"Meet Your Personal Cobot! Will it Change You? Can You Resist It?"

Framing Participatory Research in Makerspaces as a Trading Zone

Tudor B. Ionescu, Vienna University of Technology (tudor.ionescu@tuwien.ac.at)

ABSTRACT

This paper focuses on the collaboration between members of the "do-it-yourself" community and professional researchers occasioned by a publicly funded project aimed at introducing collaborative industrial robots to a high-tech makerspace. It conceives of this kind of collaboration as a "trading zone" between the members of different technical cultures having shared interests in a particular technology "in the making." To trace how existing knowledge is (ex)changed and new knowledge is produced in the sociotechnical configuration of the studied project, the analysis draws on participant observation of, and interviews with members of a factory training center and a makerspace. The analysis emphasizes two kinds of transition. First, it traces the transformation of entrenched knowledge and practices pertaining to collaborative robot safety, as the technology is being appropriated by members of the "do-it-yourself" community. Second, it traces the reconfiguration of the makerspace prompted by encounters with research institutes and companies, which entailed the projectification and professionalization of its activities. Based on this case study, the paper discusses the utility of the trading zone model for analyzing and operationalizing participatory research in makerspaces.

Introduction

Recent debates in peer production research (Smith et al., 2020) point to the resurgence of an automation discourse that calls on information and computer technologies to boost the productivity and competitiveness of European production facilities. The newest version of this discourse, known as "Industry 4.0" (Kagermann et al., 2013), envisions a distributed,

interconnected, highly automated factory. Although, over the past decade, the vision of a "fourth industrial revolution" did not trigger significant changes in the traditionally conservative European manufacturing domain, the vision of a distributed, interconnected factory seems to have imperceptibly conquered other aspects of economic and social life, notably through the so-called "gig economy" (Woodcock & Graham, 2019) and a new wave of rationalization of the public and private sectors through digitization. In this context, peer production researchers have asked whether "a socially constructive approach to technology" can provide a viable alternative to the "depopulated vision of Industry 4.0" (Smith et al., 2020, p. 9), while noting that what Smith et al. (2020) termed "post-automation" is already practiced in hackerspaces, makerspaces, fablabs and other public contexts. Among other things, the vision of "post-automation" emphasizes "democratic deliberation over the technology itself" and "[s]eeing technology as productive commons" (p. 9).

Against this background, the present study focuses on a publicly funded research project aimed at "democratizing" collaborative industrial robots (short cobots) by introducing them to an Austrian high-tech makerspace. Thanks to their unprecedented safety features, cobots are a technology that aims to provide an alternative to the "depopulated vision of Industry 4.0" by promising humans permanent roles in factories as part of "human-robot teams" and visions of "human-robot symbiosis" (Wilkes et al., 1999) designed to fulfill the seemingly contradictory goals of increasing productivity and flexibility while keeping up worker and customer satisfaction. Makerspaces are shared machine shops in which different digital, manufacturing, biological and other technologies can be used on premise by members of the public (Seravalli, 2012). While typically, makerspaces provide their members with access to additive and subtractive manufacturing technologies (e.g., 3D-printers, laser cutters, etc.), conventional and collaborative industrial robotic arms have only recently started to figure in such locales, with safety concerns and lacking expertise in robotics being important barriers to their appropriation by members of the "do-it-yourself" (DIY) community. While not being a new kind of institution (Smith, 2014), makerspaces have gained popularity in the past 15 years by providing infrastructure and support to members of the DIY community (Dickel et al., 2019) and other interested individuals and institutions to implement their ideas with the help of the latest manufacturing technologies.

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Studying the introduction of cobots in a makerspace arguably provides an opportunity to analyze "post-automation" from a micro-perspective, focused on the production of knowledge and the problems entailed by the notion of human-robot collaboration. Previous research emphasized the tensions and contradictions between the ideal of democratizing technology and "neoliberal business-as-usual" amidst DIY locales (Braybrooke & Smith, 2018). The aim of this paper is to go beyond the realization that idealized democratic institutional models may be misappropriated by business interests. Instead, I am interested in whether and how different exchanges centered on technologies "in the making" are possible between individual and institutional actors even in "makerspaces defined by institutional encounters" (Braybrooke & Smith, 2018). In this sense, drawing on theory from the fields of science and technology studies (STS) and organizational studies, I conceive of the sociotechnical configuration of the studied project as a *trading zone* (Galison, 1997; Collins & Evans, 2002) focused on the exchange of knowledge, expertise, and practices between members of different technical cultures. According to Collins et al. (2007), depending on the configuration of power relations between the participants to the trade, there can be different types of trading zones, which can transition one into another. I draw upon this nuanced trading zone concept to trace two transitions—the transformation of entrenched knowledge and practices pertaining to cobot safety as the technology is appropriated by members of the "do-it-yourself" community, and the reconfiguration of the makerspace determined by result-oriented collaborations with research institutes and companies, which entailed the projectification and professionalization of its activities.

Case Study and Methodology

Collaborative industrial robots were first introduced as devices capable of manipulating heavy work pieces in collaboration with human workers (Colgate et al., 1996). To ensure safety, these devices embodied the principle of passive mechanical support, which—combined with traditional robotic technology—brought about the now stabilized image of an industrial cobot as an anthropomorphic robotic arm endowed with strength and sensitivity. The certification of cobot applications for industrial use requires the manufacturing companies to present a certification consultant with all the details of an application, including the precise layout of the operational environment, the intended human-robot collaborative operation modes (ISO, 2016; Rosenstrauch & Krüger, 2017),

the specifications of the end effector and the objects being manipulated, and the application's source code (Michalos et al., 2005). Given these specifications, the consultant carries out physical measurements (forces, moments, angles of attack, etc.) based on a series of predefined hazard scenarios considered relevant for the respective application. If the residual risks (i.e., the risks that cannot be eliminated using technical means) of the application are acceptable with respect to the applicable norms, the consultant grants a safety certificate.

Much like personal computers, today, (personal) cobots can also be ordered, installed, and operated by anyone willing to invest in a handy universal helper. They come with downloadable apps and intuitive "zero-programming" user interfaces. Recently, they also started to figure in makerspaces for various purposes. This prompts the questions of which safety norms apply in makerspaces, considering that all possible maker applications—from idea to workspace layout and source code—cannot be known in advance; and, more generally, of how much safety is enough when an industrial cobot is operated outside of a factory or a research lab.

The project on which this paper is focused set out to answer these questions to facilitate the crowdsourcing of cobot software and applications by members of the DIY community in cooperation with an interdisciplinary research team. The empirical data were collected using an ethnographic approach (Amann & Hirschauer 1997; LeCompte & Schensul, 1999) based on participant observation and interviews with makerspace representatives and other members of the project team, consisting of robotics researchers and cobot safety experts, human-robot interaction (HRI) researchers, industrial robotics engineers and trainers, and makerspace employees (trainers and programmers). I observed two project phases, lasting for about two years, by participating in all project meetings as well as by observing project-related activities and conducting interviews in a makerspace and a factory training center. During this time, the composition of the project team changed several times, especially in the makerspace. In the first phase, I focused on the interests of the different partners converged around the shared goal of "democratizing cobot technology in makerspaces." Then, in the second phase, I observed how the safety issue was being dealt with by the different actors involved in the project and how the makerspace reconfigured its internal organizational structure to fulfill its duties in the project.

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DIY Locales as Research & Development Sites

Bijker (1999) proposes the term "democratization of technology" denoting a form of resistance against established institutions and regimes of knowledge production, in which experts play dominant roles in spite of their "interpretive flexibility" (Bijker et al., 1987). In Bijker's view, participation and pluralism are determinant features of democracy, which can also be transferred to technology in terms of development and use. Smith et al. (2020) note that, although the social construction of technology "is nothing new", the recent discourses proclaiming a so-called "fourth industrial revolution" driven by "cyber-physical production systems" tend to forget about the historical role of the social component in production systems. What Smith et al. (2020) refer to as "post-automation" seems to draw from Bijker's "democratization of technology":

> "... post-automation is about the subversion of technologies that appear foundational to automation theory, and appropriating them for different social purposes, on less functionalist terms. Post-automation looks to a more open horizon based in democratic and sustainable relations with technology, and that thereby develops socially useful purposes in human-centred not human-excluding ways." (p. 9)

Tanenbaum et al. (2013) suggest a clear link between the "maker community" and the democratization of technology, by arguing that "DIY practice is a form of nonviolent resistance: a collection of personal revolts against the hegemonic structures of mass production in the industrialized world" (p. 2609). As Tanenbaum et al. (2013) note, through this form of nonviolent, nonthreatening resistance, the members of the DIY community become themselves "co-designers" and "co-engineers" of technologies normally created by experts in laboratories, scientific institutions, and private organizations by first appropriating them and then contributing to their (further) development in a significant way.

Some authors regard the maker movement as an effect of a so-called "Third Industrial Revolution" (Rifkin, 2011; Troxler, 2013), which is characterized by the shift from a hierarchical towards a so-called lateral distribution of power in the manufacturing domain. This shift is facilitated by novel digital communication infrastructures and means of energy production. Fablabs (fabrication laboratories) in which members of the DIY community have access to the newest (often additive or subtractive) manufacturing technologies

(e.g., 3D printers, laser cutters, CNC mills, etc.) helped to blur the "labour-capital-divide" and the "white-collar-blue-collar-divide" by facilitating the re-emergence of the "owner-maker" and of the "designer-producer" (Troxler, 2013).

Recent work in peer production studies gives a more nuanced image of makerspaces and the DIY community. Not only are makerspaces a 'new old' kind of institution, having roots in the so-called Technology Networks, which emerged in Britain during the 1980s (Smith, 2014); but instead of embodying the idea of resistance against dominant institutions and regimes of technological innovation, some of them seem to be increasingly defined by 'institutional encounters' with organizations and regimes from which they wish to delimit themselves (Braybrooke and Smith, 2018). In the 1980s, technology networks were "community-based workshops [which] shared machine tools, access to technical advice, and prototyping services, and were open for anyone to develop socially useful products" (Smiths, 2014, p. 1). Some 20 years later, as Braybrooke & Smiths (2018) note,

> "[d]epending upon the specific institutional encounter, makerspaces are becoming cradles for entrepreneurship, innovators in education, nodes in open hardware networks, studios for digital artistry, ciphers for social change, prototyping shops for manufacturers, remanufacturing hubs in circular economies, twenty-first century libraries, emblematic anticipations of commons-based, peer-produced post-capitalism, workshops for hacking technology and its politics, laboratories for smart urbanism, galleries for hands-on explorations in material culture, and so on and so on … and not forgetting, of course, spaces for simply having fun." (p. 10)

This brings up the question of how makerspaces can maintain their autonomy as a more democratic alternative to rule-based, normative institutional models in dealing with traditional organizations (Braybrooke & Smiths, 2018). The same authors conclude that "[t]he social value in makerspaces lies in their articulation of institutional tensions through practical activity, and in some cases, critical reflexivity" and therefore should not be devalued because they cannot "overturn institutional logics all by themselves" (p. 11).

Other strands of research speak of the diversity of motivations and programs driving the members of the DIY community around the world. Lindtner (2015) notes that in China, actors in makerspaces appear to have a political agenda when they engage in doing

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things in a country-specific way as an 'antiprogram' to widespread Western manufacturing technology and culture pervading Chinese factories. By contrast, Davies (2017) argues that in the United States, makers do not seem to have political motives or to compete with traditional manufacturing sites. Instead of subscribing to ideals of democratizing technology and manufacturing techniques, US makers and hackers seem more concerned with being part of a community for purposes of leisure and socialization.

The growing encounters between members of traditional organizations, like companies or research institutes, and members of the DIY community determined Wolf et al. (2014) to regard shared machine shops as 'real-world laboratories':

> "These spaces provide niches for experimental learning that expand the scope of established modes of research and development which are predominantly embedded in professional contexts of industry or science. As a specific property, [shared machine shops] have a capacity for inclusion because they provide infrastructures for novel forms of collaboration as well as self-selected participation of heterogeneous actors (in terms of expertise, disciplines, backgrounds etc.) who can join the related endeavours."

As real-life laboratories, shared machine shops are places where people can join collaborative projects, whereby "experts and professionals meet with hobby enthusiasts and DIY innovators and work together on new, unexpected projects" (Wolf et al., 2014, p. 7). As Dickel et al. (2014, p. 4) note, "[shared machine shops] might also be places of serendipity, where experts and professionals meet with hobby enthusiasts and DIY innovators and work together on new, unexpected projects." Yet, while the terms 'real world laboratories' and 'real world experiment' shed light on the roles DIY locales play in society, they do not say much about how and why exactly collaborations between different kinds of (un)certified experts come about, unfold, flourish, and fail. By framing such collaborations using actor-network theory, Wolf and Troxler (2015) investigate how knowledge is co-created and shared in open design communities. Other authors have pointed to the existence of a logic of exploitation (Söderberg & Maxigas 2014), which, for example, determines private companies to crowdsource software and hardware by drawing on the availability and expertise of so-called 'independent developers' (Drewlani & Seibt, 2018). Drewlani and Seibt (2018) note that the independent developer is a co-

creation of the interested company and the co-interested developers (in an actor-oriented sense), who are enrolled in company-controlled development activities.

Complementing this body of work, my focus in this paper is on a very specific kind of encounter—between robotics and human-machine interaction researchers on one side, and members of the DIY community on the other one. While peer production studies have looked at how additive and subtractive manufacturing technologies are being used, little attention has been given to the appropriation of assembly technologies, like industrial robots, which are essential in complex product manufacturing processes. My perspective also departs from the dichotomous view of makerspaces and other institutions (companies, research institutes, government agencies, etc.) as being entirely distinct entities, which only interface through well-defined protocols of collaboration. Instead, my observations suggest that makerspaces can play multiple institutional roles at once, for example, by being open to the wider public while hosting technologies and members with a level of expertise comparable to that of 'certified' institutions and experts. Such relationships between makerspaces and other institutions thus appear to be interwoven to such an extent, that a clear distinction between them is no longer possible beyond the observation that DIY locales are, in principle, open to interested members of the public, while other institutions generally are not. As I shall argue, this particular socio-technical configuration facilitates the emergence of trading zones between the members of different types of (research) institutions, with makerspaces (including their members and 'member-employees') playing a dual role; of trading partners and facilitators of the trade.

Framing Participatory Research in Makerspaces as a Trading Zone

Galison (1997) coined the term *trading zone*, representing "[a] site—partly symbolic and partly spatial—at which the local coordination between beliefs and action takes place" (p. 784). Such coordination is made possible through interlanguages (trading languages, pidgins, creoles), which facilitate the communication between different epistemic subcultures (e.g., theoretical and experimental physics) sharing a common goal (e.g., to build a radar system). Drawing on Galison's work, Collins et al. (2007) note that there can be several types of trading zones, which do not necessarily build on interlanguages alone but also on what Collins & Evans (2002) call "interactional expertise"—expertise that, for

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example, is sufficient to interact with participants and carry out a sociological study; or boundary objects—"objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star & Griesemer, 1989, p. 393). Schubert and Kolb (2020) provide an example of a trading zone between social scientists and information system designers, while emphasizing the importance of "symmetry" as "a mode of mutual engagement occurring in an interdisciplinary trading zone, where neither discipline is placed at the service of the other, and nor do disciplinary boundaries dissolve" (p. 1). The trading zone concept has also been applied to exchanges between non-scientific communities (Balducci & Mäntysalo eds., 2013; Gorman ed., 2010). In these examples, the different groups involved in the trade seem to have sufficient epistemic, political or other kinds of authority to act as approximately equal partners in the trade. The balance of power relations between trading partners determines whether a trading zone tends to be collaborative, coercive, or subversive (Galison, 2010; Collins et al., 2007).

Collins et al. (2007) define 'trading zones' "as locations in which communities with a deep problem of communication manage to communicate" (p. 658), while stressing that "if there is no problem of communication there is simply 'trade' not a 'trading zone'" (p. 658). One type of trading zones identified by Collins et al. (2007), which does not rely on inter-languages, is the so-called "boundary object trading zones, which are mediated by material culture largely in the absence of linguistic interchange" (p. 660). Drawing on Collins et al. (2007), I would argue that in the studied project, the cobot performs like a multi-dimensional *boundary object*, both materially and conceptually. This performance stimulates and justifies exchanges between researchers and members of the DIY community—as two different "user-developer" groups—and between different kinds of institutions. Having triggered common interests with the members of different technical cultures, who were motivated by the shared goal of "democratizing" cobot technology, the situated interactions between the different actors involved in the project facilitated the emergence of a trading zone. Although the problem of communication, which became evident by the example of the perception of cobot risks and safety by researchers and makerspace members, lasted throughout the project, the two groups agreed to disagree in some respects, while focusing on issues of joint interests—such as training programs and cobot applications.

As Galison (2010) notes, one way to determine whether a particular sociotechnical configuration may be conceived of as a trading zone is to look at what is being traded, by whom, and how power is distributed among the partners of the trade. To provide situated answers to these questions, in the following, I will turn to an account on the empirical material before revisiting the trading zone model in section 3. In interpreting this material, I will mainly draw on Carlile's (2002) conceptualization of "effective boundary objects" (p. 452), developed during an ethnographic study of a high-volume product development project:

> [a]n effective boundary object at a semantic boundary provides a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary." [...] At a pragmatic boundary an effective boundary object facilitates a process where individuals can jointly transform their knowledge.

According to Carlile (2002), "knowledge boundaries" emerge between different functional roles in a company (e.g., marketing, production, design and manufacturing engineering), across which knowledge in the form of (effective) boundary objects is exchanged and transformed. In Carlile's (2002) view, "knowledge is localized, embedded, and invested in practice" and represents "both a source of and a barrier to innovation" (p. 442).

Drawing on this theoretical framing, in the following I will investigate how collaborations between researchers and members of the DIY community are facilitated in makerspaces; how cobot safety is being construed and negotiated by the different individual and institutional actors involved in the studied project; and how knowledge about cobot safety and applications is produced in a context previously unforeseen by the creators of the technology.

Actors' Hopes and Expectations for the Project

During the project preparation phase, the representatives of the different institutions involved in the project—a robotics research institute, a human-machine interaction group from a university, a factory training center, and a makerspace—emphasized the need for "democratizing" cobot technology. For the HRI researchers, this meant making it more accessible to a wider range of potential users. These researchers believed that the technical and economic potential of cobots was curtailed by the strict safety norms and

standards governing the industrial uses of the technology. In addition to the safety issue, some HRI researchers considered that strictly controlled factory and laboratory environments impose limits on the creativity of application developers.

The researchers from the robotics institute were interested in meeting the "maker scene" to gain access to a pool of potential contributors to open source robotic software. In this sense, these researchers expressed their hopes concerning the organization of "hackatons" and other development competitions. The roboticists were also interested in exploring new ways of ensuring human-cobot interaction safety, which would allow more flexibility and creativity than current industrial safety norms.

The representatives of the makerspace stressed that "this kind of project" was exactly what they were looking for in order to develop their expertise in the domain of robotics. Besides providing its paying members with access to a wide range of industrial tools and machines, the makerspace is part of a holding company, which turned a former factory into a business hub, hosting co-working spaces, company offices, and the respective makerspace. With its over 500 members, many of whom are artists, students, and diverse professionals, one of the makerspace's roles in this configuration is to draw talent and expertise into its ecosystem.

The representatives of the factory training center expressed their wish for the project to reduceloosen cobot safety certification requirements and costs. Also, they stressed the industry's need to increase the pool of skilled cobot programmers and operators. In this sense, the makerspace could serve as an additional robotics training site located in a city. The training center organizes a high number of courses with diverse participants, ranging from teenagers to unemployed middle-aged persons.

Negotiating Safety at the Boundary

One of the project goals was to design the architecture of the cobot system for the makerspace and to define the system's safety features that would allow safe trainings in the makerspace. The goal was for makerspace members to be able to interact with the cobot safely and directly without application safety certifications and supervision by trainers. With these goals in mind the project sought to find a suitable technical solution both for the factory's training center and the makerspace. To this end, several face-to-face and online meetings were organized. In the following, I will discuss some of the recurring themes observed during these meetings. The reporting technique used is that of short

"critical event vignettes" based on field notes, which "depict scenes that were turning points in the researcher's understanding or that changed the direction of events in the field site" (LeCompte and Schensul, 1999, p. 273).
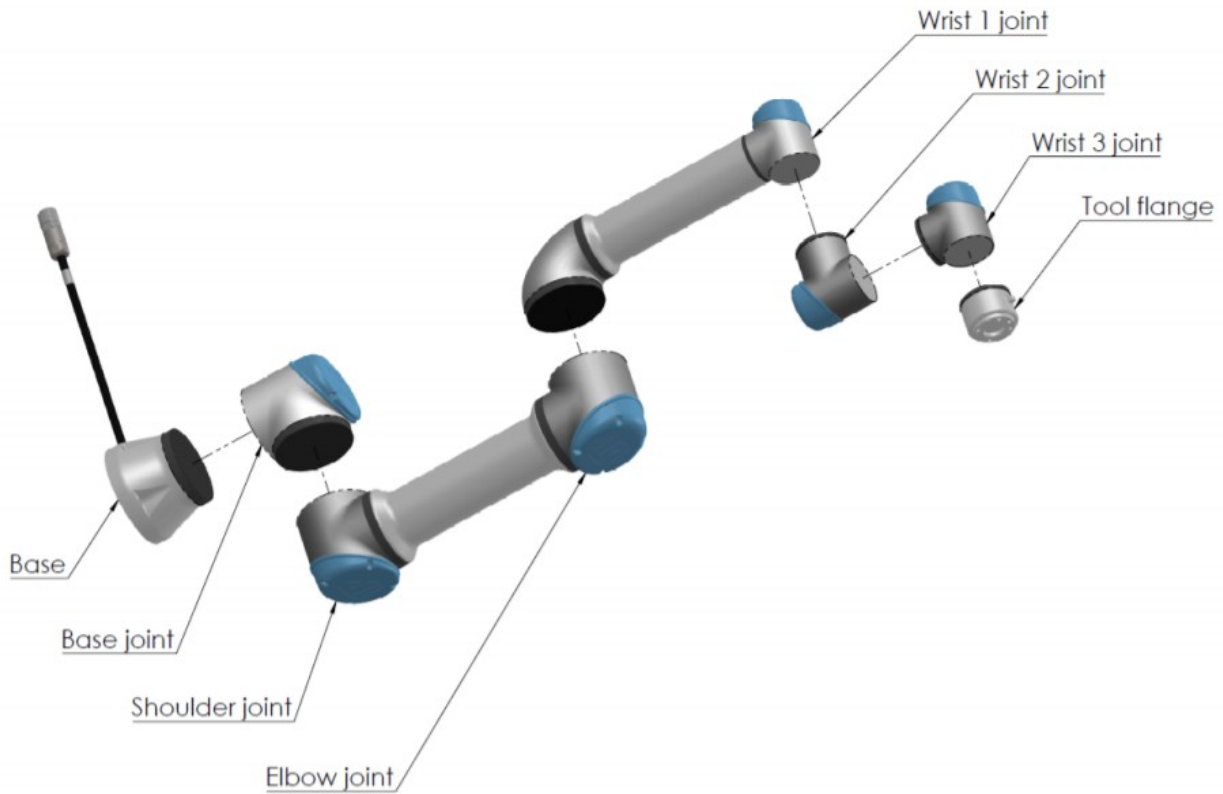

Figure 1: The axes (or joints) of a typical 6-degree of freedom robot.

Vignette 1 – Trading flexibility for safety. In one meeting, the participants discussed the problems faced by the factory when certifying new cobot applications. Certifications consist of scenario-based risk and hazard analyses conducted by external consultants. The meeting's focus was on the safety certification of "cobot training" as an application. As one trainer explained, a surprising result of the certification process was that the range of the end effector of the 6-axis robotic arm used was significantly limited in the horizontal plane in order to minimize the risk of head injuries:

> "The robot arm is not allowed to reach higher than a few centimeters above the table. [She indicates 10-15 cm with her hand.] This was not thoroughly thought through by the consulting company. One teaches a move at 140 mm and does not see anything."

To enforce this constraint, the consulting company limited the range of the robot's "elbow," i.e., the third axis from the base (see Figure 1). This solution puzzled the safety experts from the robotics research institute, who did not understand the purpose of this measure, since "the third axis could be anywhere" and might therefore still pose safety risks. Moreover, as one trainer pointed out, in productive applications, the third axis limitation did not exist because it would make the robot practically useless. As a result, whereas trainees would learn how to use the robot in a reduced functional mode, on the shop floor they would be exposed to another, less restrictive one. The trainers considered this discrepancy unacceptable.

This vignette suggests that cobot safety is contingent on the context of use, which entails different trade-offs between safety and flexibility. In the context-dependent application of the norms by certification consultants, common-sense aspects seem to have less weight in the process than measurements and hazard scenarios—something that was considered problematic by trainers. "Safety" thus seems to be flexibly interpretable by consultants and factory representatives.

Vignette 2 – Deferring to training and experience. In a follow-up meeting, the researchers from the robotics institute laid out their plan for a so-called "cobot safety concept" for makerspaces and training centers. In these settings, additional cobot safety features could be incorporated or detached depending on the experience level of the current user. There would be two working modes—a safe one and a less restrictive, creative one, the latter of which could be used during trainings. As one safety expert argued, deferring safety to training and experience was motivated by the principle that, "whenever one works with a hazardous technology, one necessarily needs training." This philosophy was in line with that of the makerspace representative participating to the meeting, who proposed that the safety concept be accompanied by a "training concept" having several attainable levels:

> "When a person reaches a certain level, they get an OK from the experts. We need to think about a good training concept. [...] After completing all training modules— we've done everything we can! Now you have to take care yourself."

As the discussion continued, a more nuanced image of the safety and training concepts emerged. The training modules and levels would be tied to the safety features of the

robot. After receiving a basic safety training, makerspace members would be allowed to use the cobot in a power and force-limited mode. An additional training module would qualify users to teach the robot and to have it pick and place 3D printed parts, which do not have sharp edges. A further module would grant the privilege of working with the robot at higher speeds and forces. On another note, one of the robotics experts explained that, in safety certifications, a difference between qualification and competence is made. To attest competence, the number of usage hours and completed projects or simulations, and other kinds of practical experiences with cobots may be taken into consideration. "Whether or not these experiences are successful is not important," the expert concluded.

   This vignette suggests that in contexts where application-based certifications are not feasible, experts relate their perception of safety to user experience. Most project team members considered the training and experience of users mandatory even in makerspaces, thus making the development of a linked safety and training concept an "obligatory passage point" (Callon, 1984) in the project. In the actors' view, in the case of an accident, authorities would scrutinize the ways in which these trainings have been organized and how the different levels of safety have been ensured in relation to the experience of users. As a result, the safest strategy for implementing cobot safety in the makerspace turned out to be similar to the one implemented by the factory's training center. During these meetings, the safety and training concepts appeared to take shape iteratively and collaboratively in a path-dependent way. The role of "the experts" in defining the safety features of the cobots and the different levels and permission of the training programs was uncontested.

Vignette 3 – The responsible user. While the project team worked on defining a new safety and training concept, one member of the team found out that another makerspace had already permanently installed a cobot, which could be used by members at their own will. The safety concept used in that makerspace was based on common sense; or on "a sane human mind," as one of its representatives explained. Members were only offered a basic safety training, which included indications about which objects the robot was not allowed to manipulate (e.g., knives and other sharp tools). The users were then considered responsible for their own safety as per the general terms of agreement stipulated in their membership contracts.

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The peer pressure generated by this unexpected turn of events produced a certain shift in power relations between the robotics safety experts and the HRI researchers on the team, the latter of whom were less concerned with the safety issue and more eager to install the cobot in the makerspace as soon as possible. The competing makerspace had brought about—although indirectly—a new image of cobot users as responsible and accountable individuals, capable of taking care of their own safety. Accountability was ensured by having all members sign a liability waiver—a common practice among makerspaces. This user model also questioned, to some extent, the need for an elaborate safety and training concept in the project. In response, the safety experts on the team provided a new set of options concerning the system architecture, which now included a "gradual" safety model. Also motivated by budgetary concerns, one variant of this model foresaw the acquisition of a basic cobot without any additional safety features, provided that it was operated in a very slow mode. As more experience would be gained by observing how members interacted with the cobot, the safety experts hoped that a better-informed decision could be made concerning the additional safety systems required. However, the makerspace should "seriously consider how much residual risk they were willing to accept," the roboticists insisted.

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The three vignettes illustrate how the members of different technical cultures jointly sketched out a new cobot safety concept for makerspaces—a new context of use for this technology. In this process, the roboticists and industrial engineers set out from a common understanding based on the relevant industrial safety norms, with which they were familiar. The safety norms figuring in the first vignette may be regarded as boundary objects of the "standardized forms and methods" type (Carlile, 2002, p. 452), which provided the actors with what Carlile calls "a shared format for solving problems across functional settings" (Carlile, 2002, p. 451). Yet, as the discussion progressed, it became clear that the application of these norms in non-productive settings, such as the training center, led to impractical solutions, with which all actors were unsatisfied. Thus, while the safety norms arguably succeeded in establishing what Carlile refers to as "a shared syntax or language for individuals to represent their knowledge" (Carlile, 2002, p. 451), they failed to provide the actors with a sufficiently flexible problem-solving framework to tackle the issue at hand. To resolve the "negative consequences" (Carlile, 2002) of working with

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the norms at the boundary between factory and makerspace, the actors' focus shifted from the norm to its application, whereby the notion of a "safety concept" seemed to replace *the* norm as a boundary object, which could only help to specify differences and dependencies between different application settings (i.e., the third axis limitation is only required in the training center, not in production). Refocusing on the development of a new safety concept facilitated a process through which the actors were able to transform their knowledge in a collaborative way. This transformation occurred gradually as the actors chose to articulate this concept independently of the norm and to negotiate compatibility with it after having converged to a workable solution for makerspaces and training centers alike. Being more flexible and context-sensitive, the "safety concept" thus seemed to perform more effectively as a boundary object than the norms.

As Ewenstein & Whyte (2009) note, boundary objects are multidimensional and articulated. In the case of the cobot as boundary object, one of these dimensions appears in the form of the *projected user*, who differs across the three vignettes in fundamental ways. Akrich (1992) coined the term "projected users" (as opposed to the actual users of a technology) referring to those user images (or profiles) for which inventors and designers conceive technologies. While in factories, safety norms configure human-robot interactions, some makerspaces trust their members to be responsible and accountable individuals, who can work with "hazardous technologies" without extensive training. By configuring the responsibility of the *projected user* on a spectrum from total dependency on norms (i.e., factory workers for the safety of whom others are responsible) to autonomy (i.e., makers and hackers responsible for their own safety and accountable for any consequences), the actors seemed to have found and effective boundary object, which allowed them to further transform their knowledge. The trainable, configurable, and responsible user played an essential role in articulating the link between the safety concept and the training concept, the latter of which may itself be regarded as a boundary object. The flexible, module-based training concept proposed by the roboticists helped to relate the training methods and practices used in the factory's training center with those used in the makerspace.

As the results of a collaborative knowledge production process, the safety concept together with its articulating dimensions—the projected user and the training concept— may be regarded as *models*. According to Carlile (2002) models are "simple or complex representations that can be observed and then used across different functional settings"

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(p. 451). Using these models, the actors were able to jointly transform their knowledge and practices for enabling a different mode of conducting human-robot interaction research in an unconventional cobot usage context. The newly established infrastructure of inquiry also made room for qualitative methods, such as participant observation, which contrasts the measurement-based assessment methods used in industrial safety certification practice. At the same time, the researchers sought to ensure the "backward compatibility" of these models with the factory's training center, which induced path-dependencies in the process.

Let's Agree to Disagree

As part of the project, I conducted a series of interviews with the trainers from the factory training center and those from the makerspace. Concerning the safety issue, the questions clustered around the topics of how training courses are organized, how safety is being addressed in the trainings, and what potential hazards the trainers see in the trainees' interactions with cobots. The following interview extracts illustrates some of the differences in the language and practices used by researchers and industrial engineers on the one side, and cobot trainers from the makerspace on the other. For example, to the question of what could potentially go wrong during training, the trainer responded:

> "So, there can be unforeseen movements; therefore, each step [of the robot] towards the next waypoint is being tested before the entire program runs because there are some [robot] motions, where—and this happened a few times during workshops—the robot chooses a completely different way as one would expect."

The problem of unforeseen motion paths is pointed out by the trainer as one potential safety issues occurring during workshops. Unforeseen pathways between predefined waypoints occur because the so-called inverse kinematics algorithms, which compute the six robot joint angles for any given target pose and then rotate the elements of the robot arm until that target pose is reached. The discussion continues around this issue:

> "*Me*: So with MoveJ [joint based movement, as explained before] or which kind of movement?
> *Trainer*: Definitely not linear. I think it must have been MoveJ. For sure.

Me: And this happens also when you are running the simulation on the teach pendant first, or…

Trainer: This, funnily, we don't do.

Me: Ok.

Trainer: We do not watch the simulation [of the movement].

Me: … pause … Me neither!

Trainer: Ok. [Laughing together]"

One way to avoid unexpected robot pathways is to first simulate them using the robot's software. Yet, in the makerspace using the simulation to preview the robot's movements during trainings does not appear to be a common practice. Although intrigued by this answered, I tried to avoid being normative by admitting that simulation is not always necessary. The next excerpt illustrates how unforeseen movements are being perceived by trainer and trainees and how the latter go about explaining what happens behind the scenes:

> *"Me:* Is this [the unexpected movement] something that disturbs the workshops or is it funny when it happens? What is the effect?
>
> *Trainer:* The effect is mostly "oh, I did not reckon with that." [The trainees] are surprised but they are not scared. […]
>
> *Me:* And if they ask „what just happened?"—How do you explain that?
>
> *Trainer:* We try to find out together, to remove [the problem]. I think I never spoke in a workshop about inverse kinematics. I try to avoid that because, to be honest, I am not knowledgeable enough myself to properly explain that. What I do explain is that, during the different movements—that is, MoveJ—the robot uses the axes in such a way that it is most effect for itself. And in the case of a linear movement, it goes from point to point in a line, which is not the case with MoveJ. So this is my explanation for the two movement types."

In this excerpt, the trainer seems to argue in favor of providing non-expert explanations for unexpected robot movements, while invoking her lack of knowledge concerning inverse kinematics. In these situations, the trainer seeks ways to legitimize simplified explanations over robotics terminology in an attempt to distill the necessary practical

knowledge from a theory that is inaccessible to non-experts. Nevertheless, the trainer adopts the technical term 'MoveJ', which I had dropped earlier in the discussion, thus showing how the language exchange takes place. To the question of whether one would gain something by talking about inverse kinematics during the workshops, the trainer responded:

> "I don't think so. I think, to be honest, that inverse kinematics is only relevant when one is really interested in robotics, that is, when one wants to go deeper. But for programming, if one is taught how—and this pertains to intuition—to learn something not through reading but through "doing" and to understand and for that there are possibilities in the makerspace; and everyone who works with [the robot] knows it that every step that I program must be tried out and not with 100% speed. And I think that this way, one gets a tremendous feeling about what is possible and what is not."

The trainer stresses that speaking about this problem using robotics terminology is neither necessary nor desirable. Then, she goes on and sketches the profile of a projected cobot user, who is likely to be encountered in the makerspace. The responsible cobot user is a pragmatic individual, who is well-aware of the safety hazards entailed by working with the cobot and who is nonetheless more interested in programming the cobot than in learning about its internals. This user is expected to benefit from the resources of the makerspace (interested peers, more experienced trainers, other workshops, etc.) to learn about safety and other issues. The makerspace thus appears to be a well of practical knowledge and possibilities—one only needs to ask and come up with ideas, whereby the role of reading is superseded by that of "doing." Together with the image of the pragmatic, responsible cobot user, downplaying the importance of robotics theory and terminology may be regarded as an act of resistance to well-established forms of knowledge, learning, and acting that are characteristic for traditional institutions; a resistance articulated around knowledge gained through and (re-)invested in practice rather than theory; and a form of resistance through doing that keeps the power relations between makers and researchers balanced and the principle of symmetry upright.

Innovating "en perruque"

The French expression "travail en perruque" (literally, wig work) or simply "la perruque" (figuratively, *homer*) arguably provides an intriguing perspective upon how some "makers" and "hackers" go about their work, time, and interests; and the potential conflicts that may arise from misalignments of expectations concerning their activity in makerspaces. As Anteby (2003) notes, "[a] 'homer' is an artifact that a worker produces using company tools and materials outside normal production plans but at the workplace and during workhours" (p. 454). The "homer" or "la perruque" consists in "[t]he use of materials and tools by a worker at the place of the company, during working time, for the purpose of manufacturing or transforming an object outside the production of the company" (Kosmann, 1999, p. 20). In a sense, makerspaces legitimize this kind of work by providing the tools and spaces for members to spend their own time pursuing their interests. Yet, sometimes this legitimate "travail en perruque" can lead to situations in which the tools, space, time, and interests of the actors misalign. In this sense, members having a certain level of expertise and reputation in the community can be paid by the makerspace to explore a technology at their own will.

In the studied project, for example, the makerspace contracted an existing member, who was skilled in programming, to experiment with the cobot to the end of finding novel potential collaborative robot applications. The programmer's freedom was thus constrained to some extent by the requirement to produce a result in line with the goals of the project. At the same time, there were no restrictions as to how, when, and where exploration should happen. After some time, the assessment of this "uncertified expert" was that, with the exception of a stop-motion application (i.e., using the robot to film or photograph plants and other (living) things over long periods), cobots could only do what other specialized machines, like 3D printers or circuit board assembly machines, already did better. Instead of a collection of applications, the programmer presented a new robot software, which he created outside the allotted contingent of hours for which he was being paid. The idea, so he told me, came during a long train ride. He integrated an inverse kinematics library for the UR5 cobot into an existing 3D simulation and programming environment, in which different kinds of curves could be drawn by a user and followed by the robot, both in the simulation and reality. Whereas the idea was not entirely new, the way in which it was implemented was very interesting and innovative.

Some of the researchers involved in the project, including myself, regarded this "homer" as a fulfillment of the hopes and expectations with respect to open innovation in

makerspaces. The programmer—a "hacker"—proved that, within a few weeks, a single creative and skilled individual can achieve results that other institutions would pursue using much greater investments and bureaucratic overhead. Yet, to the disenchantment of the entire project team, the "hacker" was not willing to publish the source code without what he considered a fair remuneration for his efforts. This was frustrating for the members of the project team, since the exchange of ideas that preceded the development of this software also contributed to its design. After a period of evaluation and negotiation, the makerspace management decided not to acquire the rights for the newly developed tool, to terminate the contract with the programmer, and to hire a trained roboticist to work on the project.

This episode suggests that contract-based "gig" collaborations between makerspaces and their members may lead to unexpected outcomes. In this sense, "gig" collaborationsremind of a kind of "colonial" trade, in which the members of one culture offer goods that are sought after within the dominant culture. At the same time, those goods are appreciated and valued in different ways in the two cultures. In the case of software, the goods only have monetary value if they are acquired in some way by the members of the dominant culture. In other words, the programmer was faced with the following alternatives: to publish the software using an open source license, try to sell it to someone else, or just use it and, eventually, develop it further for personal purposes. This pushed the trade toward a dead end, since the participants to the trade attempted to capitalize on the results of a work that partly emerged from a collective effort and were thus supposed to be made available in the public domain. A red line was thus crossed.

The programmer's work "en perruque" may also be interpreted as a kind of resistance against collaborative and plan-based work, which is common practice in traditional institutions. The fact that the makerspace management refused to legitimize this kind of attitude, although it was in line with the goals of the project, suggests that the makerspace finds itself on a path of institutional transition. As part of this transition, norms and practices that are common in traditional institutions replace the flexible "gig"-based contractual forms of collaboration. Whereas shortly after its inauguration, the makerspace provided creative refuge primarily to the members of the local community of artists and to members of the public, almost two years later, it seeks to professionalize its staff and organizational culture. This is perhaps also an effect of the Covid-19 crisis, which made high-tech makerspaces even more dependent on public funding than before. At the

same time, some of the early members saw an opportunity in legitimizing work "en perruque" in the makerspace, while drawing some financial benefits from their acclaimed creativity. Especially when public funding is used, there is hope for another mode of working, in which people get paid for their creative work without having to protect and commercialize using instruments like patents and startups. Dwelling on such expectations thus seems to foster different forms of resistance to adopting the instruments, norms, and practices of traditional institutions by members of the DIY community.

Reconfiguration

From an institutional point of view, the studied makerspace appears to continuously reconfigure itself into new forms and contents, which emulate the institutional forms encouraged by public funding bodies, like the Austrian Research Promotion Agency (FFG). For example, the makerspace set up a textile workshop shortly after an FFG call for proposals emphasized exactly that topic. The studied project also resulted from a reconfiguration of the makerspace as the first one in Austria to provide public access to collaborative robots, which coincided with an FFG call emphasizing robotics technology. The thematic orientation of the studied makerspace thus appears to be malleable, which allows it to transform its workspaces and offering very quickly—for example, from robotics lab to textile peer production workshop. With member operations being very low during the Covid-19 crisis, this reconfiguration also seems to have rendered the makerspace more consequent in attempting to acquire and produce "certified" knowledge and expertise; and to capitalize on those "goods." The management also seeks to attract people who possess the knowledge, expertise, and skills that are deemed useful in the context of a certain, often temporary strategic orientation of the makerspace from research institutes and companies.

For example, by hiring a trained roboticist for the project, the makerspace seized the opportunity to absorb some of the expertise of the researchers from the robotics institute by creating the premises for transitioning towards a homogeneous trading zone. In exchange, the robotics institute gained access to a new sociotechnical infrastructure, with the help of which entrenched industrial safety norms and standards could eventually be rendered more permissive, or fulfilled in other ways. This suggests that, introducing a new technology in makerspaces may cause some degree of institutional isomorphism (DiMaggio & Powell, 1983) through professionalization and normativity. In this sense, the

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studied makerspace seems to be indeed "defined by institutional encounters" (Braybrooke & Smith, 2018) with research institutes and companies.

Discussion

My observations suggest that the exchanges and interactions between the members of different technical cultures produced knowledge that might have otherwise remained inaccessible within a single culture. When crossing the boundary between industrial research settings and DIY locales, relatively stable models are transformed more profoundly than through exchanges between researchers and engineers alone. As Carlile notes, knowledge is invested in practice and individuals may be unable or unwilling to change "successful" knowledge because changing that knowledge comes at the cost of "altering what they do to develop new ways of dealing with the problems they face" (Carlile, 2002, p. 446). In this sense, participatory HRI research seems to take "successful" knowledge, invested in laboratory and industrial practices, to its limits; and then to open it up towards the inclusion of the participants' knowledge and practices.

Within the sociotechnical configuration of the studied project, I mainly observed two types of exchanges across different boundaries. First, there were exchanges at the institutional level, between the different types of organizations involved in the project. In exchange for the infrastructure and the pool of participants that it offered, the makerspace received expertise in the domain of robotics and HRI from two research institutes and an industrial training center. The training center exchanged their safety requirements and expertise gained through expensive certification processes for a new safety concept and the promise of access to a new training infrastructure. The makerspace seems to have positioned itself as a facilitator of the trade between different kinds of institutions, while taking part itself to the trade.

A second type of exchanges occurred at the conceptual level between the researchers and engineers involved in the project. United by the common goal of "democratizing" cobot technology for different purposes, they transformed their knowledge by converting "within" to "across" boundary objects, notably the cobot itself. When used in an industrial context, the cobot seemed to convey the image of a pre-programmed machine, which configures worker routines. By contrast, in the makerspace it was perceived more like as a computer that moves, which allows its users to explore its capabilities in a playful way. The news about a makerspace having already permanently installed a cobot affected the

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project team's preliminary safety concept, which built on an elaborate training program combined with very specific active safety systems. These "epistemic moments" prompted an inversion in the perception of the user-cobot relation, with users becoming interacting subjects rather than objects of inquiry for researchers and engineers. It is in these moments that a kind of epistemic trade appears more evidently to be at work. The goods of this trade are epistemic in nature because they challenge the entrenched beliefs, practices, and knowledge of the participants in unexpected ways. The "epistemic goods" being traded between the members of different technical cultures seem to be of little value within one's own culture—perhaps because they are considered less important than other objects and thus play secondary roles in knowledge production processes.

The "problem of communication," which Collins et al. (2007) require to justify the use of the trading zone concept lies in the distinct languages used by the members of the researchers and those of the makerspace members. This problem was overcome when a "trading language" (Galison, 1997) emerged, which facilitated the communication between makerspace members and researchers, while allowing the members of each culture to pursue their own interests. The resulting sociotechnical configuration of the project resembled a collaborative, heterogeneous trading zone, which produced the new image of the responsible cobot user as well as a novel robotics software that fit the spirit and the various interests of makerspace members. However, the balance of power and interests between the actors involved in the trade was fragile and a difficult financial situation determined the makerspace to seek more aggressive ways to capitalize on the outcomes of the project. This reconfiguration led to misalignments of expectations, which delegitimized gig-based trade between the makerspace and its members. By hiring a professional robotics engineer, the trading language also disappeared as the researchers suddenly found themselves on the same page with the makerspace representatives. With professionalization and the introduction of new hierarchical levels and norms of conduct, the makerspace seeks to position itself in Austria as a professional institution, which can quickly adapt to new research topics and forms.

In the context of the studied project, the makerspace appears to have transitioned from one trading mode to another. Whereas in the beginning, the project attracted the members of very different technical cultures, thus facilitating the emergence of a heterogeneous, fractioned trading zone around the cobot as a boundary object, almost two years later, a shift toward what Collins et al. (2007) call a "homogeneous" trading

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zone could be observed, in which the trading partners shared a robotics interlanguage that included notions that were specific to the use of robots in makerspaces; such as, 'member applications' in addition to productive applications, 'responsible users' and 'safety concept' in addition to certified human-robot collaboration / coexistence / interaction, 'flexibilities' instead of restrictions, etc.).

The trading zone model complements that of makerspaces as "real-life laboratories" (Dickel et al., 2014) by suggesting that the collaboration between techno-scientists and lay or "uncertified experts" (Collins & Evans, 2002), and between research institutes and DIY locales are inherent to the co-construction of technologies and their users (Oudshoorn & Pinch, 2003) as a process of transition towards a potentially sustainable mode of knowledge production rather than a controlled experiment. At the same time, the trading zone model helps to discern between the ways in which democratic deliberation can (or cannot) help to appropriate robotic arms—a paradigmatic automation technology—for peer production and other non-industrial purposes. In this sense, the present case study suggests that, to foster sustainable exchanges between researchers and makerspace members as well as between members possessing different kinds and levels of expertise, trade must be fair in the sense that the contributions of all the parties involved should be balanced and equitable. Mutual respect for each other's expertise is required of both researchers and participants. Through mutual respect, hierarchical boundaries induced by the members' diverse educational backgrounds can be blurred. And, the benefits of the trade must be shared one way or another with the members of the other culture, to whom the receiving parties remain indebted.

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