The Views of Hospital Laboratory Workers on Augmenting Laboratory Testing with Robots

Bob R. Schadenberg
Hideki Garcia Goo
b.r.schadenberg@utwente.nl
h.garciagoo@utwente.nl
University of Twente
Enschede, the Netherlands

Lena Nyman
Jesper Keisu
lena.nyman@regionstockholm.se
jesper.keisu@regionstockholm.se
Karolinska University Hospital
Stockholm, Sweden

Vanessa Evers
v.evers@utwente.nl
University of Twente
Enschede, the Netherlands
Nanyang Technological University
Singapore, Singapore

ABSTRACT

One way to address shortages in the workforce and improve the safety of health workers is through robots. Here, we will specifically look at whether and how robots might augment workers working on the pre-analytical phase of clinical testing in hospital laboratories. We conducted eight interviews with workers using futuristic autobiographies. Through our analysis, we identified three themes. Workers envisioned robots to increase their well-being and change blue-collar workers' tasks towards that of automation operators. The latter was perceived to be a change towards doing more meaningful tasks (cognitive tasks, rather than manual labour). Additionally, workers have a need to better cope with structural changes and temporary fluctuations in the workflow. More general-purpose robots could address this.

CCS CONCEPTS

• **Human-centered computing** → *Contextual design*; • **Computer systems organization** → *Robotics*.

KEYWORDS

Speculative design, robots, hospital laboratory, laboratory testing

ACM Reference Format:
Bob R. Schadenberg, Hideki Garcia Goo, Lena Nyman, Jesper Keisu, and Vanessa Evers. 2023. The Views of Hospital Laboratory Workers on Augmenting Laboratory Testing with Robots. In *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (HRI '23 Companion), March 13–16, 2023, Stockholm, Sweden.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3568294.3580157

1 INTRODUCTION

There are several trends that are increasing the demand for, and increase the strain on, labour in the hospital setting [14, 18, 29]. According to the World Health Organisation, population growth, ageing population and workforce, and changing disease patterns are expected to drive greater demand for well-trained health workers in the next ten years [29]. This leads to shortages in health workers. One of the key factors to the shortages of health workers is the high rate of repetitive strain injuries sustained by these workers due to ergonomic risks on the job. Specifically, tasks that require repeated movements without adequate recovery time, or prolonged standing or sitting are cited among those that cause musculoskeletal disorders among healthcare workers [10]. The impact of injuries is exacerbated by the ageing workforce, as older workers often suffer more severe injuries and take longer to recover than younger workers. This problem is further exacerbated by the COVID-19 pandemic, which contributed to an unprecedented increase in demand for health workers [6], and at the same time increased dropout rates of these workers due to contracting COVID-19 themselves [2], or due to declining mental health [15, 19].

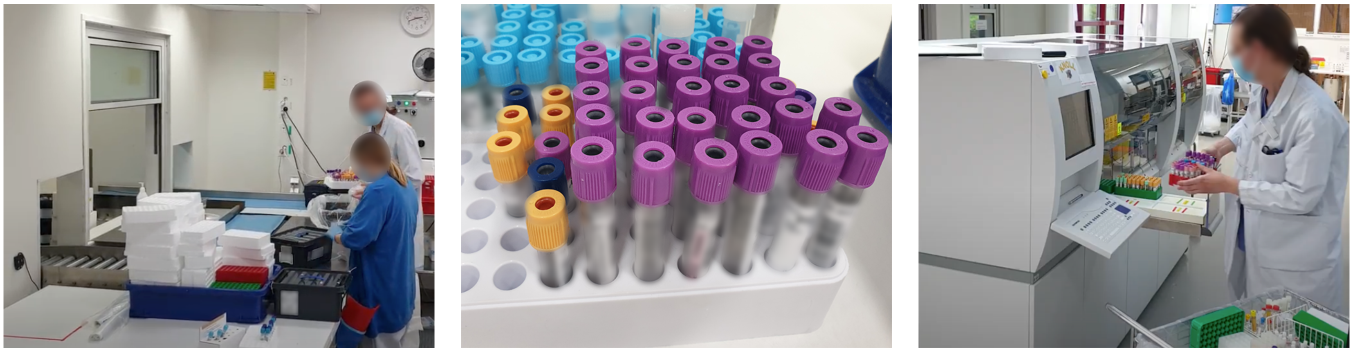
One way to address shortages in the workforce [9, 28], improve the safety of health workers [9, 28], prevent errors [3, 17], and combat future pandemics [30] is through robotics. In this paper, we will specifically look at the potential roles of robotics in testing within hospital laboratories. Such testing is typically divided into three phases: the pre-, intra-, and post-analytical phases. The process starts with a physician ordering a test sample from a patient and ends with the physician taking action based on the results [20]. Here, we will focus specifically on the conventional pre-analytical phase that occurs within the hospital laboratory. At this phase, test samples for specific clinical tests have been collected from a patient and transported to the hospital laboratory. There, it starts with receiving test samples from within or outside the hospital. These test samples need to be unpacked, registered, sorted and pre-processed so that they are ready for the respective clinical test, before being transported to the department that performs the clinical tests (also see Figure 1 and Hawker [16] for a more detailed description).

While automation of hospital laboratories started in the mid-'80s [28], advances in robotics and artificial intelligence allow robots to work collaboratively with workers. This opens up a range of new tasks that can be augmented through robots. However, it is important to be cautious when deploying robots, because of the risk of (unintentionally) displacing human work by eliminating preferred tasks; the larger context of work needs to be considered. To understand how robots and workers can complement one another's strengths, we need to understand the needs and values of the workers [22, 27].

This paper investigates how robotics might play in the pre-analytical phase of laboratory testing. We report on the results from semi-structured interviews with hospital laboratory workers. Through these interviews, we aim to uncover what this process should look like in the future and how it, potentially, might be augmented through robotics.

HRI '23 Companion, March 13–16, 2023, Stockholm, Sweden

ACM ISBN 978-1-4503-9970-8/23/03.
https://doi.org/10.1145/3568294.3580157



(a) Two lab members unpacking a batch of boxes that contain test samples.

(b) A rack of test samples ready to be sorted by the respective automated machines.

(c) One of the automated machines that sort test samples on type and destination.

Figure 1: The pre-analytical phase of clinical testing within the hospital.

2 METHODS

2.1 Research context

The Karolinska University Laboratory of the Karolinska University Hospital in Sweden participated in this study. This hospital is one of the largest university hospitals in Europe and plays a central role in providing healthcare in the greater Stockholm area, as well as providing services to other care providers throughout the country. The laboratory is spread out over six separate sites within Stockholm. Four are smaller sites that only carry out standard and emergency clinical tests, and two are large sites where all kinds of clinical tests are performed. Combined, the sites process over 26 million clinical analyses a year. While the laboratory consists of multiple departments, the pre-analytical department of the laboratory is the primary focus of this study. This department is responsible for the pre-analytical phase of clinical testing and is present at the two larger sites.

2.2 Participants

We conducted eight semi-structured interviews with workers involved in the workflow of clinical testing within the hospital. Participants had 2 to 30 years of experience (M = 13). Their occupations included three assistant nurses, a laboratory assistant, a coordinator, a head chemist, a chemist, and a biomedical analyst. The participants were recruited by the hospital itself, taking special care to include a wide range of occupations and experience.

2.3 Procedure

Participants were initially blind to the goal of the interview and were informed of it during the debriefing. After signing the informed consent form, providing optional consent for recording the interview, and the introduction, we discussed up to six futuristic autobiographical stories with each participant. The interviews lasted up to one hour, which for some participants was insufficient to discuss all six FABs. We encouraged the participants to use their imagination, and think creatively, and that there was no right or wrong answer. Once the participant came up with a narrative related to the story, we further probed and asked the participant to elaborate. The interviews were held in English. For those who consented to the interview being recorded, we automatically transcribed the interviews verbatim using Amberscript[1] and manually checked each of them afterwards. For those who did not consent to the audio recording, we only took notes on what they said.

Rather than directly asking participants about their needs and values, which can often be daunting to do so on the spot, we utilise design fiction as a tool to open up a space for discussion. Design fiction is "the deliberate use of diegetic prototypes to suspend disbelief about change" [Sterling, cited by 5]. Diegetic prototypes refer to prototypes that exist in the world of fiction (diegesis). Design fiction consists of something that creates a story world and prototypes reflecting the story world that together create a discursive space [12]. The design fiction method that we will use in our study is *futuristic autobiographies* (FAB) [8]. FABs, created by the researcher, are stories that take place in the future where the participant is the key character. When participants are presented with such stories, they are asked to create an autobiography that describes how the story came to be and complete the story. The completed stories are then used to open the space for a discussion on a certain topic.

The interview started with four FABs that did not mention robots, in order for us to understand how the participants foresee their future lab. These stories were designed to understand what they enjoy most in their work, current needs that they would like to have solved, dangerous situations that might occur, and how the department could improve on handling future pandemics. After discussing these stories, we moved to two robot-centred stories, in order to assess whether robotics could play a role in the participants' lab. These stories related to the envisioned role of robots in the lab, and their anticipated collaboration with robots.

To further stimulate the participant's imagination, which can sometimes be difficult using FABs [8], we changed the autobiographical nature of the stories not to be about the participant, but about the participant's future self. The stories were framed such that this future self is talking to the participant. This way, we sought to make it clear that the participants' current knowledge and experience are changed in the future, in a way that only their own imagination can describe.

[1] https://www.amberscript.com/

2.4 Data analysis

We analysed the transcripts through thematic analysis [7]. This involved two researchers (the interviewers) who were familiar with the data, generated initial codes, generated themes, and finally reviewed, defined, and named themes together. For the coding of the transcripts, we adopted an inductive approach, rather than trying to fit the data using a pre-defined coding scheme. The stories the participants come up with are not necessarily realistic, so we have to look beyond what they literally mention. We, therefore, viewed the data within a contextualist framework, meaning that we "acknowledge the ways individuals make meaning of their experience, and, in turn, the ways the broader social context impinges on those meanings while retaining focus on the material and other limits of 'reality'"[pp. 81, 7].

3 RESULTS

Three themes were identified through the thematic analysis. Two themes relate to the use of robotics, and one theme is a more general need.

3.1 Theme 1: Robots are envisioned to increase the well-being of workers

The tasks carried out by workers in the pre-analytical department are not without risk to their health and safety. All participants talked about injuries caused by exposure to ergonomic risk factors associated with highly repetitive tasks and heavy labour. Specific tasks that were mentioned included unpacking the boxes containing the test samples, and pushing a heavy trolley packed with processed test samples that need to be delivered to other departments within the hospital. These tasks can cause injuries to the wrists, back, shoulders, or feet when standing for too long. Another health risk that was often mentioned is the risk of coming into contact with the contents of a test sample due to spillage.

When envisioning the future, participants generally wanted technology that could aid them or take over tasks that pose a risk to their health. Technology may be able to detect any leaking test samples and intervene without risk of infection. The repetitive or physically demanding tasks were also frequently mentioned as tasks where technology could help. The participants mentioned that technology such as robots is better suited for these tasks because they believe that robots are faster and perform them more consistently. As such, technology could increase productivity, reduce health risks to workers, and reduce human errors by taking over such tasks.

3.2 Theme 2: Robots are envisioned to change their job to automation operators

Participants mentioned that they enjoy working with their colleagues, variety in their work, and solving problems. The manual labour that they have to do, such as unpacking boxes or distributing test samples within the hospital, are tasks that are necessary, but not very enjoyable. Instead, they would rather focus on (cognitive) tasks that they find more meaningful and for which they received formal training. In their view, robots could help them by taking over such tasks, so that they can then focus on these more meaningful tasks.

When envisioning the future, much of the hospital laboratory would be automated, where their work would be transformed into automation operators. They would take care of the machines, process the odd samples that the machines are unable to handle, and solve any problems within the flow. In their view, machines break down every now and then, which halts the testing process and would need to be fixed as soon as possible. Machines would also not be able to process all types of samples, as there would always be non-standard samples that require a human to process them. As automation operators, they would then still be in control and responsible for the pre-analytical phase of clinical testing.

3.3 Theme 3: Need for flexibility to enable adaptation to process changes in the workflow

Every health crisis will be different and will require adaptations to the pre-analytical phase of clinical testing. In turn, this requires workers to be flexible in work and quickly adapt to changing circumstances. Taking the current COVID-19 pandemic as an example, additional workers had to jump in or were newly hired throughout the whole clinical testing workflow to manage the increase in workload. Some had insufficient knowledge of handling test samples, which resulted in more incidents. Moreover, the large amount of COVID-19 test samples that had to be processed also required adaptations in the pre-analytical phase, because these samples tended to clot. This was something that the current machines could not handle well.

The inflexibility of IT systems was also frequently mentioned by participants as a source of frustration, additional work, and increased chance for human errors. Departments that are involved in the clinical testing workflow, both inside and outside the hospital, often use different software systems. These systems are often not connected to each other and require different inputs. As a result, workers need to manually insert electronic forms from one system to another or need to find workarounds. For instance, research on COVID-19 test samples was also made more difficult because of the need to use standardised electronic forms that could not be altered. As a workaround, researchers would verbally convey the additional information on how to process the samples for a certain study, increasing workload and the chance for human errors.

Lastly, the workload of workers is subject to change and requires them to be flexible. Test samples are being transported to the hospital from the surrounding area. When there is a lot of traffic, this transportation is delayed. This then causes a sudden influx of samples that may not have been anticipated by the workers, who then have to adjust to processing the samples when they arrive. As mentioned earlier, the COVID-19 pandemic was another source that increased workload. Furthermore, the workload also changes naturally throughout the week, where it is relatively quiet on Mondays and Fridays because fewer people get tested on those days. The fluctuations in workload can cause workers to need to work late, but can also lead to bottlenecks in the pre-analytical phase when not enough workers are available to process the test samples. This can be problematic when there are many samples coming in that are put on ice, which needs to be handled quickly, or samples that need to be analysed immediately (emergency samples).

4 DISCUSSION

The vision that emerges from our analysis is that of a robot that can be flexibly used for a variety of tasks within the pre-analytical phase of clinical testing. These robots are to improve the safety and productivity of workers and allow them to focus on more meaningful (cognitive) tasks and supervise the robots. In general, the participants had a positive attitude towards automation. Not only could more robots used within the pre-analytical phase be a way for them to focus on more meaningful tasks, but it could also increase the productivity of the lab, help them cope with the increasing workload, and reduce tasks that pose a risk to their safety and health.

4.1 Envisioned change in work

The work of blue-collar workers was anticipated by participants to change into that of an automation operator. Currently, blue-collar workers in the hospital laboratory have to manually unpack, register, and transport samples, where automation is used mostly to sort and pre-process the test samples. Participants anticipated the work of these workers to change where they only do manual labour for atypical samples (e.g., samples with incorrect or missing information), which cannot be processed through a standardised automated workflow. And for emergency samples, which need priority in the workflow. They would also need to monitor the machines and robots, address any problems that occur, and monitor the overall pre-analytical phase of clinical testing, as they would still be responsible for it. The work of white-collar workers was not mentioned by participants, even though nearly half participants had a white-collar job.

Overall, the more cognitively demanding tasks are tasks for which blue-collar workers in the hospital laboratory are trained and which they perceived as being meaningful. This is in contrast to the manual labour tasks of unpacking, sorting, and transporting test samples. These tasks were not liked and posed safety and health risks to them. The envisioned augmentation of blue-collar workers takes advantage of the strengths of robotics in doing repetitive standardised tasks and combines those with the strengths of people: problem-solving skills, adaptability, and creativity of the workers [21]. Thus, while the tasks would change, the job is envisioned to remain [1].

The change in tasks also brings challenges. Incumbent workers would need to adjust to the new tasks and obtain new skills. The history of automation shows that this could lead to worker displacement, resulting in a wage income loss [4]. Additionally, the tasks that the robot could take over also provide workers with relevant tacit knowledge. For instance, during the drop-off of test samples at the hospital laboratory, workers can talk to the drivers and inquire about the current traffic. This then allows them to anticipate any incoming shipments that might be late due to traffic.

4.2 More general-purpose robots

To improve the ability of workers to handle any changes in the workflow, or increases in demand for labour at certain stages, a more general-purpose robot is required. The demand for labour changes during the day, weeks, months, or as a result of external events such as a health crisis. This can create bottlenecks in the workflow that demands the prioritisation of workers to be resolved. Current generation automation is often highly efficient at processing standardised input, which also makes them inflexible to any deviations in input or in changes to the process itself. For instance, there are robots that efficiently sort test samples [e.g., 26], or transport goods within the hospital [13, 24]. More general-purpose robots, such as described by Dömel et al. [11], are currently still in a prototype phase. Moreover, the analysis from Murphy et al. [23] shows that there were only a few cases where existing robots were adapted to new use cases during the COVID-19 pandemic. Having robots that are accessible enough to be adjusted (e.g., attaching different grippers) and programmed by blue-collar workers could aid in coping with changes in an existing task, or adapting to new tasks.

4.3 Future work and limitations

All participants were from a single hospital in Sweden. To what extent our findings are generalisable to other hospital laboratories is uncertain. Additionally, the participating department already had experience with industrial and collaborative robots. This experience could positively influence their views on robotics [25]. In 2019, they held a pilot study with a collaborative robot which can scan and sort a variety of samples. While the study ended, this robot is now permanently embedded pre-processing of samples. The department also has an industrial robot (behind a fence) that opens the test sample carriers from the pneumatic tube system that is installed within the hospital. This tube system is the primary method for transporting samples coming from within the hospital to the pre-analytical department. A follow-up study with hospital laboratories from different countries and from different types of hospitals (i.e., non-academic hospitals) would be needed to identify differences in views on robotics.

5 CONCLUSION

In this paper, we describe the views on how robots can augment workers in the pre-analytical phase of clinical testing done by hospital laboratories. We conducted eight interviews with hospital laboratory workers using futuristic autobiographies. Through our analysis, we identified three themes. Workers envisioned robots to increase their well-being and change blue-collar workers' tasks towards that of automation operators. Robots, combined with automated machines, would then process standard test samples, whereas blue-collar workers would only process atypical and emergency samples. Additionally, they would monitor and address any problems with the machines or robots, and monitor the entire pre-analytical phase of laboratory testing. This change was perceived by workers as a change towards doing more meaningful tasks (cognitive tasks, rather than manual labour). Additionally, workers have a need to better cope with structural changes and temporary fluctuations in the workflow. More general-purpose robots that can be easily adapted and programmed by blue-collar workers could address this.

ACKNOWLEDGMENTS

This work was made possible through funding from the European Union's Horizon 2020 research and innovation program under grant agreement no: 101017008 (HARMONY).

REFERENCES

[1] David H. Autor. 2015. Why Are There Still So Many Jobs? The History and Future of Workplace Automation. *Journal of Economic Perspectives* 29, 3 (8 2015), 3–30. https://doi.org/10.1257/jep.29.3.3

[2] Soham Bandyopadhyay, Ronnie E Baticulon, Murtaza Kadhum, Muath Alser, Daniel K Ojuka, Yara Badereddin, Archith Kamath, Sai Arathi Parepalli, Grace Brown, Sara Iharchane, Sofia Gandino, Zara Markovic-Obiago, Samuel Scott, Emery Manirambona, Asif Machhada, Aditi Aggarwal, Lydia Benazaize, Mina Ibrahim, David Kim, Isabel Tol, Elliott H Taylor, Alexandra Knighton, Dorothy Bbaale, Duha Jasim, Heba Alghoul, Henna Reddy, Hibatullah Abuelgasim, Kirandeep Saini, Alicia Sigler, Leenah Abuelgasim, Mario Moran-Romero, Mary Kumarendran, Najlaa Abu Jamie, Omaima Ali, Raghav Sudarshan, Riley Dean, Rumi Kissyova, Sonam Kelzang, Sophie Roche, Tazin Ahsan, Yethrib Mohamed, Andile Maqhawe Dube, Grace Paida Gwini, Rashidah Gwokyala, Robin Brown, Mohammad Rabiul Karim Khan Papon, Zoe Li, Salvador Sun Ruzats, Somy Charuvila, Noel Peter, Khalil Khalidy, Nkosikhona Moyo, Osaid Alser, Arielis Solano, Eduardo Robles-Perez, Aiman Tariq, Mariam Gaddah, Spyros Kolovos, Faith C Muchemwa, Abdullah Saleh, Amanda Gosman, Rafael Pinedo-Villanueva, Anant Jani, and Roba Khundkar. 2020. Infection and mortality of healthcare workers worldwide from COVID-19: a systematic review. *BMJ Global Health* 5, 12 (12 2020), e003097. https://doi.org/10.1136/bmjgh-2020-003097

[3] David W. Bates and Atul A. Gawande. 2003. Improving Safety with Information Technology. *New England Journal of Medicine* 348, 25 (6 2003), 2526–2534. https://doi.org/10.1056/NEJMsa020847

[4] James Bessen, Martin Goos, and Anna Salomons. 2019. Automatic Reaction-What Happens to Workers at Firms that Automate? In *A World with Robots*. Boston University School of Law, Boston, MA, USA, 159–169. https://scholarship.law.bu.edu/faculty_scholarship/584

[5] Torie Bosch. 2012. Sci-Fi Writer Bruce Sterling Explains the Intriguing New Concept of Design Fiction. https://slate.com/technology/2012/03/bruce-sterling-on-design-fictions.html

[6] Ivy Lynn Bourgeault, Claudia B. Maier, Marjolein Dieleman, Jane Ball, Adrian MacKenzie, Susan Nancarrow, Gustavo Nigenda, and Mohsin Sidat. 2020. The COVID-19 pandemic presents an opportunity to develop more sustainable health workforces. *Human Resources for Health* 18, 1 (12 2020), 83. https://doi.org/10.1186/s12960-020-00529-0

[7] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (1 2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[8] EunJeong Cheon and Norman Makoto Su. 2018. Futuristic Autobiographies: Weaving Participant Narratives to Elicit Values around Robots. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, New York, NY, USA, 388–397. https://doi.org/10.1145/3171221.3171244

[9] Giorgio Da Rin. 2009. Pre-analytical workstations: A tool for reducing laboratory errors. *Clinica Chimica Acta* 404, 1 (6 2009), 68–74. https://doi.org/10.1016/j.cca.2009.03.024

[10] Tanja de Jong, Ellen Bos, Karolina Pawlowska-Cyprysiak, Katarzyna Hildt-Ciupinska, Marzena Malinska, Georgiana Nicolescu, and Alina Trifu. 2014. *Current and emerging issues in the healthcare sector, including home and community care: European Risk Observatory Report*. Technical Report. European Agency for Safety and Health at Work, Luxembourg. https://doi.org/10.2802/33318

[11] Andreas Dömel, Simon Kriegel, Michael Kaßecker, Manuel Brucker, Tim Bodenmüller, and Michael Suppa. 2017. Toward fully autonomous mobile manipulation for industrial environments. *International Journal of Advanced Robotic Systems* 14, 4 (7 2017), 1–19. https://doi.org/10.1177/1729881417718588

[12] Anthony Dunne and Fiona Raby. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming*. MIT Press, Cambridge, MA, USA. 224 pages.

[13] Giuseppe Fragapane, Hans-Henrik Hvolby, Fabio Sgarbossa, and Jan Ola Strandhagen. 2020. Autonomous Mobile Robots in Hospital Logistics. In *Advances in Production Management Systems. The Path to Digital Transformation and Innovation of Production Management Systems*, Bojan Lalic, Vidosav Majstorovic, Ugljesa Marjanovic, Gregor von Cieminski, and David Romero (Eds.). Springer International Publishing, Cham, 672–679. https://doi.org/10.1007/978-3-030-57993-7_76

[14] Global Health Workforce Alliance. 2014. *A Universal Truth: No Health Without a Workforce*. Technical Report. World Health Organization.

[15] Neil Greenberg, Mary Docherty, Sam Gnanapragasam, and Simon Wessely. 2020. Managing mental health challenges faced by healthcare workers during covid-19 pandemic. *BMJ* 368 (3 2020), m1211. https://doi.org/10.1136/bmj.m1211

[16] Charles D. Hawker. 2007. Laboratory Automation: Total and Subtotal. *Clinics in Laboratory Medicine* 27, 4 (12 2007), 749–770. https://doi.org/10.1016/j.cll.2007.07.010

[17] Giuseppe Lippi and Gian Cesare Guidi. 2007. Risk management in the preanalytical phase of laboratory testing. *Clinical Chemical Laboratory Medicine* 45, 6 (1 2007), 720–727. https://doi.org/10.1515/CCLM.2007.167

[18] Jenny X. Liu, Yevgeniy Goryakin, Akiko Maeda, Tim Bruckner, and Richard Scheffler. 2017. Global Health Workforce Labor Market Projections for 2030. *Human Resources for Health* 15, 1 (12 2017), 11. https://doi.org/10.1186/s12960-017-0187-2

[19] Wen Lu, Hang Wang, Yuxing Lin, and Li Li. 2020. Psychological status of medical workforce during the COVID-19 pandemic: A cross-sectional study. *Psychiatry Research* 288 (6 2020), 112936. https://doi.org/10.1016/j.psychres.2020.112936

[20] George D. Lundberg. 1981. Acting on Significant Laboratory Results. *JAMA: The Journal of the American Medical Association* 245, 17 (5 1981), 1762. https://doi.org/10.1001/jama.1981.03310420052033

[21] Praveen Kumar Reddy Maddikunta, Quoc-Viet Pham, Prabadevi B, N Deepa, Kapal Dev, Thippa Reddy Gadekallu, Rukhsana Ruby, and Madhusanka Liyanage. 2022. Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration* 26 (3 2022), 100257. https://doi.org/10.1016/j.jii.2021.100257

[22] Maja J. Matarić. 2017. Socially assistive robotics: Human augmentation versus automation. *Science Robotics* 2, 4 (2017), 1–2. https://doi.org/10.1126/scirobotics.aam5410

[23] Robin R. Murphy, Vignesh B.M. Gandudi, Trisha Amin, Angela Clendenin, and Jason Moats. 2022. An analysis of international use of robots for COVID-19. *Robotics and Autonomous Systems* 148 (2 2022), 103922. https://doi.org/10.1016/j.robot.2021.103922

[24] Karol Niechwiadowicz and Zahoor Khan. 2008. Robot Based Logistics System for Hospitals-Survey. In *IDT Workshop on interesting results in computer science and engineering*. 1–8.

[25] Eike Schneiders and Eleftherios Papachristos. 2022. It's not all Bad - Worker Perceptions of Industrial Robots. In *HRI '22: Proceedings of the 2022 ACM/IEEE International Conference on Human-Robot Interaction*. ACM/IEEE, Sapporo, Japan, 1025–1029. https://doi.org/10.5555/3523760.3523928

[26] Weiwei Wan, Takeyuki Kotaka, and Kensuke Harada. 2022. Arranging test tubes in racks using combined task and motion planning. *Robotics and Autonomous Systems* 147 (1 2022), 103918. https://doi.org/10.1016/j.robot.2021.103918

[27] Katherine S. Welfare, Matthew R. Hallowell, Julie A. Shah, and Laurel D. Riek. 2019. Consider the Human Work Experience When Integrating Robotics in the Workplace. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. ACM/IEEE, Daegu, South Korea, 75–84. https://doi.org/10.1109/HRI.2019.8673139

[28] M J Wheeler. 2007. Overview on robotics in the laboratory. *Annals of Clinical Biochemistry: International Journal of Laboratory Medicine* 44, 3 (5 2007), 209–218. https://doi.org/10.1258/000456307780480873

[29] World Health Organization. 2016. *Global strategy on human resources for health: Workforce 2030*. Technical Report. World Health Organization, Geneva, Switzerland.

[30] Guang-Zhong Yang, Bradley J. Nelson, Robin R. Murphy, Howie Choset, Henrik Christensen, Steven H. Collins, Paolo Dario, Ken Goldberg, Koji Ikuta, Neil Jacobstein, Danica Kragic, Russell H. Taylor, and Marcia McNutt. 2020. Combating COVID-19—The role of robotics in managing public health and infectious diseases. *Science Robotics* 5, 40 (3 2020), 1–2. https://doi.org/10.1126/scirobotics.abb5589