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The Labouring Capacity Index: Living Labouring Capacity and Experience as Resources on the Road to Industry 4.0

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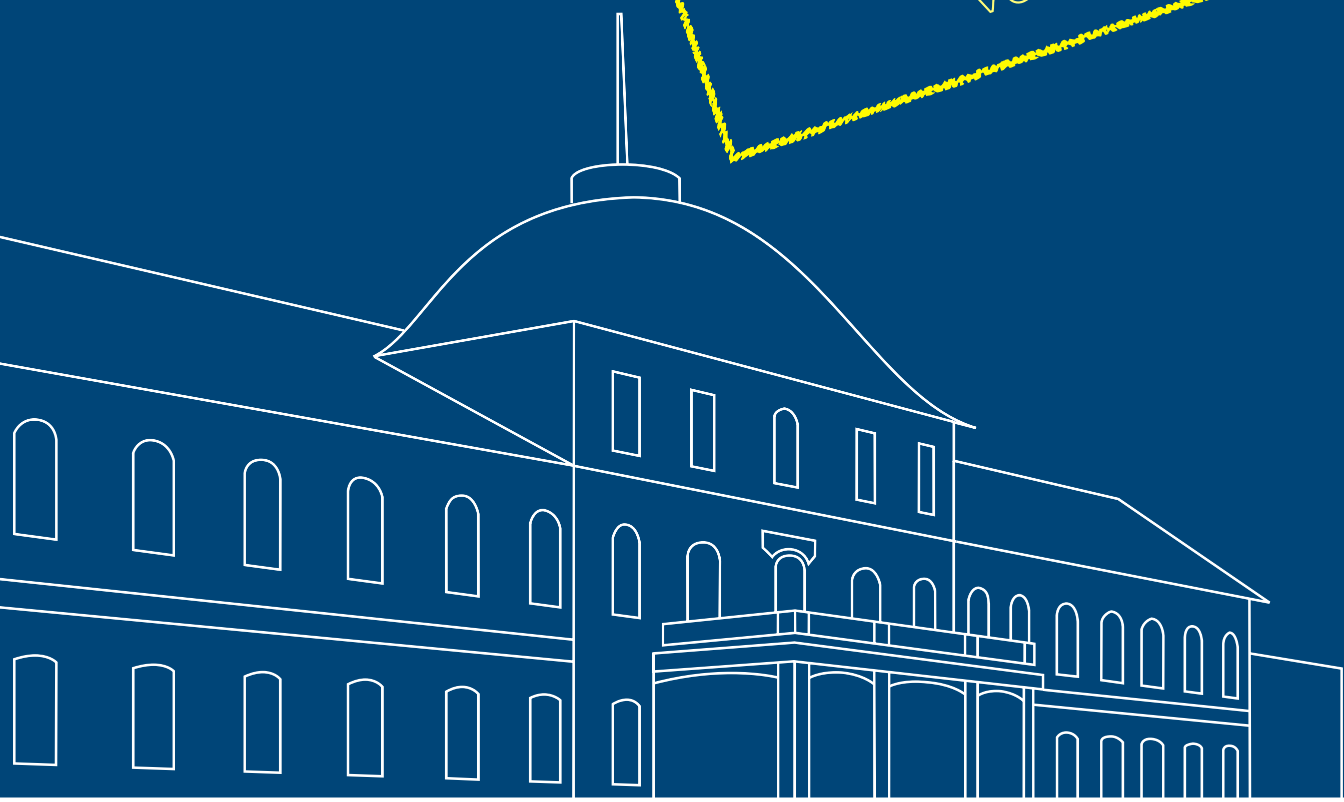

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I. Introduction: On the sociology of work and labour-market research

'Industry 4.0' is more discourse than reality. Yet, unlike many other prognostications of social change, it quickly set off a broad and vital public debate. Industry 4.0 promises to improve economic growth, competitiveness and innovative capacity, but above and beyond these it also is supposed to bring better working conditions generally, more creativity, higher resource efficiency, greater compatibility between work and private life and working conditions that better adapt themselves to the needs of older workers (Kagermann/Wahlster/ Helbig 2013: 5).

With all of these promises, the new technology associated with 'Industry 4.0' is held out as the means of progress and the way to a brighter future. How long has it been since anyone seriously associated technology with socioeconomic progress? For decades now, technology as a means of socioeconomic change has been discussed almost exclusively in a negative sense, after public attention had become fixed on some disastrous side-effect of technology. Acid rain, global warming and Fukushima are vivid examples. More typically, positive processes of change have not been linked to technological developments but rather to factors such as grand political transformations like the end of the Cold War or small social changes such as the reorganization of individual firms. Yet today, technological progress has re-emerged at the centre of a transformation that is affecting all parts of society. 'Industry 4.0' is meant to suggest that industrial revolution is back with a vehemence and with the same historical significance of earlier iterations. And just as the first, second and third industrial revolutions did not advance in leaps and bounds from one major version number to another but rather—to stay with the software analogy—with innumerable minor version numbers, builds and bugs. In the same way, a fourth industrial revolution, if it comes, will have to occur as a complex combination of social and technological changes, which might well appear radical in hindsight after many decades, but in fact will be the result of innumerable steps of trial and restructuring that lead to a substantial transformation only in the aggregate and only after the slow passage of time (Dolata/Schrape 2013).

Participants in the current discourse have reached no conclusion about whether we are at the beginning or in the middle of a new industrial revolution (or evolution). Nor is there a clear idea about which of the Industry 4.0 scenarios being discussed is technically feasible and economically sensible. Nonetheless, efforts are being made already to measure the effects of Industry 4.0 on the workforce, most particularly on employment and worker qualifications, and to prognosticate trends for occupations, qualification levels and branch structures.

The German debate on Industry 4.0 is much more narrowly focused on industry and other production-oriented branches than the related general discourse on the digitalization of work. The Industry 4.0 debate harks back to a single study (Frey and Osborne 2013), which estimated that in the coming years, 47 per cent of US jobs could be automated through the application of new digital technology.[1] Other authors, too, have recently revisited an historically important argument that had been almost forgotten (also in the sociology research on work): technological progress may well lead to the elimination of the need for human labour (Brynjolfson/McAfee 2014; Collins, 2013; Pistono 2014; Pupo 2014). Today, as so often during previous phases of rapid technological change, this argument is either positively associated with the hope that monotonous and physically strenuous work will finally be replaced with creative work (and opportunities for training workers to be more creative), or it is negatively associated with higher unemployment and widespread workforce de-skilling. These two diametrically opposed discourses inevitably pop up together whenever the connections between technology and work are discussed (Pfeiffer 2010).

Regardless of which position current studies take in this debate, and regardless of the data used and the technologies scrutinized, the question of whether human-based activity can be automated or converted into algorithms is nearly always addressed using the distinction between 'routine' and 'non-routine' tasks. Routine tasks are generally seen as replaceable (the 'substitution thesis'), and non-routine tasks are correspondingly seen as more valuable (the 'complementarity thesis'). Routine work is usually thought of as the materialized, static residue of experience. However, an understanding of experience as more dynamic—as a kind of 'high-tech feeling'—has emerged (Bauer/Böhle/Munz/Pfeiffer/Woicke 2006). This more dynamic kind of experience is held to have a central and non-substitutable function and to be all the more necessary in highly automated systems. This bifurcation divides the literature. The (mostly quantitative) research looking at effects of technology on wages, qualifications and labour markets tends to equate experience with (usually automated) routine, but (qualitative) studies of complex human-machine settings in the sociology of work tradition treat experience as increasingly essential creative improvisation (Hirsch-Kreinsen 2014: 13–16). These diverging disciplines (labour-market research and the sociology of work) with their contrasting methods (quantitative versus qualitative) thus interpret experience in diametrically opposing ways but are united in the assessment that experience is of central importance for understanding how technological

[1] It is often overlooked that 1) this estimate includes not only risks tied to digitalization but also to the 'offshoring' of jobs and 2) the authors explicitly refuse to offer a prognosis, speaking rather of potential developments over a long, uncertain period of time of one to two decades.

progress affects work. This one area of commonality bridges all the divides of discipline, methods and definitions, and we want to further explore it here.

The following study is built on the working assumption that a combination of qualitative diagnoses of human-machine interaction at the micro-level with quantitative labour-market data at the macro-level will yield insights into likely future developments in the organization of work that neither approach could generate in isolation. Our goal is not to offer specific prognoses but rather to improve the methods of studying relevant developments and to build a basis for the continuous and early reporting of qualitative change in firms and jobs using the large-scale data generated by research into employment and occupations. This paper represents a first, careful step in this direction and is guided by the following questions. Can the results of qualitative case studies, based on an understanding of experience as dynamic, be used to inform the results of quantitative analyses of labour-market data that are based on an understanding of experience as routine and static? Can a combined approach change the way we evaluate relationship between Industry 4.0 and work?

We address these questions in successive steps. First, in the following section we take a critical look at the state of labour market and occupational research based on empirical or expert assessments of tasks, focussing on recent explicit arguments regarding how new technologies expand the potential for automation. We pay special attention to Frey and Osborne's study (2013) because it plays a prominent role in current discussions. Building on this in section two, we discuss possible limits to the 'routine versus non-routine' dichotomy.

The third section contains a review of qualitative studies from the sociology of work that address the concept of experience. We limit ourselves here to studies from two related approaches. The 'subjectifying work action' approach (Böhle 2013) uses a concept of experience that stands in starkest contrast to experience as 'routine'. This approach has been in circulation for two decades already. The 'living labouring capacity' concept (Pfeiffer 2014) similarly understands experience as an expression of living labouring capacity, that is, specifically not as a formalized dimension of human action. It has been used effectively to analyse changes in work caused by digitalization. Both approaches share a focus on individual-level behaviour and have provided the theoretical underpinning for numerous qualitative studies of a variety of economic sectors and job tasks.

The fourth section represents our initial attempt at designing quantitative analyses of employment data on the basis of conclusions about the nature of work experience drawn from qualitative research in the sociology of work tradition. Using the labouring capacity approach, we suggest an index that replaces static routine with a dynamic understanding of experience. This 'labouring capacity index' is designed to capture complexity, ambiguity and subjectifying work action. It utilizes indicators from the BIBB/BAuA Employment Survey of the Working Population on Qualification and Working Conditions in Germany 2012 (hereafter BIBB-BAuA Survey).

The fifth section presents our initial analysis based on the LC-Index. Our results are compared with those of other studies, including Frey and Osborne 2013, focusing on areas of economic activity that are especially relevant for the various 'Industry 4.0' scenarios.

In the final section, we discuss the extent to which our analysis demonstrates the feasibility and usefulness of the LC-index as a quantitative operationalization of a qualitative, sociology of work approach. Importantly, our goal in this paper is not to develop better prognoses of expected labour market changes associated with Industry 4.0. As argued in detail in the next section, we do not believe that such prognoses can be made with any accuracy. Instead, we strive to demonstrate, using the limited empirical data available, that conceptualizing experience as a dynamic rather than static resource brings a previously underappreciated spectrum of human labouring capacity into focus—a spectrum that is not fully covered by the formal categories of job activity, qualification level and occupation. Because this spectrum of labouring capacity is closely tied to the ability to cope with complexity and unpredictability, the central question regarding the connection between experience and Industry 4.0 is not 'which job tasks will be automated in the future' but rather 'how can the currently existing resources for shaping Industry 4.0 be recognized and exploited now?'

2. Current approaches to 'routine' and their limits

The debate about Industry 4.0 has breathed new life into the nearly-forgotten topic of technology-driven workforce reductions. Indeed, the question of whether human labour will be replaced by new, internet-supported technologies has come back with a vehemence not seen for a long time in work research, fuelled by expectations of major changes in the near future.

There has been a recent increase of research making use of large datasets of job tasks, including the hotly discussed study by Frey and Osborne (2013), which has often been oversimplified in its reception to the one prognosis that 'half of all jobs can be replaced by a machine' (e. g. Pennekamp 2014). On the basis of US labour-market data and expert opinion, Frey and Osborne offered prognoses about the extent to which current and future digital technology will lead to workforce reduction and to changes in the labour market as a whole. They were guided by the assumption that technological progress faces no hindrance except for ‘engineering bottlenecks’—job tasks that are especially difficult to automate—including specifically ‘perception and manipulation tasks, creative intelligence tasks und social intelligence tasks‘ (Frey/Osborne 2013: 24-27). Their analytical approach is thus ‘task-based’, which carries two decisive advantages in the current context. First of all, technological change at the workplace is no longer exclusively tied to what the firm does but is also influenced by the employee’s personal digital devices and their habits of using them. Second, the division of labour between humans and machines plays out in its most concrete and decisive form in the context of specific job tasks, and it is on this level that we actually see the division of labour shifting or reconstituting itself because of changes in the relationship of technology and work.

Quantitative analyses of large job task datasets may lack the nuance and face-validity of studies based on qualitative data, including, for example, sociological case studies of specific businesses and anthropological studies of specific job environments. However, quantitative data do allow for assessments of changes in work over time and across economic sectors, so they should be given serious consideration as long as their limitations are handled appropriately. Fundamental problems in the use of quantitative data arise when these are used not only to observe present and past trends but also to prognosticate future effects of technology. These problems cannot be solved statistically, for the following reasons.

1. Within organizations, the most important factor behind the implementation of new technology is not technical feasibility but economic rationality. Frey and Osborne’s study is clear about this, but those citing the study often are not.

2. Data collected at the level of the job task contain no information about the value chains that underlie those tasks. Increasingly, these value chains stretch across specific branches, and decisions about the use of new technologies today often are influenced more by their material contexts and power constellations than by individual firms’ strategies.

3. The data contain no information about which technologies influence which tasks. Previous studies fill this gap, more or less plausibly, by extrapolating from previous experience with technological development or by asking tech experts, as did Frey and Osborne. Experts, however, often overestimate the potential impact of their fields and underestimate potential hurdles that block practical applications as a logical result of their typical *déformation professionelle*. This can be compensated for by good methods, but it cannot be eradicated.

4. Previous experience with the ‘replaceability’ of living work in Industry 4.0 scenarios cannot be expected to continue onwards in linear fashion. Taking these scenarios seriously means considering a lot more than just the chances of new technology replacing or substantially changing human work. In fact, the spectrum of potential issues is not limited to questions of whether a production worker will be replaced by a robot or whether a monitoring task in procurement can be eliminated because the evaluation of suppliers can be done better by an intelligent algorithm that continually assesses factors such as punctuality, product quality and price. Many Industry 4.0 scenarios, at least at the level of discourse, go way beyond such rationalization issues. Simple prognoses based on the linear continuation of previous trends of the interplay of humans and technology fall short when faced with the complexities presented by radical changes in business models, the shifting contours of value chains, the emergence of completely new suppliers and services, the blurring of old boundaries that defined the division of labour and disciplinary turf and the rise of new groupings of hybrid, multidisciplinary prerequisites of production. The very assumption of ‘revolutionary’ developments calls the reliability of prognoses based on the linear extension of past trends into question.

5. Those applying Frey and Osborne’s US-based study to Germany often assume a one-to-one correspondence of the two economies, but the qualification structures of US and German labour markets are actually not very similar. In Germany, the variety of employment categories is greater than anywhere else in the world. As a result (and a necessary condition) of the high complexity of its national economy—indeed, it is one of the most complex in the world—an extraordinarily high number of employment categories are involved in the production of most German goods (Hidalgo/Hausmann 2009: 10573). Even within the EU28, Germany has an exceptional status. It takes, on average, 70 different occupations (ISCO categories) to account for 50 per cent of employment in any given sector (NACE categories) of the German economy. In the European Union as a whole, as in the United Kingdom, 65 jobs suffice. In Belgium it takes 64. In the majority of countries, the value is much lower, ranging between 30 and 50. Coming in last are Greece with 16 and Rumania with 15 (Fernández-Macías/Hurley 2014: 87). Germany’s special status is probably best explained by its highly differentiated dual vocational training system; two-thirds of all employees in Germany were dual-trained (Bosch 2014).

Frey and Osborne (2013) take up in their analysis what has become a standard way of thinking about the effects of technical change on labour markets (see also Alda 2013; Antonczyk/Fitzenberger/Leuschner 2008 (hereafter ‘AFL’); Spitz-Oener 2006; Spitz-Oener 2007 (hereafter ‘SO’);

Tiemann 2014). Already in 2003, Autor, Levy and Murnane (2003, hereafter 'ALM") had posed the question, based on US employment data, of why the increasing use of computers leads to an increase of more highly qualified employment. Their study classified work activity into non-routine tasks (analytical or interactive) and routine tasks (cognitive or manual), showing two effects of computer usage: a *substitution effect* (routine work is substituted) and a *complementarity effect* (support of creativity, flexibility and complex communication and thus of non-routine tasks). Ten years later, Frey and Osborne emphasized the significance of technological progress, pointing to automobiles to make their point. ALM had argued that the apparent irreplaceability of a driver shows the limits of automation, but of course, today the driverless car has become a real possibility.

A problem not only for Frey and Osborne but for many others, including for us in our intention to create a new index, lies in the imprecise task descriptions that characterize the US O*NET dataset and the German employment survey.[2] Some of these classification decisions defy comprehension, most likely because the surveys on which they are based are themselves poorly differentiated. It is curious, for example, that in Frey and Osborne's index, 'machine setters' are considered highly susceptible to automation. Thus, 'milling and planing machine setters, operators, and tenders, metal and plastic' have a 0.98 chance of being replaced by a machine, followed closely by 'crushing, grinding, and polishing machine setters, operators, and tenders' with a 0.97 chance. This surprisingly, if not absurdly high probability estimate may result from difficulties caused by combining the tasks of machine setters and machine operators, who have very different responsibilities, or from underestimating the importance of substantive differentiation based on the imperatives of production technology. Even a nearly completely self-steering CPS cannot function without a machine setter, although it might work just fine with fewer operators. The confusion begins, as it also does in the German employment survey, with the fact that the work of setters and operators can vary widely, depending on the production technology used, in terms of required skills and experience or of the extent to which the tasks are routine. This kind of problem is confounded by differences in the task descriptions used in different datasets. Thus, the BIBB/BAuA activity classifications differ from those used by SO and ALM (Alda 2013: 24ff) as do the classifications used by AFL und SO (Antonczyk/Fitzenberger/Leuschner 2008). No classification, including ours, can solve the problem that job tasks are too crudely and gen-

[2] Autor (2013: 191) criticizes generally the methodological weaknesses of the O*NET database. It provides more than 400 different scales, and different studies choose to employ different scales without apparent reason. Autor's assessment of the O*NET dataset is correspondingly reserved: 'While I have found that task measures distilled from DOT and O*NET can serve as powerful proxies for occupational tasks, I am at best only moderately comfortable with these tools because their complexity and opacity places little discipline on how they are applied and interpreted.' The IAB/BIBB dataset does attempt to avoid the 'pitfalls' of the O*NET.

erally described and thus open up a lot of room for interpretation. For example, one could find virtually limitless reasons, backed up by examples, for classifying ‘organization, planning and preparation’ tasks as interactive or analytical.

Our interest lies primarily on differentiating between ‘routine’ and ‘non-routine’. All the studies mentioned above take these categories to be central for estimating the technical potential of replacing human labour. Although they all conceptualize ‘routine’ as the most decisive category for assessing the effects of technical change in terms of the extent to which tasks can be automated, they contain only rudimentary attempts to define it. In the end, all of these ‘task-based approaches’ are based on the hypothesis of *routine-based technical change* (RBTC) (cf. Fernández-Macías/Hurley 2014: 37) and almost always equate routine with repetitive, monotonous work. Further elaboration of the concept of routine is rare. Alda (2013: 8), however, does remark in a footnote to the discussion of routine in the ALM classification that ‘[t]he concept of the routine does not refer to people describing or experiencing certain jobs as monotonous, lacking in variety or anything like that, or to people being habituated to something. It is about whether or not technology has progressed so far as to completely take over the task.’ Indeed, a ‘good and useful’ definition of routine tasks is a ‘non-trivial’ problem (ibid.: 12). By this, ALM mean that ‘the experience-based knowledge of the employee takes on a higher significance’ in non-routine tasks (ibid.: 15). However, although this comment provides a bit more clarity, it does not in our opinion resolve the basic difficulty, because what experience-based knowledge actually is—and in what sense it becomes important on a daily basis for different tasks—cannot be derived solely from the perspective of technical experts and their ideas about the tasks.

The concept of routine is not fully clarified in any of the studies that rely on it. Their elaborations, when any are offered, vacillate between denoting it as a quality of the activity itself or as an assumption about the extent to which the activity can be automated. Even when expert-generated data instead of surveys are used for classification—as with Dengler, Matthes and Paulus’ BERUFENET-based study (2014: 17)—the assignment of routine/non-routine is not oriented around the popular vernacular meaning of ‘routine’ as ‘action that has become habit, half-subconsciously performed’. Instead, assignment is much more likely to be made in consideration of the ‘divisibility into computer-programmable elements of activity and thus the degree to which these can be replaced by computers’. In other words, the reasons why specific tasks are characterized as routine or non-routine—a critical argumentative step in most all studies discussed above—are not clear. The decision process introduces a potential for circular reasoning because assignment follows an assumption already made about the likelihood of automation. No wonder, then, that findings tend to be confirmatory. Nonetheless, every index, including ours, must work with crude assumptions and category assignments. We do not criticize this on principle. However, it is important to reflect more prominently on the limits of this kind of procedure if used to base assessments of the likely impact of technology on work and employment. This is certainly the case for the categories of routine/non-routine.

Fernández-Macías/Hurley (2014: 48) also note that the widely accepted (also by Frey and Osborne) classifications of routine work, made on the basis of O*NET data for the United States, 'are not good measures of routine' because they ultimately derive from antiquated notions of production work. 'Using physical and quality control variables for the routine task index makes sense if we look at traditional production line jobs that involve mostly manual work and basic tasks with machines', they write. 'But the routine content of some jobs may be overestimated or underestimated when relying on these two variable categories' (ibid.). In their own analysis, they conclude that 'the extent of routine in different jobs...is not the key driver behind polarisation—if anything, it is more related to upgrading, in a similar way as the cognitive index' (ibid.: 69). Because this quantitative finding is consistent with a great range of qualitative findings from the sociology of work literature focusing on *subjectifying work action* and *living labouring capacity,* we focus on this connection in the next section.

3. Beyond routine: the meaning of experience in the context of Industry 4.0

Experience can be thought of as the dynamic twin of static routine. It is particularly significant in complex, highly automated and digitalized work environments. For the sociology of work and industrial sociology, this is not a new insight. The importance of experience and of subjectifying work action had been recognized by the end of the 1980s, first in studies of the transition from conventional to CNC machine tools (Böhle/Milkau 1988) and in the control of complex processes in process manufacturing (Böhle 1994). Lessons then learned were applied practically in so-called computer-controlled/experience-guided approaches in technical design (Schulze 2000). After a pilot project in the highly automated chemical industry (Bauer/Böhle/Munz/Pfeiffer/Woicke 2006), they led to a wide variety of innovations in vocational education (Sevsay-Tegethoff 2007).

What, then, is meant by ‘experience’ in the ‘subjectifying work action’ concept? The concept begins with the individual at work, in possession of the full range of human capacities. We need reason and logic to respond correctly under pressure, but we also need also intuition, ‘gut feeling’ and emotions. Humans are not completely brain-driven, we also have bodies. Our bodies ‘know’ and feel; they transmit visual and tactile sensations, and through our bodies we grasp contextual relationships that may not be immediately accessible through logic. These abilities often take time to develop, which is why usually only experienced employees possess them. Theoretical knowledge and routine serve to help with standardized processes and repetitive tasks. Subjectifying action and knowledge, however, is quite different, being defined by four central characteristics: a) holistic perception, b) exploration and dialog], c) intuition and ‘feeling’ and d) an empathetic relationship (Böhle 2013).

With experience, we gain confidence in our ability to cope with the unfamiliar and master unpredictability. The ‘subjectifying work action’ approach treats experience not as a static collection of routines but rather as a special approach to things, people and situations in the work context. It is less about the idea of having experience and more about becoming experienced and being able to use experience in specific situations. The approach might be open to the criticism that whilst forms of knowledge and action that are closely connected to the body or to sensuous experience may well play an important role in production processes that use and transform raw materials, their importance is likely to decline as production process become more and more digitalized. On the face of it, this argument is plausible, but a good 20 years of research on subjectifying work action has provided much evidence to the contrary. In fact, dynamic, experience-based knowledge has been shown to play a prominent role especially in those jobs and tasks that are commonly associated with the service and knowledge economies and that have been closely scrutinized in the context of Industry 4.0. These include, for example:

- work contexts characterized by the intense use of information, such as information brokering (Pfeiffer 1999);
- ‘virtualized’ expert work in teleservice and ‘eService’ (Pfeiffer 2000);
- planning and R&D engineering (Bürgermeister/Schambach/Rogers 2005; Pfeiffer/Schütt/Wühr 2010; Porschen 2002);
- knowledge management and project management (Habler/Bürgermeister 2010; Porschen 2008; Pfeiffer/Sauer/Wühr 2012; Pfeiffer 2014a).

Indeed, subjectifying work action and knowledge is anything but outdated in today's information society. But why? In all fields that have been explored from the 'subjectifying work action' perspective, subjectifying tasks and knowledge are seen to be especially significant in complex, unstructured work environments. Experience is thus a kind of core competence in dealing with unpredictability (Böhle 2011). Precisely those high-skill tasks that are thought of as paradigmatic for the information society are inherently resistant to comprehensive planning. Because decisions still have to be made and action still has to be taken even in the absence of complete (or even sufficient) information, the ability to act on the basis of intuition, 'feeling', free association and holistic sense perception become all the more necessary. As work processes become increasingly information-based in complex work environments, the qualitative side of living labour becomes increasingly important. Complexity must be coped with and abstractions must be continually reconnected to the core work task, regardless of whether these tasks involve the manipulation of raw materials, customer demand, patient needs or the mastering of complex interconnections. Thus, precisely in those situations in which abstract and knowledge-based tasks play a big roll, sensuous experience is more important than ever, despite the fact that it may not play a prominent role in any specific core work task anymore. Indeed, we expect that as digitalization progresses, workers increasingly will be called upon to overcome complexity and unpredictability with aplomb and generally to do the right thing in unplannable situations. This is not a phenomenon of highly-skilled labour only. Subjectifying work action is also relevant in highly automated and information-intensive production and in construction work (Pfeiffer 2007). The importance of non-routine action is tied in these areas not only to the ability to react appropriately to disruptions and change but also in preventing disruption through anticipatory intervention.

The association of experience with the disruption of standardized processes and formalized operations is widespread in our culture, and this affects the perception of industrial production and other kinds work. The idea that worker experience disrupts production is very firmly anchored in professional discourses and in the research on labour markets, but it simply does not describe the reality of what is needed today for production and innovation. In the face of ever-more dynamic changes in the demands posed by markets and other environments, even those tasks that are embedded in standardized and thus apparently robust procedures are susceptible to unpredictability. In fact, sophisticated techniques of standardization and digitalization create new complexities and new areas of system-immanent unpredictability, not intentionally but nonetheless unavoidably. The ability to deal with these on an ad hoc and situational basis is a skill that comes from experience—and it does not fit into the standard routine/non-routine dichotomy.

- socialmedia@PRODUCTION: Approaches that use web 2.0 interactive scenarios, that is, web-based applications that facilitate communication between individual human beings, as for example a ‘doodle’ for coordinating shift work. These approaches reflect the infiltration of social media into fields of business activity in which they had previously played no role. This is not Industry 4.0 in a narrow sense because only the media of communication change. However, social media applications adapted for such uses can make it easier for employees to exchange experience-based knowledge in specific situations directly. This has repercussions for corporate culture and also for employment and qualification.
- nextGEN PRODUCTION: New approaches to production or handling techniques, for example light robots or robotics concepts in which robots, for example, are equipped with dual arms or with sensitive—and adaptive—sensors. They include also additive processes such as 3D printing and the use of drones. The existence of cheap robots and drones is likely to bring about the most significant changes in areas which have been characterized in the past by high levels of human employment due to economic constraints. These include transportation and logistics, packing, delivery and mail-order services or manual and hybrid assembly. In contrast, 3D printing is quite likely to accelerate innovation cycles in industrial production (as in ‘rapid tooling’) and will thus lead to incremental change with no major effects on the labour market or employment.
- data@INDUSTRY: Fundamentally new data connections between previously unconnected physical objects open up new possibilities for the self-organizing control of production, for maintenance and for logistical networking (Cyber Physical Systems). These augment and extend previous phases of digitalization (such as ERP or PPS systems) and more fully integrate them into real-world value creation (within the firm) and into real-world logistics (via global value chains to the final user). With the potential of a wholly new degree to which data technology permeates the physical world, new scenarios tied to big data and intelligent algorithms become possible. At this level, major changes can occur that lead to changed production processes, new business models and more fluid value chains. This development is most likely to emerge first in areas that are already highly digitalized and automated. Above all, it will increase systemic complexity immensely. The effects on employment and qualification cannot be estimated generally because they arise on a very specific basis, whenever the content of tasks and the differences among tasks change. One other aspect in the context of Industry 4.0 that has attracted surprisingly little consideration so far is that the internet of things will include work-relevant wearables too. Possibly, products like the smart glove from ProGlove or the exoskeleton of the ChairlessChair will be much more relevant for changes

and for the ergonomic improvement of assembly line jobs than the more highly publicized google glass or similar applications of visual augmented reality.

Previous experiences with automation and the current state of research briefly reviewed above justifies a radical shift of perspective. Within the context of Industry 4.0, automation is simply not the most relevant question. Successful implementation will instead depend more decisively on being able to generate and use experienced-based knowledge, which is going to be indispensable for the organization of Industry 4.0 and for its smooth operation. *Table 1* in the appendix gives an overview of what lies ahead: experienced-based knowledge will be relevant in all three dimensions of Industry 4.0 in terms of its initiation and organization. Increased complexity, which continues to require (in part, now more than ever) subjectifying action for dealing with unpredictability, is, in our opinion, most likely at the levels of nextGenProduction and data@INDUSTRY.

4. From routine to experience: the Labouring Capacity Index

In the previous sections we made the argument, first of all, that current constructions of task-based indices do not capture experience in all its dimensions because they work on the basis of a routine/non-routine dichotomy. Second, we argued that experience will play a major role in the lead-up to Industry 4.0 scenarios. Together, they make up our case for using a resource-oriented understanding of experience in order to correct the deficits in the current understanding of 'routine' job tasks and their automation. From this new perspective, we revisit the 2012 BIBB/BAuA Survey. Its items allow only a very crude modelling of the uniquely and genuinely human abilities linked to the more dynamic aspects of experience, in part because these defy full formalization and standardization. Nevertheless, some survey items are congruent with issues treated in the qualitative research and thus, in our opinion, have a solid empirical basis. These could be developed into a valuable augmentation of expert-based approaches to technical feasibility issues. The essential principles for the understanding of experience from the perspective of current research on subjectifying work action and labouring capacity lead to the following guidelines for utilizing activity-based, large-N data:

- We do not ask which tasks can be labelled 'routine' or 'non-routine' following some pre-defined criteria or assumptions. Instead we search for components of the non-routine *within* tasks. Thus, the first step does not involve looking at all the activity items but rather at items that best reflect the characteristics associated with experience.
- We do not ask for expert opinion about the feasibility of automation, nor do we make inferences about feasibility based on assumptions. Instead, we try to identify components of the non-routine using the *subjective assessment* of respondents (as far as this is at all possible using items from the BIBB/BAuA Survey) across all activity items.
- We assume that the routine/non-routine dichotomy generates very little traction. No activity is purely routine or purely non-routine. Instead, we postulate a routine/non-routine continuum, or, better yet, an *experience continuum*, in every activity. This does not preclude large differences in the relevant dimensions and qualities, in the components themselves or in the relative significance of the non-routine (or experience).
- We avoid the tendency to reproduce the common bias (which creeps in despite having virtually no basis in qualitative research) in the classification of manual work and brainwork such that, implicitly or explicitly, work with machines is equated with routine whilst work with knowledge is equated with creativity. Instead, we look first for non-routine components and then, on this basis, we check the extent to which these components are found in different tasks, branches and qualification levels. Instead of identifying the routine on the basis of typical activity-based categorizations, we put the task-based approach on its head and begin with experience. With this *experience-based approach*, we hope to generate new insight especially about which tasks are most susceptible to automation.
- Above all, using concepts and empirical findings from research on subjectifying work action and labouring capacity, it is our intention to overcome the tendency to equate the 'routine' with simple, repetitive tasks in the sense of an unchanging trove of experience. Guided by the conceptual and empirical perspectives noted above, we conceptualize experience not just as something that can be acquired and 'had' but rather as an ever-adapting ability to gain more experience. This ability proves useful especially in dealing with unforeseen circumstances, above all when uncertainty about concrete work action prevails. It is useful when decisions have to be made under deadline pressure and without planning and when decisions have to be implemented successfully—defined for example as free of negative economic repercussions—even without sufficient information or in the absence of all necessary skills. As noted in section three, such situations arise even among untrained assembly

workers who, in spite of the fact that their main activity is repetitive, anticipate and prevent the causes of disruptions in production. By the logic of the classic ALM classification, this activity would be classified as an easily replaced, routine manual activity. By the logic of Frey and Osborne's schema the same activity would be classified under *engineering bottleneck "perception and manipulation*" because it can be characterized by a high share of manual labour in a constrained space and possibly also by the necessity of working in uncomfortable bodily positions.

Before we suggest an index based on the sociology of work, two issues need to be clarified. *First*, this is a tentative first draft and is subject to testing and change. *Second*, in this first step we are not interested in prognosticating the possibilities of technology-driven automation. Our goal is to make clear that such prognoses have strict limits if based on a one-sided understanding of routine. *We are thus not interested in what jobs will be lost in the future because of Industry 4.0. Rather, our concern centres on whether we currently have at our disposal sufficient competence for the initial formation of Industry 4.0.* In the following discussion about our index, which is based on labouring capacity, we want nothing more than to describe automation-resistant components of human work action as, first, a multidimensional interplay of complex challenges in specific work situations and, second, the action dimensions that are necessary for adequately responding to these challenges. Simplistic classifications of routine and non-routine negate this complexity and thus make it difficult to assess genuine human abilities and, with them, the possibilities of and limits to their automation.

Our approach starts at the state of the conceptual and empirical literature on labouring capacity and subjectifying work action, reviewed above in *section 3*. Working from this perspective, we sketch some first thoughts about constructing an index on the basis of the BIBB/BAuA Survey (cf. Rohrbach-Schmidt/Hall 2013)[3], which includes questions on performed tasks, job requirements, physical and mental working conditions and changes during the previous two years.

From this, we present a first draft of what we refer to as the *Labouring Capacity Index* (LC-Index) using individual indicators. The index captures situational and structural challenges through complexity (COM) and unpredictability (UP); it also captures the relative need for subjectifying work action in order to deal with these challenges. The index is derived theoretically

[3] This is a representative survey, regularly repeated since 1979, of about 20,000 employees in Germany conducted by the Federal Institute for Vocational Education and Training (BIBB) and the Federal Institute for Occupational Safety and Health (BAuA). It addresses the issues related to changes in work and career and the acquisition and utilization of job skills. Included in the sample are paid employees at least 15 years old who worked at least ten hours weekly.

from the sociology of work concepts discussed in *chapter 3*; it is empirically based on two decades of related empirical findings. *Table 2 (appendix)* shows how items from the BIBB/BAuA Survey were classified in the index. The index has three subcomponents and a multiplier calculated as follows.

$$LC = \left(\frac{\overline{sitCOM} + \overline{sitUP} + \overline{strCOM}}{3} \right) \cdot rEX = [0;1]$$

Whereby:

$$\overline{sitCOM} = \frac{1}{3} \sum_{i=1}^{3} x_i = [0;1]$$

$$\overline{sitUP} = \frac{1}{7} \sum_{i=1}^{7} y_i = [0;1]$$

$$\overline{strCOM} = \frac{1}{7} \sum_{i=1}^{7} z_i = [0;1]$$

- *Index Component sitCOM 'Situation-Specific Handling of Complexity'*: Indicates the frequency of situation-specific problem resolution and decisionmaking, alone and in coordination with others (F327_01, F327_02 and F327_06).
- *Index Component sitUP 'Situation-Specific Unpredictability'*: Much subjectifying work action is required when under time pressure (F411_01 and _13), when unpredictability (F411_06) is in play or has to be prevented proactively (F411_09) and when improvisation is necessary due to the lack of sufficient information, knowledge and/or skills at the right moment (F411_08 to _11 and F700_09) and when non-decision can result in bigger problems (F411_11).[4]
- *Index Component strCOM ‚Increasing Structural Complexity'*: When changes in work equipment, work objects or work organization occurred during the previous two years with repercussions for the immediate work environment (F1001_01 bis _03 = instruments of work, F1001_04 and _05 = objects of work and F1001_06 = work organization) concurrent with an increase of stress (F1001_10). An increase of stress can be taken to indicate an intensifica-

4 Unfortunately, this last item of the list refers exclusively to financial consequences, although in many jobs situation-specific pressure for action arises out of the necessity to avoid negative technical repercussions (for example, a reactor fire) or health hazards.

tion of work as a result and/or in the context of additional demands brought by change. We interpret an increase of stress as an indicator that acquiring experience has become more difficult.

- *Multiplier 'Relevance of Acquiring Experience (REX)'*: If a long training period in the firm is necessary for carrying out a task (F401), this can be taken to indicate a need for subjectifying action. Indeed, the mastering of work contexts characterized by complexity and unpredictability is more likely to be learned on the job, not through textbooks or instruction manuals. REX is coded so as to vary between 0 and 1. It is of central importance for the index because, as a multiplier, it modifies all other values. If REX= 0, the index value is set to zero, indicating zero subjectifying work action. In this case, we do not assume that the task actually requires zero experience but rather that the proportion of experience necessary to carry it out is very low in comparison to other tasks and thus will very unlikely serve as a barrier to automation.

Given the theoretical and empirical foundation outlined above, many indicators can be used to characterize labouring capacity without any stretch of the imagination. However, the construction of this index, as any index, has to overcome weaknesses in the available data and in survey design. For example, if managers are asked how often they have to make difficult decisions independently, they are likely to choose the answer category 'often' because this, indeed, is what managers are supposed to do and they likely see themselves in this role. This will be the case even when most management decisions are not very difficult because they are made in the context of facilities where production processes are steered by performance indicators. On the other hand, the consequences of individual decisions even in this context may be potentially grave, and from the labouring capacity perspective, it would be of great relevance to differentiate between process and result and to the qualitative content of 'difficult'. Take the contrasting recent empirical example of a craftsman whose job it was to monitor eight robots in automated chassis production: he was observed to have intervened up to 30 times per shift in many different aspects of the process to prevent disruptions in overall production. From the labouring capacity perspective, these kinds of tasks as phenomena of dynamic experience and are highly relevant and are at least 'sometimes' to be evaluated as 'difficult'. The probability is high, however, that this craftsman would describe these tasks differently. Because these tasks are largely unnoticed in the factory environment, he is not likely to describe them as 'difficult' or as a 'decision'. These kinds of caveats could be made about every item used in the BIBB/BAuA Survey from the LC-Index perspective. Classifying tasks that cannot be easily formalized into indices is always hampered by these kinds of problems, regardless of what kind of index is being constructed. One must make a large variety of assumptions, and there are many limits on the extent to which individual indicators really encapsulate those qualities on which the index focuses.

Despite these limitations, the LC-Index is multidimensional, as one would expect from the conceptual and empirical foundation which underlies it. All indicators show a significant correlation to each other (Spearman Rho significant at .01).

5. Labouring capacity by qualification level and selected occupations

In this section, we discuss the first draft LC-Index as generated from the 2012 BIBB/BAuA Survey dataset and place it in relation to formal qualification level and to occupations that are especially relevant for Industry 4.0. As a first step, it is necessary to evaluate the frequency distributions of index values (*Table 3 in the appendix*). The LC-Index takes on value of 0 for 16.9 per cent of surveyed employees.[5] Apparently, their tasks necessitate only a relatively small degree of living labouring capacity for dealing with situation-specific or structural complexity and unpredictability; or the living labouring capacity their tasks require cannot be captured with the relatively crude instrument of the employee survey. For the remaining 83.1 per cent of respondents, the LC-Index value varies between very low (LC>0) and very high (LC=1). The frequency distribution of these index values (LC>0) apparently follows a normal curve. The LC-Index value is very low or very high for only a small proportion of respondents; values for most respondents fall within the middle range (see the histogram in *Figure 1, appendix*). Nonetheless, the LC-Index mean is 0.54 on average and thus tends to higher index values. Looking only at cases with an index value > 0, the mean shifts further towards the maximum value of 1 (⌀LC = 0.67).

On the whole, the tasks of 74.06 per cent of all surveyed employees have an LC-Index of greater than 0.5 (*Table 3, appendix*). It follows that the majority of employees in Germany have acquired informal skills in dealing with unpredictability and complexity; they can react appropriately to unexpected situations without complete information. In other words, the overall average LC-Index value being greater than 0.5 indicates that the majority of employees possess a dynamic ability to acquire experience and apply it when needed in complex work situations. This

[5] In contrast to many of the indices discussed above, our dataset includes only gainfully employed men and women.

high value thus shows that the typical juxtaposition of routine and non-routine fails to capture a great deal of useful information. Despite all the methodological limitations certainly inherent to this first attempt at measuring an elusive construct, this result is remarkable especially in light of the fact that the BIBB/BAuA Survey items and their wording are very closely tied to the conventional understanding of experience as routine and of machine work as simple and repetitive.

In order to gain more insight into the potential range of applicability of our first draft index, we now interpret the LC-Index in terms of formal qualification level. To do so, we follow the common practice of differentiating four levels of formal qualification on the basis of the highest qualification certificate acquired: cases with no training or academic education, cases with a vocational training certificate, higher non-academic qualification (technicians and „Meister"), and finally academic degrees. The boxplot (*Figure 2 and Table 4, appendix*) shows the distribution and the differences in the means for the four qualification levels. Persons in the sample with no qualification had on average a mean LC-Index value of 0.38. Persons with a vocational training certificate had on average a mean value of 0.54, technicians score highest with a mean of 0.64 and thus even higher than those with an academic degree who had on average a mean value of 0.61.

Thus, in accordance with received wisdom, higher qualifications are somewhat associated with higher demands on job performance stemming from complexity and unpredictability and, in this context, with a higher necessity for subjectifying work action. The boxplot (*Figure 2*) shows a very wide distribution of LC-Index values among the least qualified. The lowest quartile extends almost to LC-Index = 0, and the highest quartile reaches LC-Index > 0.65. In contrast, the distribution of LC-Index values among the highest qualified persons in the sample, also in terms of the range covered by their lowest and top quartiles, is very narrow (see also *Table 4, appendix*). This result can be interpreted as indicating that the group of persons with the lowest level of formal qualification carry out a great variety of tasks with great variation in the extent to which their jobs require them to use experience to overcome complexity. This strongly suggests that the formal qualification structure alone sheds little light on the degree to which an task is dominated by routine. Indeed, the wide distribution affirms qualitative studies showing that 'simple' work is, upon closer inspection, much more complex than first appears. This is evident especially in areas that are of central significance for Industry 4.0 such as the automotive industry. Here, job demands typically associated with skilled work began long ago (with the introduction of teamwork and innovative production systems) to encroach upon seemingly simple and repetitive tasks. These tasks are, as a result, saddled with highly ambivalent performance demands (see for example Lacher 2006; Pfeiffer 2007). The extremely wide distribution of the LC-Index can be partly explained by these kinds of substantive changes in the tasks themselves. However, the distribution is also likely to have been affected at least in part by the wording of the items used. One might plausibly argue, although it would have to be affirmed with appropriate tests, that the items used are better suited for capturing tasks that are more typically associated with high formal qualification. It is possible, then, that the broad spectrum of tasks carried out by employees with no formal certificate of qualification is inadequately differentiated, in which case these tasks would have to be interpreted and assessed on a case-by-case basis.

Continuing with the next step we consider the LC-Index values of 15 selected occupations. These occupations, chosen from the list of 55 currently defined occupational categories (Maier et al. 2014), feature prominently in the Industry 4.0 discourse (*Table 5, appendix*). The means of the LC-Index values vary among occupations. The occupational category of 'packers, warehouse operatives, transport processors' has the lowest ∅LC-Index value (0.40), whereas the category of 'IT core occupations' has the highest (0.70). The boxplot (*Figure 3, appendix*) shows also a tendency to low LC-value means for the occupations 'packers, warehouse operatives, transport processors', 'goods inspectors, dispatch processing operators', ,construction occupations, wood and plastics manufacture and processing occupations' and 'metal construction and installation, sheet metal construction, installation'. The issues discussed above in relation to low qualification levels could be involved here, too. The distributions may actually result from real differences among the tasks, but they may also be an artefact of item wording, which is imprecise and does not always fit well to these occupations. Despite these limitations, the significance of labouring capacity and subjectifying action for dealing with situation-specific unpredictability and complexity is clear. In 13 of the 15 occupations observed, the average LC-Index is greater than 0.5. Accordingly, the index indicates that the majority of the occupations associated with Industry 4.0 in the discourse are characterized by high demands due to complexity, unpredictability and subjectifying work action. It is remarkable in this context that the IT occupations dominate the highest positions in the LC-Index value ranking, followed by technicians, engineers and the classic technical occupations that require the typical German three year vocational training like ,industrial mechanics, tool mechanics' or ,electrical occupations'. Regardless of whether their formal qualification is vocational or academic, employees in these areas seem to apply their living labour capacity to a similar degree to cope with complexity, even today.

6. Rather than prognosticating about the effects of automation, use experience as competence to master change

Whether we stand today at the cusp of another industrial revolution will not be known until many generations from now. But there is little doubt that we will experience accelerated change in work organization and performance in the coming years and that digital technology will play a key role in these changes. The desire to discover simplifying explanations of dynamic change is understandable, but simple stories do not adequately describe what is captured in the available large datasets. We discussed in this paper why currently circulating prognostications regarding the degree to which human labour can be automated are crude, at best, and why the often-cited figure of 47 per cent of US employees who stand to lose their jobs to automation (on the basis of Frey/Osborne 2013) is not adequately substantiated, especially not for the German labour market. We argued above that these and similar approaches for diagnosing which aspects of human work are susceptible to automation are based on an unsophisticated understanding of routine labour and are thus starkly limited in their predictive power. Our thesis is, instead, that the crux of the matter lies not in whether work tasks are routine or non-routine, but whether workers have the capacity for coping with unpredictability and complexity. This thesis is based on two decades of qualitative empirical research on the meaning of experience and on the empirically well-grounded concepts of subjectifying work action (cf. Böhle/Bolte/Drexel/Dunkel/Pfeiffer/Porschen 2009) and living labouring capacity (cf. Pfeiffer 2014). Proceeding on these conceptual grounds, we developed an index using indicators of the 2012 BIBB/BAuA Employment Survey of the Working Population on Qualification and Working Conditions in Germany. It captures job demand structures as situation-specific unpredictability and situation-specific and structural complexity. Insofar as it is at all possible given the restrictions imposed by the wording of items used to describe work tasks, it enables us to generate a picture of current performance demands for informal, dynamic, experience-based knowledge and action. The LC-Index is thus based on qualitative empirical research and the conceptual and normative implications it suggests. For this reason, it is in our estimation more promising than relying on expert-based assessments of what is presumed to be areas susceptible to automation or what is presumed to be routine.

In a recent special issue, the German periodical *Wirtschaftswoche* (2015) ran the provocative title, '*Industrie 4.0 scheitert am Menschen*', that is, that the emergence of Industry 4.0 is being blocked by worker deficits. Its thesis was based on a study by the business consulting firm CSC (CSC 2015). They asked where all the necessary 'IT geniuses' are supposed to come from, as German companies continue to have problems recruiting personnel with 'the requisite IT skills and assembly-line know-how for creating the fourth industrial revolution'. Although the article notes that only half of the surveyed companies plan to engage in personnel training in areas related to Industry 4.0, the main problem is seen not in the obvious dearth of far-sighted companies but rather in 'giant gaps in the human-based factors of production' (Wirtschaftswoche 2015). German corporations on the whole could certainly invest more in apprenticeship and, above all, in professional development, and they will have to do so increasingly in the face of Industry 4.0. Yet our conceptual considerations regarding an LC-Index and our initial analysis of the 2012 BIBB/BAuA Survey (even if cautiously interpreted) actually point in the opposite direction: it is not the workers who have the most serious deficits. German employees are not only well trained and qualified, even now they regularly face situations that require them to overcome unpredictability and situation-specific and structural complexity. For doing so, not only have they acquired the necessary labouring capacity but they also know how to apply it effectively.

On the basis of the analysis of the LC-Index presented here, we come to the following summarizing conclusions.

- 74 per cent of employees in Germany require living labouring capacity for overcoming complexity and unpredictability. They have acquired the requisite experience-based knowledge for doing so and apply it in carrying out their tasks.
- All tasks that require no formal qualifications or that appear to be simple are not the same in terms of the experience they require. Rather, LC-Index values for these tasks vary quite widely, thus indicating wide variation also in the degree to which they involve overcoming complexity and subjectifying work action. Premature presumptions regarding routine and non-routine work should be avoided.
- In those occupations which seem to be central for the implementation of Industry 4.0 scenarios we find relatively high LC-Index values. Vocational-track and academic-track occupations are both represented in the upper echelons of the LC-Index ranking. Thus in the current work environment both tracks (not just the academic track, as so often assumed) lead to tasks that require the ability to deal with complexity to a relatively high degree.

If Industry 4.0 means that 'all employees face much higher complexity, abstraction and problem solving demands' and are expected to demonstrate 'very high degrees of self-directed action, competence in communication and self-organization' (Kagermann/Wahlster/Helbig 2013: 57), then the analysis presented here gives reason for optimism. If one looks for gaps, as the *Wirtschaftswoche* was doing, it turns out that the most important gap is not tied to the human factors of production. This is supported even by a cautious interpretation of our data. If today 74 per cent of employees in Germany are competent to deal with complexity on a regular basis, the potential for an even greater transformation is already at hand. Anyone who has mastered the practical use of experience-based knowledge to overcome complexity will also be able to master the kinds of formal professional development programmes and informal skill development processes made necessary by Industry 4.0. Paths to appropriate vocational and academic continuing education programmes just have to be opened, even as the hurdles that separate different training tracks have to be lowered. Exactly on this point, academic education institutions especially need to be made more dynamic. But for their part, firms need to make it easier for workers to establish their best work-learn-life balance (cf. Meyer/Müller 2013).

Our results reveal deficits not only in human factors of production but also in firms and in the established forms of technology development and work organization. If there is anything that cannot be duplicated in an increasingly digitalized world, it is the unique variety of formal qualifications of Germany's workforce. The dual system of vocational apprenticeship and professional development has created a diversely qualified 'middle' in Germany, in contrast to most all other countries in the world. Not only does this significantly increase the German economy's capacity for innovation (cf. Pfeiffer 2015)—an assertion supported by our analysis. It also gives rise to the fact that not just a small group of highly qualified employees but indeed the majority of Germany's employees are capable of dealing with complexity and unpredictability. Experience as a dynamic resource instead of static routine: human labouring capacity, in all its diverse and under-appreciated facets, is a major reason why individuals can learn to deal with complexity and unpredictability. As has already been recognized, it is this ability, which we have tried to measure quantitatively using the LC-Index, that enables us to engage the increasingly significant 'ironies of automation': '[t]he more we depend on technology and push it to its limits, the more we need highly-skilled, well-trained, *well-practised* people to make systems resilient, acting as the last line of defence against the failures that will inevitably occur' (Baxter/Rooksby/Wang/Khajeh-Hosseini 2012: 65, our own italics).

The central question regarding the link between experience and Industry 4.0 is thus not: Which tasks potentially could be lost to automation *tomorrow*? The more relevant question is instead: How can the specific potential of living labour be used and recognized for the formation of Industry 4.0 *today*?

Industry 4.0 technologies will result in deep changes in production, assembly and maintenance work. This has nothing to do with the introduction of one new technology (such as with the introduction of laser technologies a few years ago). Industry 4.0 bundles a variety of new technologies and application scenarios, all of which vary in terms of the maturity of the technology involved and the systemic effects they set off. In Industry 4.0, future forms of automation will be more disruptive and risky because they introduce a wholly new quality of demands on performance.

Industry 4.0 should be seen as an innovation process for a productive environment in which established procedures for incremental automation along known technological paths and using well-practised teams are reaching their limits. Industry 4.0 does not involve simply automating already-established manufacturing routines but rather managing and forming the innovation process, which is itself open-ended and to some extent never fully plannable. At the same time, however, new technologies and their advantages have to be integrated into mass production robustly and quickly. Even in the early phases, plant availability must not be endangered.

- **Innovators often lack specific production and process knowledge:** Many relevant technologies originate not in established R&D labs of the capital goods industry but in information technology. With applications like big data, there is often a lack of concrete knowledge about production technologies and little experience with production processes that involve the handling of materials. Industry 4.0 companies coming from the IT industry often have no feel for the exigencies that arise in the highly synchronized mass production of technologically sophisticated products. The high dynamism and the high variety of technical possibilities are often too much for even top decision makers and management to cope with. In this environment, solutions to problems are implemented that unnecessarily increase complexity and thus put plant availability at risk.

- **Long-practised forms of work organization and regulation are approaching their limits:** Established processes and institutions of codetermination or of the regulation of worker safety and data security are failing to adapt quickly enough to technological innovation. It is becoming ever more difficult to keep an eye on every relevant issue and intervene in a timely manner. Even already-introduced technologies change through software updates more often and more significantly than in the past, which necessitates new assessments and possibly also new rules of data security and worker safety. New procedures have to be developed in order to avoid getting stuck in an exclusively reactive posture.

- **Skilled employees are needed more than ever and must be able to do more, but the areas in which they work are perceived as unattractive:** Industry 4.0 will increase the need for more highly qualified and more narrowly specialized warranty operations in many areas of production, assembly and maintenance. Intelligent processes increase systemic complexity through their sensors and algorithms. Human workers will thus need to apply much more specialized knowledge and experience-based knowledge than ever when disruptions occur, although they will occur less often. Yet, current production-line jobs are still highly constrained by shifts and clocks and are thus not attractive for highly qualified technicians. The demands on those who must create good jobs and recognize good performance are thus also increasing.
- **Generate sustainable competitive advantages that are not easily copied:** On the one hand, the early integration into production of Industry 4.0 technologies is necessary from the perspective of generating competitive advantages, but on the other hand, this strategy is also a source of risk and expense. Technologies that are in a beta-testing phase today will be standard in a few years. Competitors can catch up by implementing them with less risk and cost. Sustainable competitive advantages can be secured only when specific, not easily copied applications are developed. The strategically most important interface, and the one that needs to be given the most attention, is the division of labour between human and machine, between human experience and algorithm.

These challenges can be best met by including the 74 per cent of our workforce that already possesses a high amount of experience-based knowledge in the early *formation* of Industry 4.0. The needed resource is already available: employee’s labouring capacity. However, there is no great participatory tradition for innovation in technology development, which brings up the issue of how it can be introduced. What changes are necessary in our still quite rigid and still very hierarchical corporate organizational structures that would free employees to bring their capabilities to bear in self-organizing, agile innovation processes across corporate divisions and across disciplinary lines? How can the experienced-based knowledge of employees be brought into *participative processes of technology development*? And how, finally, can the new jobs that are created be organized within innovative processes and participatory organizational forms so as to guarantee that *innovative work environments* arise in which people are able to develop living labouring capacity? This is necessary if, in the future, those workers are to be enabled to deal with complexity and unpredictability, most especially in an Industry 4.0 setting. In other words: How can Industry 4.0 on the factory floor be organized as an innovation process by and with the employees?

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Appendix

Table 1: Relevance of experience based knowledge for Industry 4.0

	Requiring subjectifying work action		**Changing requirements for living labouring capacity on the level of:**		
Dimensions of Industry 4.0	for the formation of Industry 4.0	for dealing with increased complexity	instruments of work	objects of work	work organisation
socialmedia@ PRODUCTION					
data@ INDUSTRY					
nextGEN PRODUCTION					

Table 2: LC-Index and classifications based on BIBB/BAuA survey 2012

LC component	BIBB-/BAuA indicators		LC characteristics and codings
sitCOM situation-specific handling of complexity	**How often does it happen in your occupational activity ...** (often, sometimes or never)		Composed of arithmetic mean values. Coded 0 for never, and 1 for often or sometimes.
	F327_01	that you have to react to and solve problems?	
	F327_02	that you have to take difficult decisions autonomously?	
	F327_06	that you have to communicate with other people in your occupational activity?	
sitUP situation-specific unpredicability	**How often does it happen in your occupational activity ...** ... (often, sometimes, rarely or never)		Composed of arithmetic mean values. Coded 0 for never, and 1 for often or sometimes.
	F411_01	that you have to work under strong pressure of time or performance?	
	F411_06	that your work is disturbed or interrupted, e.g. by colleagues, inferior materials, machine malfunctions or phone calls?	
	F411_08	that you are expected to do things you have not learned or you are not proficient in?	
	F411_09	that you have to keep an eye on different work processes or sequences at the same time?	
	F411_11	that even a small mistake or a slight inattentiveness can lead to larger financial losses?	
	F411_13	that you have to work very quickly?	
	F700_09	that you don't receive all the information necessary for performing your work correctly?	

LC component	BIBB-/BAuA indicators		LC characteristics and codings	
strCOM increasing structural complexity	**In the last two years, have...** (yes/no)			Composed of arithmetic mean values. Coded 0 for no increase, and 1 for increase.
	F1001_01	new manufacturing or process technologies been introduced?	instruments of work	
	F1001_02	new computer programs been introduced? (not only new release versions of existing programs)		
	F1001_03	new machines or equipment been introduced?		
	F1001_04	new or significantly changed products or materials been employed?	objects of work	
	F1001_05	new or significantly changed services been provided?		
	F1001_06	there been significant restructurings or reorganisation pertaining to your immediate work environment?	work organization	
	Change in the last two years? (increase, remain unchanged or decrease)			
	F1001_10	How did work pressure and stress change?		
REX Relevance of acquiring experience	F401	Is a quick briefing at the workplace sufficient to perform your occupational activity, or is a longer working-in period required?	Coded 0 for quick briefing is sufficient, and 1 for longer time needed.	

Table 3: LC-Index frequency distributions

LC-Index	Distribution BIBB/BAuA 2012 N_{AV} = 17.479
AV = 0	16.88 %
0 < AV ≤ 0,25	0.35 %
0,25 < AV ≤ 0,5	8.7 %
0,5 < AV ≤ 0,75	47.95 %
0,75 < AV ≤ 1	26.11 %

Figure 1: LC-Index histogram

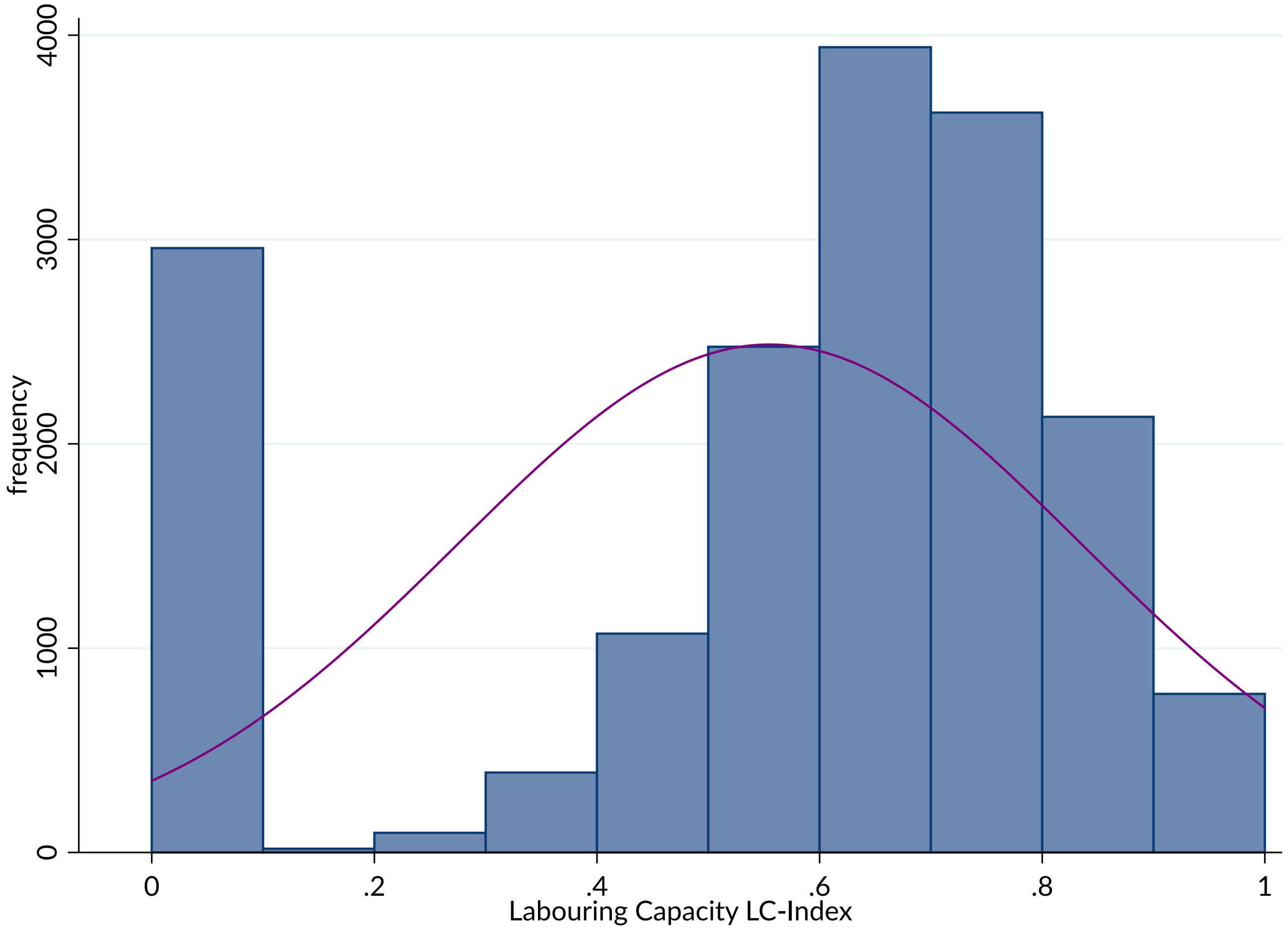


Figure 2: Boxplot LC-Index and formal qualification levels

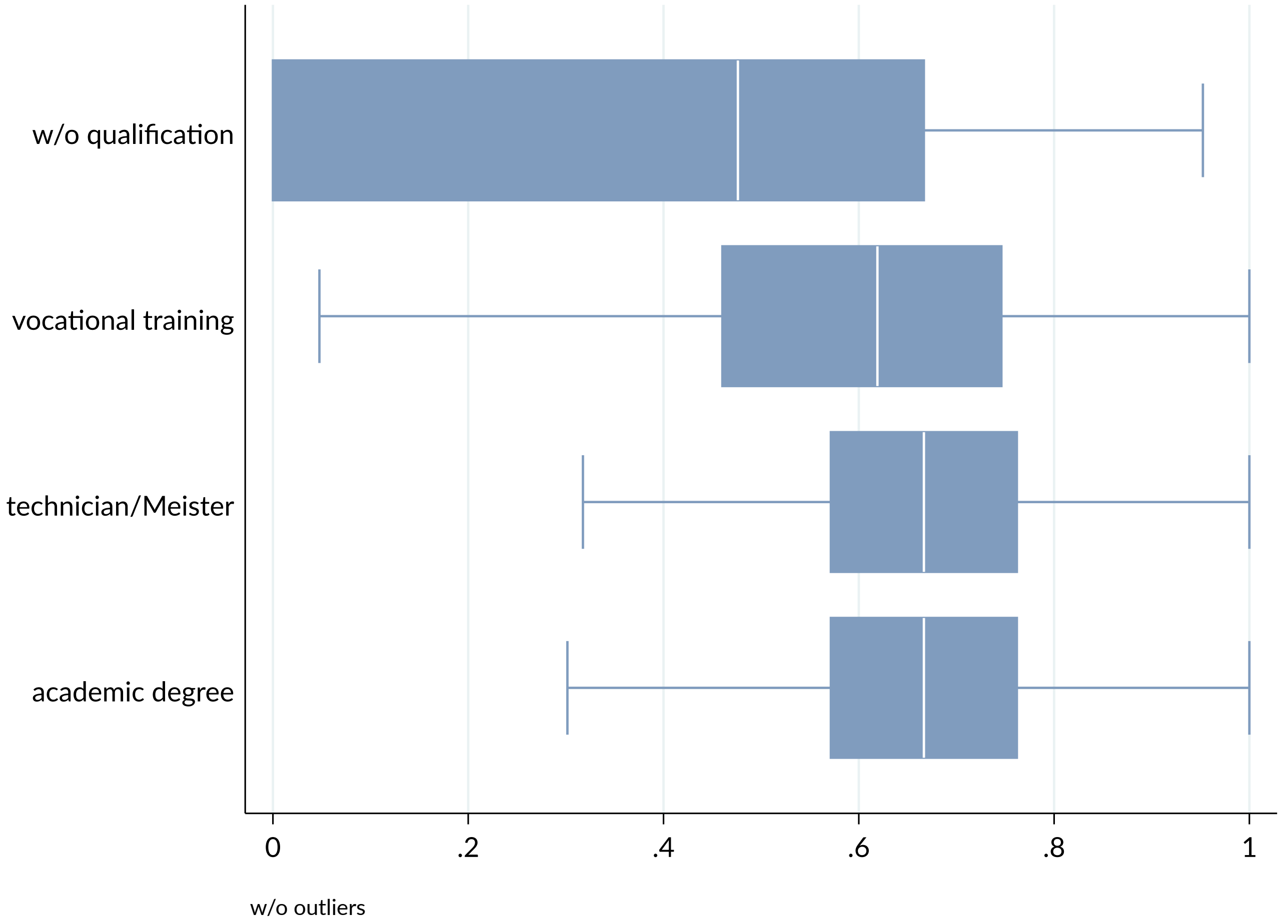


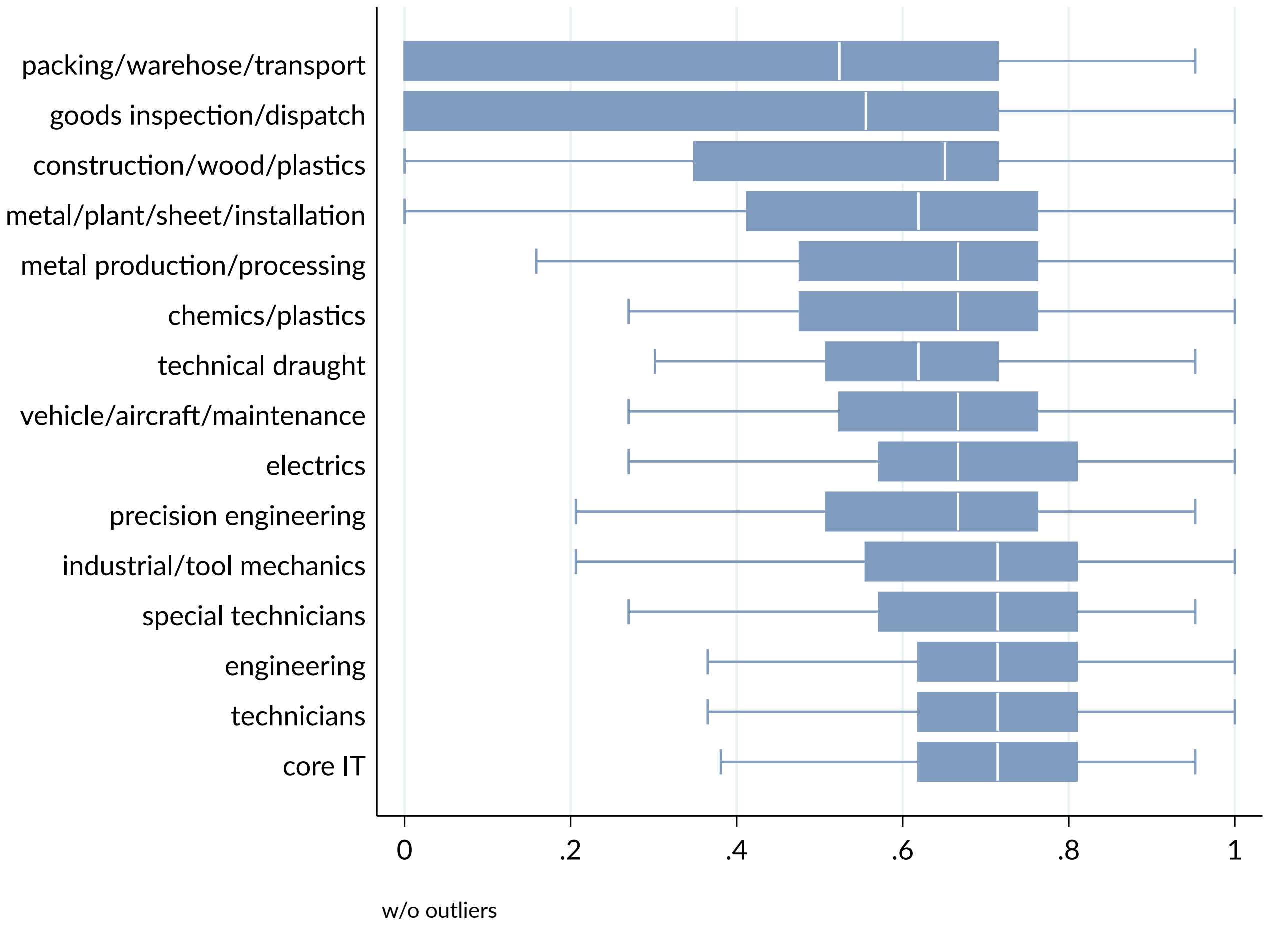
Table 4: LC-Index – distribution by formal qualification levels

Formal qualification	N_{LC}	LC-Index (mean)	SD
no qualification	1.158	0,376	0,325
vocational training	10.153	0,538	0,289
technician/„Meister“	1.477	0,642	0,224
academic	4.686	0,609	0,24
Germany LC all	**17.479**	**0,555**	**0,281**
Germany LC>0	14.528	0,668	0,139

Table 5: LC-Index for selected occupationinal fields

Occupational fields	N_{LC}	LC-Index (mean)	SD
Packers, warehouse operatives, transport processors	361	0,404	0,336
Goods inspectors, dispatch processing operators	152	0,426	0,34
LC theoretical mean		0,5	
Construction occupations, wood and plastics manufacture and processing occupations	413	0,518	0,31
Metal, plant, and sheet metal construction, installation, fitters	362	0,538	0,313
Germany all LC	17.479	0,555	0,281
Metal production and processing	179	0,569	0,272
Chemical and plastics occupations	135	0,575	0,281
Technical draughtsmen/-women and related occupations	71	0,582	0,235
Vehicle and aircraft construction, maintenance occupations	190	0,608	0,267
Precision engineering and related occupations	93	0,623	0,218
Electrical occupations	361	0,628	0,258
Industrial mechanics, tool mechanics	340	0,633	0,256
Specialist skilled technicians	86	0,647	0,214
Engineers	690	0,675	0,212
Technicians	525	0,678	0,209
Core IT-occupations	509	0,697	0,177
	0,526	**14986**	**0,298**

Figure 3: Boxplot LC-Index for selected occupational fields



For the German version see
Pfeiffer, Sabine; Suphan, Anne (2015): Der AV-Index. Lebendiges Arbeitsvermögen und Erfahrung als Ressourcen auf dem Weg zu Industrie 4.0. Working Paper 2015 #1 (draft v1.0 vom 13.04.2015), Universität Hohenheim, Fg. Soziologie.
Download: http://www.sabine-pfeiffer.de/files/downloads/2015-Pfeiffer-Suphan-draft.pdf

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