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ORIGINAL PAPER

Cobots, "co-operation" and the replacement of human skill

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Abstract
Automation does not always replace human labour altogether: there is an intermediate stage of human co-existence with machines, including robots, in a production process. Cobots are robots designed to participate at close quarters with humans in such a process. I shall discuss the possible role of cobots in facilitating the eventual total elimination of human operators from production in which co-bots are initially involved. This issue is complicated by another: cobots are often introduced to workplaces with the message (from managers) that they will *not* replace human operators but will rather assist human operators and make their jobs more interesting and responsible. If, in the process of learning to assist human operators, robots acquire the skills of human operators, then the promise of avoiding replacement can turn out to be false, and if a human operator loses his job, he has been harmed twice over: once by unemployment and once by deception. I shall suggest that this moral risk attends some cobots more than others.

Keywords Cobots · Unemployment · Social robots · Workspaces

Introduction

Automation does not always replace human labour altogether: instead, it can result in human co-existence with machines, including robots.[1] Production processes which are repetitive, involve exertion and can be completed independently lend themselves to total automation (Jesuthasan & Boudreau, 2018). But many processes are not like this. They require human adaptability and dexterity both to keep lines moving and to introduce efficiencies. *Collaborative robots–cobots* for short—are designed to participate at close quarters with humans in processes which distribute types of tasks between humans and robots (Bloss, 2016).

Because the human being is not in control of the cobot, he or she is not related to it exactly as tool user to tool. Instead, and to acknowledge the autonomous working of the robot in a shared industrial process, "collaboration" is the term used. "Collaboration" fits for a second reason, which is that cobot actions complement human actions in the achievement of a goal. In one typical role, robots will tirelessly pick and place components on a line for humans to assemble: the placement is always precise and enables a working rhythm to develop between human and machine. In another application, a robot will dispense and apply glue to objects, or hold materials at the right angle for specialist human welding. Again, robots can pick finished items for packing, even ones that are as easy to deform as paper cups.

Cobots present at least three kinds of ethical challenges. Unlike other industrial robots, they are often not fenced off from humans on a factory floor. They can collide with or otherwise harm human operators, and so they must be designed so that humans are safe in their vicinity.[2] Accordingly, cobots are often small and lightweight, and are fixed in position. Sometimes their hard surfaces are given soft skins. When mobile, they are designed to stop where humans are present, or move at very low speeds near people.

The second ethical challenge concerns data collection (van Wynsberghe et al., 2022, p. 261). Cobots can be designed to record and report to managers on their interactions with human operators, e.g. how quickly operators carry out their tasks, and whether interactions with some humans but not others result in stopped production (Bendel, 2018; Moore et al., 2018). This kind of data collection is intrusive,

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[1] For a very clear summary of differences between co-existence, collaboration and co-operation in the senses relevant to robots, see Bauer et al. (2016).

[2] For a general survey of ethical issues raised by cobots, see Bendel (2018), Fletcher and Webb (2017); Moel et al. (2022).

might not be consented to, and might questionably be used for decisions about dismissal.

A third sort of challenge, and the one that will dominate my discussion, is the possible role of cobots in facilitating the eventual total elimination of human skill from processes in which humans are initially involved with cobots. Here the problem is not that of cobot surveillance of particular human operators. Instead, it is to do with the elimination of humans altogether from an industrial process that once shared with humans. Even when humans are not eliminated altogether, the skills they first exercised alongside a cobot can be superseded, and they need not be left in the end with jobs that are better than, or even as satisfying as, the skilled jobs they once had.

This issue is complicated by another: cobots are often introduced to workplaces with the message (from managers) that they will *not* replace human operators but will instead assist them, protect them from injury, and make their jobs more interesting and responsible. As we shall see, some cobots are also *marketed* that way (Campbell, 2019). But if, in the process of learning to assist human operators, robots acquire the skills of human operators, then the promise of avoiding replacement can turn out to be false, and if a human operator loses his job, he has been harmed twice over: once by unemployment and once more by deception. Automation that results in deskilling when upskilling was promised is another kind of deception. I shall suggest that the risk of these kinds of deception attend some cobots more than others.

The rest of this paper is divided into four sections. In the first, I shall draw from the recent robotics literature a short summary of the current capabilities of machines that can be described as collaborative robots. These capabilities are not always well described by marketers of the commercial versions of these robots, or understood by their potential purchasers. Still less are the complexities of integrating commercial cobots into an industrial environment always understood by purchasers.

In the section entitled "Does participatory design and Integration preclude human replacement?", I discuss two recent academic case studies that illustrate the difficulties of integration even in settings where cobots are eventually absorbed into production processes. Adapting a cobot to specific industrial purposes is often a matter of programming that models human skills. Human workers who assist the programmer by helping to unveil the skills involved in their pre-automation roles, and by diagnosing malfunctions in the automated process, might be colluding unwittingly in their own replacement, and this is itself an additional source of moral risk.

The marketing of industrial robots sometimes anticipates difficulties of integration and provides a narrative that enables managers to reassure workers: in the section called "Deceptively easy: worker creation of robot skill in Baxter and Sawyer", I illustrate this point, starting with descriptions by Rethink Robotics of two of their cobots: namely, the Baxter and Sawyer models. Both of these have remarkably intuitive user interfaces which enable human workers quickly to train them for pick and place tasks and for packing. Human workers use their own knowledge of the postures and movements they themselves adopt for a task in a specific production setting, and manipulate the arms of the robot so that their own postures and movements are automatically imitated and repeated in that setting. This kind of reproduction of skill is disturbingly direct and quick, increases the replaceability of the human worker, and is at odds with the original marketing for Baxter as a kind of apprentice to its human trainer.

Finally, In the fourth section, I reflect on the protections needed for workers who contribute to the automation process by assisting software designers, or who make available their practical know-how through manipulation or imitation.

"Collaboration" and collaborative robots

Cobots "collaborate" in a narrow sense of that term, connected to the efficient division of labour: industrial tasks that robots are readily capable of, such as heavy lifting, positioning, and long-term precise repetition, including repetitive inspection, are taken away from humans in a production line and performed by the robot. As for humans in the process, they contribute their adaptability, situational awareness and sometimes their fine-grained dexterity. In other words, at least ideally, the respective contributions of humans and robots correspond to the different strengths that, in general, humans and robots each bring to a production process.

"Collaboration" in the wider, normal sense is a matter of several agents sharing a goal and co-ordinating their actions to achieve it over time. Human collaborations may be one-sided, as when only one of the agents contributes most of the time and effort to a project that was supposed to be shared equally. Ideally, however, the contributions of the various agents are timely, indispensable to the final result, effective for producing the result, and not overtaxing or debilitating to any of the contributors. In non-ideal situations, human collaborations can involve competition between the agents, or temporary antagonisms and disagreements about the means of achieving the goals, or fluctuations in willingness to implement the means. In the case of cobots, competition, disagreement and fluctuations in willingness are not possibilities.

Collaborative robots are defined by task-, time- or space-sharing with humans. Every collaborative industrial robot contributes with human beings to some industrial process or other. In most of these the robot and the human operate close to one another in space, but the process may be divided into tasks that are not necessarily performed at the same time. A robot and a human being may complete discrete consecutive tasks, or, more rarely, perform simultaneously their respective parts of a shared task.

The typical cobot is a stationary arm capable of lifting and manipulating an object weighing a few kilograms. Uncommonly, capacities for large payloads exist: the COMAU ORA can carry 170 kg (Michalos et al., 2022). The larger a payload an arm can carry, however, the greater potential harm to a human operator working close to it. Sometimes the arm has a skin that cushions impacts with humans, should they occur.

Where cobots are mobile,[3] they are often mobile platforms with arms and manipulators fixed on top (Michalos et al., 2022, Fig. 4). They typically move on flat, open factory floors and are able to be guided by floor markings. Human operators occupy designated spaces on these floors and move in stereotypical ways for predictable lengths of time and at predictable intervals. Moving machines are programmed, typically, to change places slowly, and to come to an immediate stop when they come near humans. When it comes to self-monitoring, cobots can keep track of their own force and speed, and can keep both under certain thresholds. TS/ISO standards adopted in 2016 highlight four types of robot-human interactions: (a) safety-rated monitored stop; (b) hand guiding; (c) speed and separation monitoring; and (d) power and force limiting. (Michalos et al., 2022, p. 23).

Rudimentary voice commands to robots from humans are now possible (Michalos et al., 2022, p. 32; Marguglio et al., 2022, p. 122), and robot interactions with social aspects are welcomed by workers (Elprama et al., 2017). More rarely, augmented reality can allow for exchanges in real time of digital information that play the role of human mutual monitoring (Evangelou et al., 2021). Again,

> [b]ased on the stereoscopy effect, the user can see 3D objects such as parts, safety zones and robot's trajectory. These functionalities aim to support operators in the assembly lines as well as increase his/her safety awareness for potential hazards. Additionally, the operator can see messages in the form of text that provide alerts and informatregarding the production. This technology is considered the most immersive, since it blends virtual and real-world components, targeting one of the strongest human senses, that of vision (Michalos et al., 2022, p. 33).[4]

"Collaboration" in its normal sense often suggests mutual awareness in real time of the performance of tasks by the agents who are co-operating. Take the case of three people who are trying to manoeuvre a large piece of furniture up a steep, narrow flight of stairs. Each must not only be aware of their own position and the position of the furniture relative to the stairwell, but also the position of the other furniture movers, their grip on the furniture, and the load they are supporting at different times. Each must also be aware of the strain they each display at different times when having to bear the weight of more or less of the furniture at different places on the stairs. Some of this mutual awareness is assisted by linguistic exchanges.

"Collaboration" with robots is not usually nearly as complex as the collaboration between human furniture movers that we have just been imagining. It is usually less of a feat of continuous self-perception and bodily adjustment. Although robots are routinely equipped with sensors that alert them to the presence of a nearby human (often a nearby human's hands), they are rarely expected to adjust their operations to their collaborators as sensitively as the human furniture-movers do. It is true that certain robots engaged in industrial production can adjust the positions and speeds of their arms to human manual guidance and even exchange information in speech or (in the case of robots) simulated speech (Michalos et al., p. 32). But this is atypical.

So long as the distribution of strengths between humans and robots remains stable, human jobs that complement robotic capabilities will probably remain, as will the need for cobots. But there is no genuine insurance against the destabilising possibility that, for certain industrial processes, ways will be found by roboticists or managers of reducing the number of humans required, or eliminating the demand in an industrial process for tasks that humans are currently better able to perform than robots. We turn to this possibility in the next two sections.

Does participatory design and integration preclude human replacement?

The prospect of being made redundant by technology is fearful to many workers in manufacturing. But there is a certain approach to technology integration—participatory design (see Quinlan-Smith, 2022; Welfare et al., 2019;

[3] I disregard drones, small mobile robots used in e.g. pipe maintenance, and exoskeletons: though all are discussed by Michalos, the former do not seem to participate in production processes, and the latter are not easy to conceptualise as collaborators, but only as wearable tools.

[4] See also Michalos et al. (2016), Makris et al. (2016), Gkournelos et al. (2018).

Charalambous et al., 2015)—according to which that fear can be reduced by including those who think they will be disadvantaged by a technology in the integration process—e.g. as advisers to programmers and system integrators. Thus, representatives of a human workforce about to "collaborate" with cobots might participate in the design of the cobot and the manufacturing cell. Still according to this view, so long as managers and designers make clear to a workforce what they are trying to achieve with automation, and so long as they communicate the benefits, along with a method of fitting adapted human jobs to a "collaborative" workflow, there is no reason why the transition to work with robotics cannot be harmonious (See also Cole, 2020; Pierce et al., 2004; Wagner et al., 2003; Björling & Rose, 2019). More generally, technology design can be conducted so as to involve those who are excluded or marginalised on grounds of race, class, gender and so on by social structures in general (Costanza-Chock, 2020, ch. 2). More generally still, technology can be designed to embody highly general values, such as democracy, justice and well-being (Flanagan et al., 2008). To the extent that work contributes to human well-being (Arneson, 1990), the replacement of human beings in industrial processes may be recognised by managers as something to be avoided.

Although, as we shall see, there is evidence that a value-driven and "participatory" approach to automation alleviates workers' fears of being replaced, it also suffers from a certain amount of idealisation (Ionescu, 2020). Decisions to automate industrial processes are sometimes made relatively hastily and speculatively by managers, that is, without sufficient understanding of the limitations of the relevant technologies, and the effects on the human workers who are left.[5] This means that there may be no coherent view of the result of automation, or of the steps required to achieve this result. What is more, even when innovation has a managerial "champion" who has thought it through, and workers co-operate, fears of no job or a worse job on the part of humans are not necessarily baseless.

I start with some anecdotes about the haphazard introduction of robots into industrial processes. In a Youtube video (AutoStore, 2021), a satisfied user of Autostore warehousing robots in Australia admits that, even after the decision was made by his company to introduce them into a new factory setting for picking and packing its products (advanced locks), it was unclear whether its relatively small number of employees (just over 60) and its relatively small number of daily picks (around 1000) justified the investment. It was only afterwards that some unexpected benefits emerged, including large reductions in electricity usage and stock wastage. These alone made savings that vindicated the decision to automate.

Autostore robots work at a distance from human packers, but cobots, too, are sometimes introduced speculatively. This is acknowledged even in the promotional material of robotics firms that seek to sell cobots. In an article in *Automation World* (2019) supplied by Mitsubishi Electric, two of its robotics experts, Ben Sagan and Adam Welch, caution against introducing cobots without detailed thought about the ramifications:

> it's not just about payloads or cycle times. There are very important issues involving human safety and training," explains Welch. "Despite what you may have heard, you can't just plop a cobot onto the factory floor and expect it to start working. You need to do proper planning so the cobot is used in the proper place and for the right reason. We're finding that companies are spending a lot of time and money trying to force a robot into an activity where it just doesn't fit"
> Sagan agrees. "There are lots of misconceptions about cobots, such as that you don't need safety equipment, that they're easy to program without training or that they're just plug and play. The truth is, you can't just find somewhere to shoehorn them in. When that happens, they end up becoming just the latest toy, standing in a corner collecting dust" (AutomationWorld, 2019).

Two academic case studies of the effects in "human factors" terms of the attempt to automate manufacturing processes with cobots illustrate the practical and ethical issues that arise when the introduction of cobots is not fully thought through.

In the first case study (Charalambous et al., 2015), a company making aerospace parts was studied while in the process of automating the welding of a component with an irregular geometry. Manual welding could not be relied upon to produce leakproof results in this component, and the new robotic process was meant to solve this problem. For example, it was meant to reduce significantly the number of times that the component had to be reworked or scrapped following failed leak tests. Workers familiar with the manual process were actively involved in developing the automated process. In the new process, human operators working in a manufacturing cell would supervise a robot developed to produce reliably a standard leakproof weld in the component. Significantly, the robot in this case was not a mobile cobot, i.e. lightweight and in motion among people. Such a robot would not have been able to cope with payload.

[5] This is despite the fact that techniques exist for analysing jobs into tasks that are suited to cobots. See Doyle Kent and Kopacek (2021), who draw on Jesuthasan and Boudreau (2018). It is interesting that Jesuthasan and Boudreau are able to distinguish between jobs that lend themselves to cobots and jobs that are better suited to total automation. The key variables for total automation are whether the tasks are physical, repetitive and independent (vs interactive).

Instead, it was a fixed industrial robot placed within a manufacturing cell in which human operators were co-located.[6]

Automation in this case was largely a success. A crucial factor was the involvement of human operators in the development process who were familiar with the manual process. These operators were able to identify shortcomings in the handling of the welding task by the robot prototype when it was displayed at the premises of the system integrator. Some of these shortcomings were based on the robotic welding leaving out aspects of the human method of welding that was being replaced. Since some of the shortcomings presented themselves when the manufacturing cell containing the robot was shown by the system integrator to the manual operators, one lesson learnt was that the manual operators might have been involved earlier in the design of the cell (Charalambous et al., 2015, p. 2148).[7]

The human operators not only suggested modifications of the automated process but acted as focal point of communication between, on the one hand, the rest of the welding workforce and, on the other hand, both senior management and the system integrator for the automated manufacturing cell (Charalambous et al., 2015). By hearing directly from senior management what the purpose of the automation was, and by being able to judge whether welding problems would in principle be solved by the robot, human operators advising the integrator were able to provide initial endorsement of automation from a worker perspective (Charalambous et al., 2015). By making suggestions that improved the results of automated welding, the same workers were able to feel responsible for some of the detail of the automation.

It is unclear from the case study whether one of the results of automation would be the unemployment of any of the workers involved in the manual welding,[8] but it seems that some of the manual workforce was expecting considerable change in the organisation of manufacturing, and that senior management was unable to predict, or was unwilling to spell out, the effects on workers of introducing the robot. To the extent that the transition to an automated cell was unnecessary stressful for manual welders, it was morally objectionable.

In other respects, the case study confirmed some of the received wisdom in the literature about the effective introduction of technology already referred to at the beginning of this section. First, senior management involvement in, and commitment to, automation helps; so does early communication with those whose work practices will be most affected; the appointment of someone in the organization to champion a particular automation process is an advantage; so also is bespoke training for those who are affected by the automation process (Simões et al., 2020).

A more delicate question is whether the introduction of the robot improved the worklife of the manual welders. Part of what is being asked is whether the job of welding robot-overseer improves on the job of a welder. To approach this question, it is useful to apply Gheaus and Hertzog's (2016) analysis of the principal things that make work good. According to them, there are four aspects of good work distinct from being paid decently to do it: (a) the ability to develop and master skills; (b) the community provided by working with others; (c) the social contribution one makes with one's job; and (d) the social recognition attached to one's role (See also Smid et al., 2020). Gheaus and Hertzog also mention things that make work bad, which include repetitiveness and unrelenting physical exertion. To the extent that cobots in general remove repetitiveness and exertion, they make work better according to this framework.

Does that mean that the shift from welder to welding robot-overseer in our case study is an unmitigated improvement according to the Gheaus-Hertzog criteria? Not necessarily. The overseers cease to be able to exercise welding skills, which may or may not lead to a decline in social recognition. On the other hand, they continue to work with others in a manufacturing cell, and the welding robot frees them of the burden of having to remake or scrap defective components. Presumably the new role involves less social contribution, since the social benefit of the well-made component is at most the joint responsibility, not the sole responsibility, of the human involved in the welding. And in the new role the human is not welding at all. He or she may indeed be making a social contribution by monitoring the welding robot: preventing accidents, say. But the monitoring function may itself be eligible for automation on the grounds that machine monitoring is more reliable than human monitoring.

The second case study considers the introduction of a cobots into small to medium-sized Danish enterprises (Wallace, 2021).[9] In none of the 15 cobot deployments examined

[6] Email correspondence with S.A. Fletcher, one of the co-authors of the 2015 case study.

[7] See also Del Mar Otero and Johnson (2022).

[8] Fletcher's impression in 2021 was that no human welders were made redundant. Nor was this part of the automation plan.

[9] "The study builds upon a series of semi-structured interviews carried out with 15 different Danish companies between June and December 2019. In one case, follow-up interviews were carried out in order to talk to a number of other informants. The companies were chosen as representing a range of experiences in cobot implementation, as well as company size. Eight of the companies are characterised as having under 250 employees, three have between 250 and 500, and four having over 500. All the interviews were held at the company's premises and were preceded by an introduction.to the manufacturing process and direct observations of the cobots and/or the projected cobot installations. … All the interviews were based upon the same interview guide initially developed through a number of pilot interviews. It comprised 24 questions organised in the following categories: 1. Introduction 2. Before purchasing the cobot/initial considerations 3. Organisation and implementation 4. Technical factors 5. Human factors 6. Closing reflections" (Wallace, 2021, pp. 301–302).

did cobots and humans work simultaneously on the same task. Instead, the pattern of work always consisted of a sequence of robotic operations followed by a sequence of human ones. In every case, cobots were added to already automated assembly lines. In all, 28 robots were involved in these processes, and all were from the UR series made by Universal Robots.[10]

UR machines are robotic arms fixed on a surface that human operators can sit at. Among other operations, these arms can be programmed to insert screws into, polish, spray, and pack, items on a line. In the companies studied, cobots were not effortlessly or seamlessly inserted into work routines. Instead, companies ran extended experiments—lasting between 3 months and 2 years—to test different ways of deploying the cobots, the experiments running alongside established automated processes.[11] Human jobs had to be rethought to accommodate a role for robots, and expertise from outside the workplace e.g. in programming, sometimes had to be bought ad hoc (Wallace, 2021, p. 302). To cope with the continuous problem-solving required to integrate the cobots, nothing less than someone with a "fiery soul"—someone with extraordinary determination–was needed (Wallace, 2021, p. 303). This echoes the finding of previous studies about the need for a "champion" for a novel automated project.

Up to a point the message of the Danish case study is similar to that of the previous case study. Designing and implementing an automated process is:

> …[a] co-evolutionary process involving cycles of ambiguity and uncertainty as solutions go on to pose new problems faced by multiple actors. Despite the ambitions of firms and the increasingly intelligent systems and off-the-shelf products developed by robot designers, these ... problems leading to changing practices and shifts in human relations pose significant challenges (Wallace, 2021, p. 299).

More simply, the message is that it is hard to get a collaborative robot to fit successfully into a manufacturing workplace, and that bringing this about makes considerable demands, including moral demands, on the people involved.

It is not that the factories considered in the Danish case study were new to automation or that robotics is relatively untried in manufacturing in general, still less manufacturing in Denmark. On the contrary, the case study associates the problems with the fact that there have already been several waves of automation in manufacturing, and that cobots in the second decade of the twenty-first century belong to the so-called "Fourth Industrial Revolution" made possible by digitization (Wallace, 2021, p. 300).

A further fact is that the design requirements for robots that can safely operate in the same space as humans conflict with the desirability of robots that can lift or transport big payloads. Then there is the hybridization of manufacturing jobs, jobs done jointly by cobots and humans:

> As roles and tasks are modified and hybridised, rather than replaced, the need for humans to carry out only a part of a previous job becomes common. In the face of this, return of investment (ROI) calculations used to determine the economic validation of investing in cobots can become ambiguous and a matter of interpretation. Removing parts of jobs cannot be considered a direct saving in labour, leaving economic advantage to be achieved through partly freeing up workers to "do something else" (Wallace, 2021, p. 301).

Companies often associated their adoption of cobots with benefits to workers: cobots would eliminate or reduce hard or boring work, would open educational opportunities etc. In addition, the prospect of working with cobots might attract a new multi-skilled type of employee. In practice, the process of making cobots fit into the workplace intensified the comparison of cobot and human skills, as if they were in potential competition for eventual integration:

> What the cobot is capable of and what the human can do are revealed in relation to one another. Consequently, human work becomes valued not in terms of say skilfulness or aptitude, but in respect to this significant other. If the cobot or indeed the human is seen as quick, the other becomes slow, if one deemed expensive the other cheap, flexible, inflexible, and so on. The capability of one becomes related to that of the other (Wallace, 2021, p. 303).[12]

Although the cobot is marketed as an enabler of shared work, as opposed to something that can entirely replace human work, "[i]n practice, the cobot is set to carry out as much of a task as is technically possible. Accordingly, [cobots] are viewed not as potentially cooperating within teams of humans, but as cheap industrial robots capable of replacing manual labour" (Wallace, 2021, p. 303). Presumably this means "viewed by *human workers* as capable of replacing manual labour" (Wallace, 2021, p. 303). The case study gives an anecdote about a highly skilled worker who, when faced by a manager with the possibility of working with a cobot, said immediately that he would leave the

[10] For videos of these robots in action in manufacturing see https://www.universal-robots.com/applications/.

[11] On the moral issues raised by the experimental introduction of new technology, see van de Poel (2017).

[12] See also on this point van Wynsberghe et al. (2022, p. 261).

company. Although the manager in question said that the welder's reaction was out of the ordinary, it makes sense as a reaction to the prospect of eventually having one's job replaced.

The case study suggests that, ironically, the process of getting the robot to work sometimes heightens appreciation of the capabilities of human workers. Given the difficulties of incorporating cobots, some managers regret embarking on a plan of adding them to a factory workforce in the first place. For example, although they are good at doing repetitive work to a consistent standard, UR robots are not able to adapt to experimental reconfigurations of work processes, as humans are. Nor is it easy to simulate human skill in robot action that is designed to mimic human skill:

> Difficulties in programming a cobot to replace a human worker grinding the edges of a cut glass plate serve as an example. After several attempts, the cobot could only achieve a successful operating cycle once the programmer had physically learnt from the operator how to grind the glass properly. She had understood the principle involved but had not understood the particular arrangement of picking up the part, approaching the grinding wheel and moving it through a precise trajectory. The human skill then becomes explicit, not just to the programmers and technicians but also to the operator[s] themselves (Wallace, 2021, p. 305).

The case study revealed a difference between technicians and operators. Technicians might have better career prospects than mere operators, but they could also be called upon to do the work of operators as necessary (Wallace, 2021). Operators, for their part, might lose some of the well-being and status of their pre-cobot working: they would be turned instead into servicers of a robot—fillers-up of its fluids and feeder trays, monitors of its normal operations, and so on (Wallace, 2021, p. 306).

The picture that emerges from both case studies is that introducing cobots is a protracted, experimental, process with no easily predictable results for the managers, workers or the programmers involved. There are no guarantees at the beginning of the process that human work will not be replaced outright eventually or even in the near term. This means that human workers volunteering to help companies automate their skills can be involved (sometimes unwittingly) in a process of moving themselves closer to unemployment.

On the other hand, there are no guarantees for managers that cobots will be able to take over successfully tasks that have been carried out by humans in industrial processes. It may emerge after a significant investment in programming that plates *cannot* be ground or that metal *cannot* be bent as well by cobots as by a human. In that case, not only management and programming time has been wasted: the effort of workers trying to adapt to cobots while being uncertain about being replaced by them has come to nothing. Arguably, this is not only wasted effort, but wasted generosity, on the part of co-operating workforce.

Deceptively easy: worker creation of robot skill in Baxter and Sawyer

In the previous section, we concentrated on a process of introducing cobots into manufacturing that involves an extended and sometimes intense collaboration between human workers, programmers and managers. The workers bring to the process skills that are to be automated; the programmers try to anatomise those skills in code, and managers decide whether to initiate automation and whether, after experimenting with different cobot contributions to a process, it is worth proceeding to a more permanent implementation. We have seen that one effect of introducing cobots is that the new process can put humans at the service of machines: replenishing their raw materials or restoring cobots to working order when they break down. Would this process be open to less moral criticism if workers had more of a role, and a more *direct* role, in training the cobot to fit in—a role *less* mediated by programmers and systems integrators than we have seen in the two case studies just reviewed?

This is the possibility that supposedly guided the development of the Baxter robot by Rethink Robotics. Baxter is a two-armed robot mounted on a wheeled pedestal (Fitzgerald, 2013). Its full height is around 6ft. It has a head mounted above the arms. The head unit has 360-degree sonar, cameras and a display. The display shows various facial expressions to convey understanding or confusion on the part of the robot in response to human operator interactions. Cameras are also located in the torso of the robot and at positions on the arms that are able to monitor what the robot handles. The overall effect is humanoid, and, unlike the disembodied UR robotic arms considered in the last section, Baxter has aspects of a social, service robot.

The most remarkable features of Baxter are its intuitive user interface, and arms and grippers which can be moved by manual operators into precise positions and orientations required by a chosen manufacturing process, and which Baxter can be made to remember at the touch of a button. For example, Baxter can be positioned to pick and place objects with one hand/arm, while simultaneously performing a distinct operation with different sets of objects with the other hand/arm. It can be deployed in the morning to place objects on a conveyer belt and in the afternoon to pack finished goods. Three use cases involving picking, intricate placing, stacking and packing were chosen by developers on the basis of information on user-requirements gathered from US manufacturers (Fitzgerald, 2013, p. 5).

Unusually, for a cobot usable in manufacturing, Baxter was designed as a plug and play device:

> Baxter is designed to be an affordable and user-friendly solution for manufacturers of all sizes. It is a complete system with rolling pedestal, electrical and/or vacuum grippers, warranty, and software updates, at a total price of around
> $30,000. Traditional industrial robots require weeks or months of work by programmers and system integrators to solve a manufacturing task. Baxter requires no integration costs and can be unboxed, assembled, trained and running in less than one hour (Fitzgerald, 2013, p. 1).

Furthermore, Baxter's humanoid appearance was intended to project friendliness, and ease of use. It was supposed to be "as easy to train as a child" in a practical task (Fitzgerald, 2013, p. 2). The developers describe with evident approval the impression that the robot makes:

> users think of Baxter as a tireless apprentice that is eager to learn and perform new tasks, to free themselves to oversee the robot and do more interesting work (Fitzgerald, 2013, p. 2).

The idea that Baxter plays the role of apprentice to the manual operator who choreographs its movements conveys a radically different relationship of manual worker to robot from that of filler-upper, maintainer and watchman of the machine. Apprentices serve out their terms under someone who has mastered a craft or trade. The master is the person whom the apprentices learn from and defer to, and who disciplines the development of their own abilities in a craft or trade. So the idea of robot apprentice conveys subservience, much as the better-established idea of a robot butler does. The machine is there to serve rather than, as in the Danish factories, to be served.

Although the rhetoric of apprenticeship seems to lend added status—something like master craftsman status—to a manual factory worker, reinforcing the marketing message that collaborative automation is elevating for e.g. manual welders, polishers and assembly line workers, it is possible to see it as highly deceptive, with potentially a bigger threat of making human workers obsolete than the set-up of worker, programmer and manager. The reason is that Baxter's interface allows the worker to show Baxter exactly the motions it needs to go through to take a human worker's place in an assembly line.

In the set-up of worker, programmer and manager that we encountered in the two case studies of the previous section, it is the repeated efforts of programmers to capture movements they could not reproduce through code that culminates in the robot simulating the action of the worker. But with Baxter that middle man is consciously cut out. The movements are imprinted directly onto the robot arms by movements of the worker, not through the intervention of a traditional programmer. This is the direct donation of skill to the robot, not initiation of a programmer into a manual skill which the programmer subsequently tries to capture. Still less is it the long-term attempt by an apprentice to simulate mastery of a craft. So the idea of Baxter the robot apprentice seems, on inspection, to be highly misleading, partly because it seems to create, and then to disappoint, the expectation of a kind of robot that does not worsen the position of a human worker whom it allegedly supports.

Baxter was introduced to the market in 2012. It was succeeded in 2015 by Sawyer. Sawyer is much more like the UR robot from the Danish case study than Baxter. It is single-armed and lacks a full body. It occupies less space but has the same 7 degrees of freedom.[13] Like Baxter, it has series elastic actuators, in which a motor and spring drive a joint, as opposed to a motor and gearbox. This design enhances the safety of people working in the vicinity, but has other drawbacks, to which we will return shortly.

An important question about Sawyer, in view of the preceding discussion, is whether it, too, can be billed as a "friendly apprentice". As it takes over the facial display that contributes importantly to Baxter's humanoid appearance, and as the facial display seems to express willingness to co-operate, it may well qualify as "friendly". But clearly it is less humanoid, less mobile and, with only one arm, it can give the impression of being a reduced version of Baxter. Instead of a co-worker, it is, to look at, a sort of animated UR arm. In common with the UR arm, it seems to reduce the machine collaborator to the (admittedly varied) functions of an arm and hand, as opposed to a whole-bodied co-worker. By the same token, it seems not to amount to a unitary co-operating agent, but a functioning sub-assembly of a would-be robotic apprentice. The UR robotic arm is different from Sawyer, since it appears never to have been developed as a social or humanoid robot. While the progress from Baxter to Sawyer seems to dehumanise the robot collaborator—to reduce it to a version of the powers of co-ordinated human body parts, the makers of UR robots have apparently had no aspirations to humanise cobots. This may be morally creditable, as will emerge.

It is an interesting and important fact about Baxter and Sawyer that they did not succeed in the market they were designed for. Rethink Robotics went out of business in 2018, and, its brand and IP assets were acquired in the same year by the German company, Hahn.[14] Hahn has produced a new

[13] For a summary of differences in specification between Baxter and Sawyer, see Lovedale (2015).

[14] https://www.rethinkrobotics.com/.

Sawyer (in black as opposed to the original Rethink red) which continues to be developed for manufacturing applications. But, according to *The Robot Report* (Crowe, 2018), Baxter and Sawyer, at least in their earlier versions, were unsuited by their elastic joints to manufacturing applications. These joints made Baxter and Sawyer noisy when operating, introduced imprecision, and lowered cycle times:

> "The [Series Elastic Actuators] introduce substantial flexibility in the joints of the robot. That is good for safety, but bad for precision and motion performance," said Ilian Bonev, co-founder of Mecademic, professor at École de technologie supérieure and holder of the Canada Research Chair in Precision Robotics. "It is extremely difficult to control a flexible manipulator, especially when trying to minimize cycle times. Thus, Rethink probably spent too much effort trying to fix hardware problems through software" (Crowe, 2018).

Whether Sawyer has a future as a collaborative robot, Baxter has already been applied successfully as an easy-to-program robot for students in robot laboratories, and its social robot characteristics lend themselves to Baxter's being used as a robotic lecturer for computing students (Fernandez-Llamas et al., 2018). If its eventual destination is the university classroom, Baxter will have travelled very far indeed from the role of friendly apprentice assisting former factory floor workers.

Cobot-transformed human jobs

A lesson of the preceding section may be that it is morally better not to exaggerate the benefits to workers of being joined on the factory floor by cobots.[15] There is no need for the role of cobot to be mixed up with that of friend or apprentice, and it may be deceptive for those spurious roles to be introduced either in the marketing of the robot, or in the reassurance that may be given to manual workers anxious about the prospect of being replaced altogether by automation, and without a clear idea of what "collaboration" with a robot might amount to.

On the other hand, it seems neither pretentious nor damaging to design a robot collaboration in which the capacity of the robot to exert power in lifting or grasping, and to repeat operations without boredom or fatigue, or to carry out repeated inspections without inattention, is allied to the manual worker's understanding of the pre-automated process for manufacturing or assembling familiar products, and the standards these products have to meet. In this case, it seems unnecessary for the robot to be social or humanoid, and if it is neither, some of the morally criticisable misleadingness of the Baxter marketing pitch may be avoided altogether. In particular, the aim of analysing and reproducing all of a manual process in the form of an algorithm is dropped. In one of the case studies previously encountered, a welding robot was designed to simulate the whole of what was previously an entirely human (though unsatisfactorily inconsistent) welding process. The process of reproducing human skill in a machine, however imperfectly, facilitates the process of replacing the human production of the skill altogether, whether or not total replacement is intended or foreseen from the beginning. This facilitation is at odds with a goal of human robot co-operation, or at least is easily open to misinterpretation as the attempt to replace human skill altogether.

For the rhetoric of human–robot "co-operation" to be credible, human and robot must each contribute to a common goal. For this "co-operation" to be morally valuable in the sense of benefiting humans, the co-operation must play to strengths of the two "agents" who are joining forces.[16] Playing to the strengths of the two agents is precisely *not* a matter of enlarging the capacity of the robot to the exclusion, or undue reduction, of the role of the human being (see Ferreira, 2022). Enlarging the capacity of the robot as far as possible is better seen as belonging to a goal of replacing the human being. Passing off replacement in the long term for co-operation seems both deceptive, and, in the medium term, demoralising to human workers if the tasks left to them in the "co-operation" are increasingly those of mindless, asocial, machine-feeding and care-taking.

Admittedly, there is a moral difference between automation that eliminates skill, and automation that eliminates jobs. Co-operative robots may permit the retention of jobs by factory workers, but sometimes at the expense of making those jobs unsatisfying and unskilled. To go back to the Gheaus and Hertzog criteria for meaningful work, the transformation from skilled welder to robot overseer and servicer may be unsatisfying, notwithstanding the fact that it gives the worker employment: it is a case of deskilling. The social recognition that goes with certain jobs may also be missing if social recognition does not keep up with the effects of automation on jobs. So might a sense of achievement be missing (Danaher and Nyholm, 2021), if the human contribution to a cobot-human process consists of mere tweaks. On the other hand, if the transition to cobots comes with opportunities for workers to acquire skills—such as coding skills—that are highly paid outside factory settings, there is

[15] For an example of exaggeration, see the Introduction to Sadrfaridpour et al. (2016).

[16] The co-operation may be a matter of joint tasks involving sensory "feed-forward" and "feed-back". See Ajoudani et al. (2018, esp. §5), Table One.

a sense in which those opportunities provide a route to social recognition even if the cobot-enabled job does not.

Deskilling and the creation of much less meaningful and socially unrecognised work are dangers that the rhetoric of co-operation conceals when it suggests that manual workers who adjust to working with a Universal Robotics arm are passing to a "supervisory" role with respect to the robot and the elimination of the boring, repetitive and tiring. I am not in the least suggesting that automation that permits the retention of human jobs has no moral value. It permits manual workers to retain a salary, and sometimes to acquire new skills or some technological understanding. I am only claiming that something else has *more* moral value—namely an updating of the production process that continues the contribution to some extent of skills that predated the automation.

The findings of Bauer et al. (2016, p. 16) point to the less ambitious strategy of keeping manual workers in employment *without* keeping their skills:

- High acceptance of the new technology can be achieved among production workers and system supervisors only if they are integrated in the planning process, kept fully informed at all times, and properly trained.
- Upgrading the skills of production workers to enable them to perform new tasks related to robots opens up opportunities for new skills profiles and new ways of organizing work not currently used (e.g. training assembly workers to program robots). Upskilled machine operators and maintenance staff can also take responsibility for the support and maintenance of lightweight robots.
- Human factors research suggests that it is a good idea to include staff in the workplace design process—an approach that is already used for other work systems such as cardboard assembly, but not for robot systems. This would help improve acceptance.

The emphasis here is on keeping manual workers affected by the introduction of robots informed and involved, as in the first of the case studies discussed above. But involved in what? The planning process for the introduction of robots and, if I understand Bauer et al., the design of the workspaces that robots and workers would share—as in the first case study, where the system integrator showed workers their design of the manufacturing cell.

When it comes to skills, the emphasis is on the acquisition of new ones (such as programming skills or "support and maintenance" skills), as opposed to manufacturing or assembly skills.

The description in Bauer et al. of how manual workers fit in is incomplete, however, as it ignores the normative dimensions of both engaging workers in the planning process and re-skilling. As the first case study showed, it is possible to draw on the manual skills of workers in the design of automation that produces what the manual workers produce. Manual workers are often more sensitive to the nuances of the actions involved, such as the "jiggle" that produces the right bend in metal at the right point of a bending cycle.[17] Drawing on manual skills in this case means drawing on a worker's experience of the movements involved in steps of an assembly or manufacturing process that programmers are likely to capture too schematically, leading to results that are inferior to human ones. Participation by human workers can get programmers to represent more intricately the processes that robots have to execute. But it is when the programming reaches a higher level of sophistication that robotic skill supersedes human skill.

If workers are to contribute willingly and with full information to a process that makes their skills superfluous, then it is morally obligatory for companies to brief them accordingly. When asked to join the design process they are in effect joining a volunteer force in which they are co-responsible with managers and programmers for initiating automation or extending it. But more than that, they are sometimes—as in the first case study—co-opted as credible promoters of automation to the rest of the workforce, who may fear that the process will lead to redundancy or deskilling. Furthermore, since the whole design process can be, from managers' point of view, an exercise in discovering whether automation is actually viable in a particular workplace, and since experiments of this kind can be abandoned, workers who participate in them can do so under significant uncertainty about the result. Uncertainty contributes stresses that also have to be acknowledged in recruiting volunteers.

Bauer et al. mention two kinds of reskilling for manual workers that might result from the introduction of cobots into assembly processes. One is the acquisition of programming skills. The other is the acquisition of the skill of superintending and maintaining the cobot. As we saw in the second case study, these skills are not necessarily on a level. Some workers think they lose status when they make the transition from e.g. welder to robot welder-minder. The acquisition of programming skills is different: it might be the first step in a career change that involves a computer science degree and professional status.[18] In neither, case, however, does a manual worker get to exercise some of his skills with the support of machines, and yet this is often advertised as the benefit of introducing collaborative robots.

[17] See Wallace (2021, p. 305): "it eventually became evident that the human operator did not simply hold the part up to the edge of the bending press before bending. At a crucial moment, the operator jiggled the part almost imperceptibly and unknowingly, allowing a more precise bend to occur.".

[18] For detailed proposals about how programming skills could be introduced to workers in environments using cobots, see Ionescu and Schlund (2019).

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