possible given the limitations of a lab setting.

Also, the social elements of a robot's interaction should be carefully considered and kept relevant to the task. For example, if the robot has eyes, consider where it is looking (to avoid awkward eye contact issues), if it has arms, use them naturally during interaction, and so forth. Moreover, we learn from social human-robot interaction how important it is for robots to give proper social feedback of their state to co-workers, such as while processing ("thinking") or performing an action.

Task believability does not only entail the actual work being done, but researchers need to be careful about the roles of both the person and the robot. If the task could be easily done by a person alone, or by a robot alone, then the participant may feel that the human-robot interaction is forced, faked, or awkward. Any task should be sure to be setup such that both a human and a robot is necessary, or at the very least, this heterogeneous team is much more efficient or effective than other solutions. This will help the participant feel that they are doing real work that may happen in the real world, and to engage the interaction with the robot meaningfully and reflective of what may happen outside the lab.

Ensuring that both the person and robot is necessary is non-trivial. It is important to consider the strengths of each: robots can be highly accurate and precise, are strong and tireless, have specialized sensors, have perfect memory and have access to databases. People, on the other hand, have higher creative ability for unforeseen problems, are more flexible for on-the-fly work changes, have historical knowledge of work, have much more dexterous hands, and so forth. Creating a task that can leverage both of these skill sets in tandem will help create a believable and engaging task.

When dealing with robots, particularly research robots, it can be very challenging to develop and implement realistic work scenarios. Research robots are often not capable of real work, and even for those that are, the overhead of implementing robust computer vision, motion tracking, and dynamic control systems, can be prohibitive for small research experiments. As such, our approach is to aim to bypass these robot limitations and technical challenges with creative scenario design and storytelling.

Creating Opportunities for Exploration

Simply having a convincing work task and scenario is not sufficient for exploratory work in gender studies for social human-robot interaction. In the real world, work will not always flow smoothly and it may be the edge cases – when something does not go simply as expected – where important interactions emerge. As such, developing a robust scenario for exploration should consider a broader social view and foresee potential issues, and build those into the study as valuable interaction instances. In our work we have identified several such issues that scenarios should consider including. These were selected simply as the most likely cases of workplace issues that may arise between a person and a robot.

- In real work, robots will make mistakes, giving incorrect answers, changing their decisions, and so forth. Ensure that robots make mistakes in a study.
- People engage in small talk, and can be expected to do the same with social robots. Provide a natural and believable opportunity for simple discussion between the person and robot.
- Co-workers praise and criticize each other, and robots in real work places will sometimes have to likewise offer feedback. Ensure that the robot in a scenario offers both positive and negative feedback.
- Interpersonal touch is a very sensitive and personal social action, yet people in real work places will have to touch robots from time to time, which may involve social elements. Include an opportunity for people to touch the robot.

NOVEL PROFESSIONAL COLLABORATIVE SCENARIO

We explored various professional collaborative scenarios and work tasks for our study design, and struggled with striking the balance between validity and enabling broader exploration. We settled on a collaborative inspection task for checking difficult-to-see dirt on laundered pieces of cloths (similar to handkerchiefs). The person's role is to grab, hold up, and fold cloths, while the robot uses its sensors to find dirt, and its arms to point to the region of cloth with the dirt on it. The person also sprays the dirty area with a cleaning agent.

This is a believable and practical task that would happen in an actual factory setting. Both the human is needed (for high level of manual dexterity) and the robot is needed (for advanced sensors and ability to point in the real world). Further, the robot's embodiment is believable for the task, and realizing the scenario does not require extensive and difficult implementation. Because the robot does not need to lift or move objects, its small body size fits the task: it is portable, can point, and can look around flexibly to examine the pieces of cloth being checked. Participants were further told, to increase believability, that the robot is not good at highly precise tasks such as handling cloth and folding, and that is why a person is needed.

The robot's use of its social cues was designed to be appropriate. It uses its eyes to look at the cloth, and looks at people when speaking. The pointing gestures were designed to be natural, and when not pointing the robot uses its arms in a casual way with small gestures while speaking, as a person might. When the robot is processing to examine the cloth, it conveys this to the participant by saying things such as "hmm, let me see…" instead of leaving a potentially-awkward silence.

It is important to note that this scenario is not specific to gender studies work, but is viable for many production-line scenarios where believability and ecological validity is of paramount concern. In our case, this scenario matches our specific whole-task validity constraints imposed by the gender work.

Primary Task

The core task of our experiment was for the participant to work collaboratively with a robot to inspect the cleanliness of several laundered pieces of cloth. The participant was given a bin of squares of cloth to inspect, and was tasked with holding them up to the robot one by one. The robot took a moment to scan the cloth, giving verbal feedback (such as "umm…", or "hmm, let me see…"), and then gave a result. If the cloth was clean, the robot said so, and the participant was asked to fold the cloth neatly and stack it in the "clean" bin.

If the cloth was dirty, the robot pointed to one of the four quadrants (left-top, right-top, left-bottom, and right-bottom), saying "there is dirt on this top corner" or "this bottom corner" while pointing at the location. The participant then "cleaned" that portion of the cloth by spraying it with a spray bottle – in this case, the participant was told that the bottle only contained water, and not detergent, so that they did not need to wear gloves. We selected only four possible big regions (the quadrants) to be cleaned to avoid ambiguity when the robot points at the spot, as pointing may not be highly accurate.

Figure 2. A participant and a robot working collaboratively to sort pieces of cloth. The participant holds up a piece and the robot scans it, then indicates that dirt is detected on the top left corner with pointing and verbal feedback.

Additional Opportunities for Exploration

In addition to the base case of collaboratively inspecting and sorting pieces of laundered cloth, we added the following opportunities for further exploration of interaction. We crafted specific social situations as an opportunity to observe the reactions.

We created a situation for a participant to get feedback from the robot. While working together, at one point the robot praises the participant's work, and at another, the robot gives criticism. To praise a person, the robot says that "you are doing a great job, thanks!" To criticize, the robot says "can you please hurry up? You are being really slow." The placement of these actions were carefully fixed in the procedure (below), and the order of praise or criticism was counter-balanced.

Although generally the robot acts confidently and performs the inspection job well, we introduced a case where the robot makes a mistake: it announces the result, and then quickly backpedals and indicates that it was wrong and provides a new answer. Specifically, the robot claims there is dirt on top right corner of the cloth, but then immediately says "no, I meant over here" while moving its hand toward left top corner. Then again, the robot says "no, sorry" and pauses. The robot blinks its eyes silently (~2 seconds), then says "it's actually clean. Can you fold it and put it in the clean box?"

We specifically created a situation where the participant can talk freely with the robot. About mid-way through the interaction, the robot says that it is overheating and needs a break (we warned participants about this possibility at the beginning of the experiment). At this point the robot sits down to let itself cool off, and engages in casual conversation with the participant. Specifically, the robot starts with general small talk about the day's weather. There are three questions from the robot in total: "how's the weather today?", "do you get paid for this work?", and "do you go to the University of Manitoba?"

Conversation could not be perfectly scripted as participant questions and feedback were impossible to predict. However, several conversation trees were constructed to improve consistency across participants and if the participant strayed too far (e.g., asking detailed personal questions about the robot) then the robot brought the conversation back on track by asking the next question from the conversation trees after a short pause.

In order to create a situation for participants to touch the robot, participants were told that the robot's sensors need frequent cleaning, as the robot could not do this by itself. At points throughout the experiment, the robot complains of this, and asks the participant to clean its face and hands with wet wipes, as provided. This happens twice: shortly after the beginning, and once near the end of the experiment.

Procedure

Participants first meet the experimenter in a separate room and completed an informed consent form and demographics questionnaire. Following, the participant moves to the experiment room (layout in Figure 3). At this point, the robot stands up, waves, and introduces itself as "Nao," and asks the participant for their name.

Participants are told that the robot is autonomous and intelligent (although in reality it is remote controlled). If participants ask detailed technical questions about the robot, we deflected the question to avoid them learning too much about the experiment, by saying that the robot is being borrowed from the engineering department and the experimenter says they are not qualified to answer any technical questions.

The experimenter explains the task to the participant (but does not explain the additional situations such as criticism, praise, etc.), and goes through several examples to be sure that the participant fully understands what is expected. In addition, the experimenter explains that the robot sometimes overheats and needs to take a break, and also explains how to clean the robot when its sensors are dirty. The experimenter leaves the room (leaving the participant alone with the robot), and the study starts.

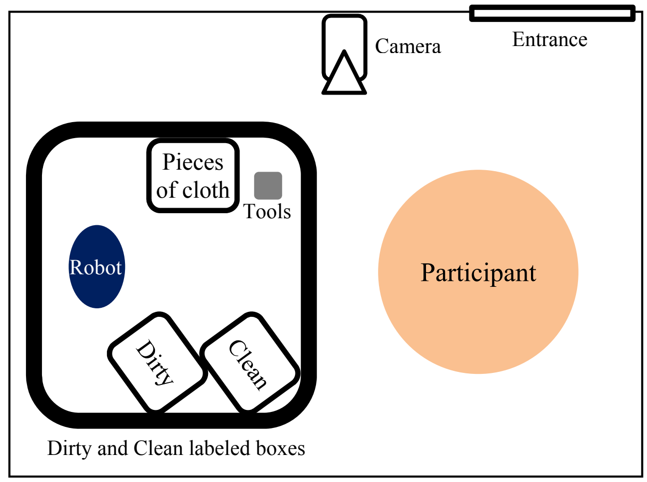

Figure 3. The experimental setup. A robot is placed on a desk next to squares of cloth that need to be sorted into the clean- and dirty-labeled bins. The camera points from right-side of the participant to record the interaction in profile. The participant can choose to sit or stand with their will.

The participant has to sort 40 squares of cloth. After 11 pieces (including 4 examples with the experimenter), the robot asks to be cleaned. After 6 additional squares, the robot either praises or criticizes the participant, with the order counter balanced between participants. After 4 more squares, the robot makes a mistake. At the 24 mark, the robot states that it was overheating and needs to rest, sits, and engages the participant in conversation as described earlier. Following, after 5 additional squares, the robot needs to be cleaned again, and after 9 more the robot criticizes or praises the person, depending on the counterbalanced order (if the robot praised earlier then it criticizes now, and vice versa).

Apart from the dedicated conversation time, if the participant asks an off-topic question such as attempting to engage in small talk, the robot attempts to stay on the task by saying "let's focus on our task. We can talk later when we are not working."

Finally, once the task is done the experimenter returns to the room and administers a post-test open-ended interview, followed by a debriefing of the experiment.

The entire procedure takes approximately 45 minutes. A full procedure overview is given in Figure 4.

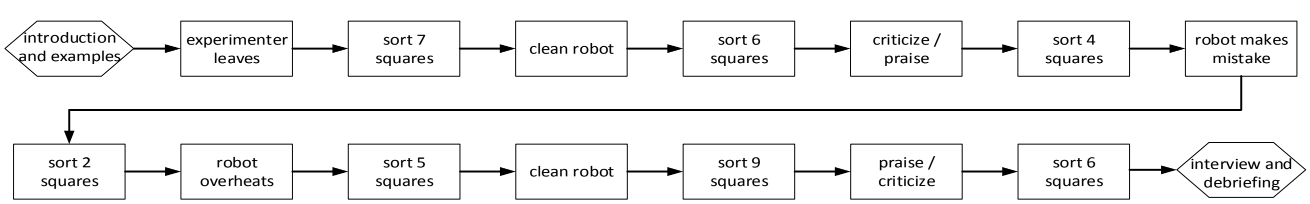

Figure 4. The entire procedure, step by step. There are 40 pieces of cloth in total (including the robot's mistake), two opportunities to touch the robot, a break while the robot overheats for casual conversation, and two places where the robot gives feedback.

Implementation

We used an Aldebaran NAO robot, a small child-sized humanoid (22.5 inches tall) with 25 degrees of freedom. This robot is capable of simple social interaction such as eye contact, head gaze, speech, and simple conversational gestures (small hand weaving, head nodding, etc.).

Rather than implementing a complex behavior system to run the experiment, and to improve consistency between participants, we employed the Wizard of Oz technique, where the researcher remotely controls the robot unbeknownst to the participant.

For this purpose, we used our own in-house Wizard of Oz interface (Figure 5), developed with C# and NaoQi SDK version 2.1. The remote controller can move the robot's head around, use buttons to play pre-defined behaviors, responses, and conversation trees, click on the screen to make the robot point at a quadrant of a cloth squares (auto-calibrated to where the participant is holding), and type custom text to speak.

Figure 5. Our in-house Wizard of Oz interface used during the experiment. The various panels and buttons enable the operator to activate a range of pre-defined behaviors, gestures, conversation topics, etc. The operator can also give low-level commands and custom speech for unexpected behavior. Here, the participant is nodding his head when the robot says the piece of cloth is clean.

INITIAL RESULTS AND REFLECTION

We conducted a pilot study using the above procedure for an initial simple validation of the scenario, that is, whether people see it as believable, and if the task is feasible (i.e., people work well with the robot).

Ten participants (4 male / 6 female) were recruited from first- and second-year sociology classes and were compensated with $20 CAD for their time. This study was approved by our institution's research ethics board. One female participant's data was discarded due to a technical problem during the experiment.

Overall, we were able to lead participants to believe that they are working with an advanced intelligent humanoid prototype on simulating an actual assembly line task. Further, we validated that the breadth of social interaction cases were successful in that they appeared to elicit authentic reactions and no participant raised concern or issue relating to these. All participants interacted properly, engaged the robot, and during our post-test interview no signs of awkwardness or feelings of make-work emerged.

One sign that people engaged the social aspects is that all participants gave verbal and socially-rooted feedback to the robot. For example, when the robot asks "can you show me a piece of cloth to inspect?" or "can you fold [the clean piece] and put in the clean box?", participants responded socially appropriately, for example, by saying "sure," "yes," "okay," and so on – note that no social response is required by the participant to successfully complete the work. One participant did not respond verbally but did via with body language, such as by nodding their head to the robot.

Participants also naturally prompted the robot similar to as they would prompt a person. For example, while lifting a square of cloth to show, participants prompted the robot using such language as "is this a clean one?", "how about this one?", "do you think it's clean?" and so on. Finally, all participants engaged in small talk with the robot during the short break.

We believe that all of this points to engagement with the robot as a social collaborator similar to a colleague, since none of this was necessary to complete the work. In fact, an unexpected occurrence was that three people tried to shake the robot's hand at the end of task, which is a typical social and collegiate gesture at a work environment.

Finally, no problems or issues were found with our exploratory social additions, such as participants receiving criticism, the robot making mistakes, and so forth. All data and indicators, including the post-test interview, point to the participants seeing these simply as a normal part of the scenario and interaction.

Overall, these results support the use of our scenario for simulation of production-line work that includes a range of socially-valid interactions, and therefore, is sufficient for our goal of developing a scenario for exploring gender work.

LIMITATIONS

Through this study we discovered limitations in our scenario. In terms of validity, in retrospect we realized that this scenario may have a slight hierarchical slant to it: the people are asking the robot's opinion, and the robot gives direction. This may feel, to some, like a manager-employee relationship and less as a colleague. We should aim to include elements of the participant directing the robot more, to improve this balance.

Other limitations revolve around opportunities for exploration. While the robot gives feedback to the participant, we did not include opportunities for the participant to give criticism or praise to the robot. This may further hinder the collegiality of the work environment. Another limitation is that there is no opportunity for either the robot or the person to give instructions to each other.

People and robots who work collaboratively will have to teach and explain things to each other, which is an aspect of collaborative assembly line work we need to be exploring.

One limitation is our investigation on differences between women and men (biological sex) instead of a person's gender identity. We agree that sex is a problematic over-simplification of gender, and that future work should aim to more appropriately include gender more fully. As an initial step, sex provides a broad-brush sampling of gender.

CONCLUSION

In this paper, we presented an argument for increased gender studies in human robot interaction, and detailed an original study design process and result, which can be used to investigate differences of women and men in interacting with a robot on assembly lines. This included arguments for criteria for improving believability and validity, and methods for improving the exploration possibilities in an experimental design. We conducted a pilot study which provided positive results for the believability of our scenario and that participants will socially engage the robot, and which also highlighted limitations and directions for further development.

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