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The European Journal of Workplace Innovation (EJWI) is an open-access, net-based, peer reviewed and English-language journal. The Journal invites research-based empirical, theoretical or synoptic articles focusing on innovation and workplace development.

The aim of the journal is:

- To develop insights into workplace innovation
- Provide case studies from Europe as well as comparative studies from other continents
- Develop and present new theories in the field of workplace innovation
- To increase international publication within the field
- To become an important publication channel for workplace innovation researches as well as the international research community.

Table of contents

Editorial

Ten Volumes of Dialogue

Egoitz Pomares

"Why a European Journal of Workplace Innovation?" this was the question posed in the journal's first editorial. The answer offered was both practical and conceptual: to create a space where different traditions of research and practice could meet. Since then, the *European Journal of Workplace Innovation* has published seventeen issues across ten volumes. Hosted by the University of Agder, it has remained committed to that original purpose: to contribute to knowledge "that unfolds within some kind of totality, a totality that no research approach can claim to fully overview" (Pålshaugen, 2015, p. 10). This editorial vision has also consistently emphasised pluralism over orthodoxy, aiming "not to impose a particular view or model," but rather to offer "an arena where a number of previously separate discourses can meet" (Ennals, 2016, p. 4).

The journal's second decade begins as the first did; with questions, not answers. In this volume, these reflections are complemented by a special editorial by Professor Hans Christian Garmann Johnsen, Managing Editor of *the journal*. His view offers a perspective on the journal's trajectory and future avenues.

This tenth volume of the *European Journal of Workplace Innovation* presents seven contributions. They address different domains of practice, reflect varied research strategies, and emerge from distinct institutional and national contexts. Parts of these contributions were first presented at the EUWIN conference *The Future of Workplace Innovation*, held in Donostia-San Sebastián (Spain) in October 2024.

The issue opens with a conceptual contribution from **Peter Oeij, Steven Dhondt and Fiejte Vaas**, who explore the compatibility between Modern Sociotechnics and the SMART Work Design model. Rather than advocating convergence, they propose a constructive dialogue between traditions, offering a vocabulary for future interdisciplinary collaboration in the design of human-centred work systems. **Eva Lindell, Anette Hallin and Bosse Jonsson** follow with a discourse analysis of how blue-collar workers are framed within Industry 4.0 narratives in the Swedish steel industry. Their study uncovers contradictions between rhetorical commitments to inclusion and the structural persistence of exclusion, highlighting the symbolic and material stakes of technological transformation. The third contribution by **Koen Nijland and collaborators** examines how smart technologies are reshaping job roles and skills among production workers in manufacturing SMEs. Their findings show not only polarisation in skills and task allocation but also the uneven organisational responses to digitalisation, particularly in relation to training and competence development.

Hideaki Nakai and Yusuke Asada shift the focus to care work, presenting a pilot study on task analysis training in disability welfare facilities in Japan. The study reports measurable improvements in work engagement among staff, suggesting that interventions can support both service quality and professional well-being. From a healthcare perspective, Niek Zuidhof and colleagues offer a longitudinal qualitative study on the use of smart glasses by nurses and care professionals. Using a theoretical framework, the article investigates how such technologies transform communication, collaboration, and perceptions of professional identity. Milan R. Wolffgramm and co-authors revisit industrial contexts through a comparative case study on collaborative robot arms. Their analysis shows how the implementation of identical technologies can result in divergent organisational outcomes, shaped by managerial strategy, workplace culture, and employee agency. Finally, Koen Nijland, Paul Preenen and Luuk Collou present a design framework for inter-organisational ecosystems that support continuous skill development. Their article closes the volume by proposing a practical, system-level model for promoting adaptive learning environments across institutional boundaries.

References:

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Nº	Title	Authors
1	*Modern Sociotechnics and the SMART Work Design Approach: A Possible Marriage*	Peter Oeij, Steven Dhondt, Fietje Vaas
2	*Exclusion and Inclusion through a Discourse of Equality – Positioning the Blue-Collar Worker in Industry 4.0*	Eva Lindell, Anette Hallin, Bosse Jonsson
3	*Jobs and Skills of Production Workers at Manufacturing SMEs: An Empirical Exploration of Smart Technology Adoption*	Koen Nijland, Dennis Trotta, Paul Preenen, Sebastian Thiede
4	*A Pilot Study on the Effects of a Task Analysis Training Program on Self-Efficacy and Work Engagement in Disability Welfare Facility Staff*	Hideaki Nakai, Yusuke Asada
5	*Zooming in on the Impact of Collaborative Robot Arms in Manufacturing Workplaces: A Comparative Case Study*	Milan R. Wolffgramm, Stephan Corporaal, Aard J. Groen, Paul Preenen
6	*Appropriation of Smart Glasses: A Qualitative Study on the Long-Term Use of Smart Glasses in Healthcare*	Niek Zuidhof, Oscar Peters, Peter-Paul Verbeek, Somaya Ben Allouch
7	*A Design Framework for Ecosystems that Facilitate Continuous Employee Skill Development*	Koen Nijland, Paul Preenen, Luuk Collou

Discussion Forum

The European Journal of Workplace Innovation Celebrates 10 Years

Hans Chr. Garmann Johnsen

The *European Journal of Workplace Innovation* is celebrating its 10th anniversary. The first issue was published in 2015 as part of the EUWI initiative (European Union Network for Workplace Innovation). The University of Agder took on the administrative role for the journal, which was established as an open-access scientific publication.

Over the past decade, the journal has published 17 issues including three special issues. These special issues focused on topics such as socio-technical systems thinking in manufacturing, sustainable work, and green jobs. The two most recent special issues were double issues. Notably, the issue on sustainable work was further developed into a book. All the issues are available online at this address: https://journal.uia.no/index.php/EJWI/issue/archive

I feeded all the issues into ChatGTP and asked if it could extract and describe the ten most important scientific and practical themes where the journal has contributed. Here is what it replied with my own editing:

1. Workplace Innovation as a Distinct Field

The journal helped define workplace innovation (WPI) as a distinct area of research and practice that integrates social, organizational, and technological dimensions of change. This has provided conceptual clarity and legitimacy to WPI as a scholarly and policy-relevant field, influencing European and national innovation agendas.

2. Employee Participation and Co-Creation

Numerous articles focus on the role of employee involvement in organizational change, including participatory design, co-creation, and bottom-up innovation. It has demonstrated that sustainable innovation is more likely when employees are active contributors, not passive recipients, of change.

3. Socio-Technical Systems Thinking

The journal has revisited and revitalized socio-technical systems (STS) thinking, especially in manufacturing and complex service systems (e.g., special issue in Vol. 5 No. 1). It has brought STS into contemporary relevance, linking it to digital transformation, Industry 4.0, and resilience.

4. Sustainable Work and Green Transitions

Special issues in 2021 (sustainable work) and 2025 (green jobs) show EJWI's leadership in linking WPI to sustainability, climate transition, and the green economy. This extended the scope of WPI research to global challenges, showing how work design can align with environmental goals.

5. Innovation in Public Sector and Human Services

Several articles explore how workplace innovation functions in healthcare, education, and social care, often emphasizing quality of care and worker well-being. This has highlighted how WPI enhances service quality, organizational learning, and job satisfaction in mission-driven sectors.

6. Digitalization and Technology-Driven Change

The journal explores how digital technologies intersect with WPI, including automation, remote work, and data-driven innovation. These articles have emphasized that technological change must be accompanied by organizational and social innovation to be effective and ethical.

7. Leadership and Organizational Culture

EJWI has explored how leadership styles, trust, and organizational values shape the implementation and outcomes of innovation initiatives. This has offered practical guidance on how leadership can enable or block innovation, especially in flat, knowledge-based organizations.

8. Inclusion, Equality, and Quality of Working Life

The journal has contributed to gender, age, and inclusion debates in WPI, including studies on older workers, female academics, and marginalized groups. It has showed how innovation can either challenge or reinforce inequality and offered frameworks for more inclusive workplaces.

9. Theoretical and Methodological Advancements

EJWI has supported the development of new frameworks, evaluation models, and methodologies for understanding and measuring WPI. It has demonstrated advanced action research, case study, and mixed-method approaches tailored to complex organizational environments.

10. Policy and Ecosystem Perspectives

The journal links WPI with regional innovation systems, labour market institutions, and national innovation strategies. This has implications for policy thinking on how to support innovation ecosystems that go beyond technology to include social innovation at work.

I believe these ten points resonate well with my own reading and experience with *EJWI*. In fact, one of the main debates we have had over the years has been how to define the field of research. The editorial policy has consistently embraced pluralism—thanks in large part to the influence of the late Editor-in-Chief, Richard Ennals. His motto, *learning from differences*, has also become the guiding principle of the journal. To illustrate this, I asked ChatGTP to make a word cloud. It looks like this

Both the list of the ten themes and the word cloud above illustrates that defining the field is not a straightforward task. Nevertheless, there is still a degree of coherence and consistency reflected in the themes identified. Striking a balance between pluralism and focus should continue to be the journal's ambition.

Both the list of the ten themes and the word cloud above illustrates that defining the field is not a straightforward task. Nevertheless, there is still a degree of coherence and consistency reflected in the themes identified. Striking a balance between pluralism and focus should continue to be the journal's ambition.

As the European Journal of Workplace Innovation enters its second decade, a key ambition is to deepen its identity as a pluralistic yet coherent platform for workplace innovation research. The themes that have emerged, ranging from socio-technical thinking and sustainable work to inclusion and digital transformation, reflect the journal's broad scope and practical relevance. Moving forward, EJWI should continue to balance conceptual diversity with a clearer articulation of the field, building on Richard Ennals' legacy of "learning from differences." Strengthening interdisciplinary dialogue, encouraging policy-relevant contributions, and amplifying practitioner and worker perspectives will be essential. As global challenges evolve, the journal is well-positioned to explore how workplace innovation can support more resilient, inclusive, and sustainable work futures.

Most importantly, as we look to the future and the challenges facing society—where workplace innovation plays a crucial role in shaping democratic institutions in working life—this ambition remains as important as ever.

SMART Work Design and Modern Sociotechnical Theory

A marriage made in heaven?

Peter R.A. Oeij, Steven Dhondt, Fietje Vaas

Abstract

Organisation designers responsible for organisational change and the introduction of new digital technologies may share an interest in ensuring good quality of work but often choose different angles. Some of them, likely with an HR background typically emphasise the importance of human needs and job satisfaction when it comes to work design. Others, like organisation designers with an operations management background, might focus more on the division of labour, work processes, and sociotechnical design aspects. Some organisation designers may highlight strategic and organisational choices as prerequisites for work quality, whereas others concentrate on person-environment-fit approaches.

However, to ensure a good quality of work in the digital era, it is much more helpful if organisation designers apply a common lens. Recently, we have observed a convergence in the field of organisational and work sciences with the development of the SMART work design model; this approach integrates individual, team, and organisational elements, linking human needs, job characteristics, and organisational conditions. Previously, researchers in Europe had already connected sociotechnical design thinking to organisational design principles for production layouts and work quality criteria, particularly characteristic of the modern sociotechnical approach (MST) of the Low Countries.

This conceptual and essayistic article aims to spark a discussion on how elements of the SMART work design approach and MST can be integrated into a comprehensive approach where organisation designers can collaborate with a common language. The article argues that the WEBA tool, a method to analyse jobs from both a human needs and organisational design perspective, can serve as a bridge in this context.

Key words: work design; modern sociotechnology; quality of work; organisational design; job design

1. Introduction

The research question of this article is: How can we ensure good quality of work in digital times? In the policy debate, human centricity has become an important goal. Human centricity implies placing the well-being of the industry worker at the centre of the production process (Breque et al., 2020). Worker well-being comes with active jobs in which people have learning opportunities and limited stress risks (Karasek & Theorell, 1990). However, the presence of active jobs, with decision latitude to compensate for high job demands, is not self-evident in these times of digitalisation, like Big Data, artificial intelligence, machine learning, deep learning and algorithms. Parker and Grote (2020: 1173-1174) point out that "(...) the digital era we are in involves extensive technologies that not only change how people do things but also how work is coordinated and controlled (...). Altogether, the collective changes, referred to by Brougham and Haar (2018) as Smart Technology, Artificial Intelligence, Robotics, and Algorithms (STARA), are reshaping the information workers have access to (e.g., real-time data), where people work (e.g., co-working spaces), collaboration patterns (e.g., increasing interaction with robots), and, most fundamentally, people's work designs." How can we ensure good quality of work, as in active jobs, in digital times? Is the SMART work design approach the right answer?

Parker and Grote (2020) propose a central role for work design in understanding the effects of digital technologies. They contend that new technologies can positively and negatively affect job resources (autonomy/control, skill use, job feedback, relational aspects) and job demands (e.g., performance monitoring), with consequences for employee well-being, safety, and performance. They subsequently identify four intervention strategies: "First, work design choices need to be proactively considered during technology implementation, consistent with the sociotechnical systems principle of joint optimisation. Second, human-centered design principles should be explicitly considered in the design and procurement of new technologies. Third, organisationally oriented intervention strategies need to be supported by macro-level policies. Fourth, there is a need to go beyond a focus on upskilling employees to help them adapt to technology change, to also focus on training employees, as well as other stakeholders, in work design and related topics" (Parker & Grote, 2020: 1171).
What is the SMART work design model, and how does it work in practice?

Before addressing that question, we will provide the structure of this article. After explaining the SMART work design model, we discuss its relationship with modern sociotechnical thinking (MST). We conclude that both can be combined in theory but may result in a rather complex method for practitioners to use. We therefore propose a method called WEBA that helps to analyse jobs from both the perspective of the 'psychological' SMART model, based on human needs, and the 'organisational' MST approach, based on operations management. This WEBA method is relatively easy to apply; it goes beyond psychological needs and includes organisations' performance. We hope that the article serves to improve both the quality of work of people and the business performance of organisations, and that it offers a language

that all organisation designers, irrespective of their disciplinary background, can use in practice.

2. SMART work design model

Work design refers to the nature and organisation of employees' tasks, roles, responsibilities, and relationships, such as who makes which decisions, what jobs are included in a team, and how many diverse tasks are allocated to an individual job (Parker & Boeing, 2023: 93). Their focus on the design of work systems is on individuals' psychological and social experience of work, including whether their work is motivating, promotes wellbeing, reduces strain, and fosters growth and learning (which may be termed 'psychosocial aspects', or, when lacking or negative, 'psychosocial risks'). The most common approach to understanding which psychosocial aspects of work are important has been to assess and analyse key individual perceptions about 'work characteristics and then to model their impact on outcomes (Parker & Boeing, 2023), such as employees' motivation, wellbeing and job satisfaction.

Parker & Knight (2023) propose the SMART work design model, which identifies five higher-order categories of work characteristics, including stimulating work characteristics (task variety, skill variety, information processing requirements, and problem-solving requirements), mastery work characteristics (job feedback, feedback from others, and role clarity), autonomous (or agency) work characteristics (decision-making autonomy, timing autonomy, and method autonomy), relational work characteristics (social support, task significance, and beneficiary contact), and tolerable work characteristics (low levels of: role overload, work–home conflict, and role conflict). They tested this structure through higher-order confirmatory factor analysis, followed by validity tests linking the factors to the theoretically relevant outcomes of job satisfaction and performance.

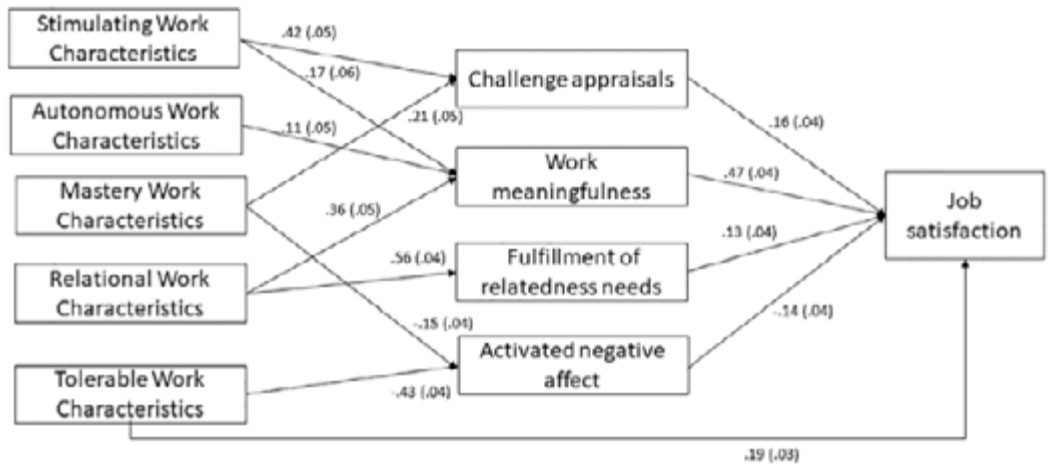
The third row of Table 1 is concerned with a link to organising conditions of the mentioned SMART higher-order factors and human needs. This is where sociotechnical thinking comes in. The Lowlands variant of 'modern sociotechnical systems design' (MST) has developed rules to design organisational conditions that can guarantee excellent organisational and job performance and holds the assumption that this will result in high job satisfaction (De Sitter et al., 1997) , although these sociotechnical researchers state that job design is more fundamental for meaningful work than the job experience of persons, which is a merely a consequence of the quality of work and not a cause of it. We return to this later.

Higher-order factor	Definition	Link to organizing conditions	Link to psychological processes	Perceived work characteristics (dimensions)
Stimulating work characteristics	High degree of mental complexity and variety due to the nature and organization of one's work tasks, activities, responsibilities, and relationships.	Horizontal division of labor	Work meaningfulness and challenge appraisal	• Task variety • Skill variety • Problem-solving requirements • Information processing requirements
Autonomous work characteristics	High degree of autonomy, control, and influence over one's work tasks, activities, responsibilities, and relationships.	Vertical division of labor	Work meaningfulness	• Timing autonomy • Method autonomy • Decision-making autonomy
Mastery work characteristics	Work is organized in a way that one can understand what one's tasks, activities, and responsibilities are, how they fit in the system, and how well they are being executed.	Co-ordination and integration via information	Challenge appraisal and lower activated negative affect	• Job feedback • Feedback from others • Role clarity
Relational work characteristics	High degree of support, connection, and the opportunity to positively impact others arising from one's work tasks, activities, responsibilities, and relationships.	Co-ordination and integration via social processes	Work meaningfulness and meeting relational needs	• Task significance • Beneficiary contact • Social support
Tolerable work characteristics	Low degree of costly quantitative demands arising from one's work tasks, activities, responsibilities, and relationships.	Effort required to achieve shared org. goals	Lower activated negative affect	• Low role overload • Low role conflict • Low work–home conflict

Table 1. Higher-order work design factors, including their definition, theorised links to organisational design and psychological processes, and their work characteristics (Parker & Knight, 2023).

By applying structural equation modelling, Parker and Knight (2023) tested the relationships between the five higher-order factors and psychological processes, i.e. psychological human needs and the outcome of job satisfaction. These relationships proved to be significant, and an additional positive direct pathway was found between tolerable work characteristics and job satisfaction. Figure 2 displays the final model.

Figure 2. The final structural equation model shows the usefulness of the higher-order constructs (Parker & Knight, 2023).



How we can understand each higher-order element of the SMART model is explained as follows (Parker & Boeing, 2023: 94-97):

- when work is Stimulating, it means that the tasks, activities, and responsibilities within the work role are varied and challenging (e.g., involving problem-solving and active cognitive processing), and that they use and develop the job incumbents' skills;
- when work supports Mastery, it means the work is organised in such a way that one can understand what one's tasks, activities, relationships, and responsibilities are, how they 'fit' in the wider system, and how well they are being executed;
- when work has Agency, it means that workers have a high degree of Autonomy, control, and influence over their work tasks, activities, relationships, and responsibilities
- when work is positively designed from a Relational perspective, workers experience support from and connection with others, as well as an opportunity to positively impact the lives of others (e.g., end-users);
- when the work design is Tolerable, this means that one's level of job demands are not overly taxing or impairing one's ability to carry out non-work roles; the effort required should be manageable relative to the person's resources.

3. Technology, digitalisation and SMART work design

Parker and Grote take a proactive stance, which means rejecting "the existing, overly passive perspective focuses on how humans need to adapt to technology, rather than how work designs and technology might be adapted to better meet human competencies, needs, and values" (2020: 1173). This is an important point of view as it reverses the 'person-environment fit' approach into a 'technology-fit' approach, implying that humans should have control over technology. Even with more agentic and automated technical systems, human needs, competencies and values remain crucial. While it is most likely that tasks will be automated, not whole jobs, such that much work will entail an intense interaction between humans and self-learning autonomous technology. Hence, the long-standing principle of joint optimisation of work systems' social and technical components is as important today as it was in the early days of sociotechnical system design (Parker & Grote, 2020). Parker and Grote place work design at the heart of understanding and shaping new technologies based on the body of knowledge on the relationship between work design and individual, team, and organisational outcomes (such as the Job Characteristics Model of Hackman and Oldham, the Job Resources and Demands model of Bakker & Demerouti and the SMART work design model, see Parker, Morgeson, & Johns, 2017).

According to Parker and Boeing (2023), for many occupations and jobs, the current risk of digital technologies appears to be the disruption of, rather than the elimination of, human work – many tasks and activities of jobs could be automated, but not whole jobs. This gives rise to the challenge of organising the work between human and digital agents to facilitate work performance and enhance employee wellbeing. Work design questions, such as which tasks are allocated to machines and which to people, and who should be in control, come to

the fore. The SMART work design model developers contend that it can support the achievement of both performance and quality of working life, and it can do so in part by improving technical design and implementation (Parker & Boeing, 2023). How do the SMART work design proponents apply their approach when introducing new technology?

SMART work design in practice

SMART work designers apply the sociotechnical systems perspective in the sense that joint optimisation of the 'social' and 'technical' components is required. They propose that the SMART work design model can be translated to serve as simple design criteria, which can inform not only non-technological innovation but also technological innovation, and therefore help to inform a useable sociotechnical systems approach. Their general approach in practice is as follows (Parker & Boeing, 2023: 99; see also Boeing et al., 2020; Hay et al., 2020a en 2020b):

- for each higher-order job characteristic or dimension of SMART, researchers outline questions that can be asked by end-users (i.e., the employees) but also considered by technology designers, managers, or others commissioning and implementing technology (see the overview of SMART-related questions about roles, risks, opportunities, and broader issues that can be asked to inform decision-making about new technology implementation in a Table in Parker & Boeing, 2023, pp. 101-107).
- Researchers first identify the overall goal of the work design. For example, in the case of Stimulating, the goal is to design work in which workers engage in tasks they find interesting, use and develop their skills;
- Researchers then identify more specific questions that can be asked to help achieve this goal. They identify more opportunities or risks that might be created with respect to achieving stimulating work as a result of technology. For example, creating a job that involves a large degree of passive vigilance can be an outcome of technological change, which is noted as a risk to be avoided;
- Finally, researchers identify broader human, cultural, and organisational considerations that might need to be made to support this aspect of work design.

Parker and Boeing posit that the SMART design approach can be applied from the design and commissioning of technology right through to implementation. It can even be considered as early as possible in the process, at the design stage, before the technology is implemented. An example of such a proactive approach comes from a research study of the early-phase design of a military submarine (see Boeing et al., 2020), summarised in the next text box.

"In this project, SMART work criteria were utilised to evaluate the proposed crewing requirements of a future submarine. End-users and those responsible for technological acquisition were involved in the workshops. In the evaluation, SMART criteria were considered alongside factors such as operational capability and the constraints of the proposed technologies. The objective was to evaluate the ability of the proposed crewing requirements to support system performance and meaningful, sustainable work. SMART 'risks' such as skill utilisation in some roles, intolerable demands resulting from significant passive monitoring requirements, and operator fatigue were all highlighted as a result of these analyses. This evaluation ultimately led to alterations to the proposed staffing requirements and further consideration of the submarine's physical layouts and technical specifications."

Source: Parker and Boeing, 2023: 99.

While Parker and colleagues are advocates of a proactive stance with the SMART design model, that is preferably starting before the new technology is implemented and to apply the model in (re)designing the wider organisational systems before tackling the redesign of jobs, they experience that it is difficult to dig deeper, because "the reality is that sometimes the level of intervention is the work design of a team or unit" (Parker & Boeing, 2023). Apart from their observation that factors such as the required detailed nature of the methods, a lack of practitioner know-how, and difficulties involved in establishing socially oriented evaluation criteria as potential barriers to wider uptake of sociotechnical approaches (Baxter & Sommerville, 2011), it is indeed a practical barrier if researchers and consultants get no 'rapport' to participate in a root cause analysis (MacDuffie, 1997) and integral (re)design of the broader organisational system (De Sitter et al., 1997).

The critique of Parker and Boeing (2023: 99) that sociotechnical perspectives are overly vague and hard to put into practice is only partly true. Putting sociotechnical perspectives into practice is indeed a challenge when organisations implement change and technology in a partial manner instead of an integral manner. An organisation is a system whose whole is greater than the sum of its parts. This implies that the renewal of one part, for example, the technology of the mode of production, has consequences for the other parts of the whole, such as work activities carried out in other departments of the organisation. If a client commissions to renew the composition of tasks of teams, and no attention is given to the underlying technological and non-technological structure, one should speak of partial instead of integral organisational change. Upskilling, stress management and time management interventions are examples of partial change. Indeed, a limited assignment is a barrier. Furthermore, one reason for partial commissions is that integral change is a far-stretching, time-consuming, expensive, complex and threatening endeavour with uncertain outcomes. Another reason is that most sociotechnical perspectives and approaches differ quite a lot, as we will outline below.

The SMART work design model and the general body of research in job design and work design have two flaws that are connected to being unable to perform a systemic root cause analysis. The first is that these design approaches lack design rules. An organisational design rule is a prescription for setting up the organisational (production) process, which is based on functional requirements to achieve goals from a systemic, integral perspective. This starts with designing the process from an order to the delivery of the product or services. We do not blame job and work design researchers, as it is simply a matter of subjects belonging to different scientific disciplines, where designing organisations is a subject of operations management. Of course, interdisciplinary and transdisciplinary collaboration would be welcomed to overcome these shortcomings. The second flaw is connected to the first one.

Due to the mentioned 'disciplinary divide' work and organisation researchers with a background in the social sciences (and HR professionals) tend to focus on consequences instead of causes of the design of production processes. While Parker and Grote (2020) are correct to posit that a proactive stance is needed, in practice, the bulk of work and organisational social scientists is restricted to carrying out research, consultancy and design assignments to adapt people to the implemented technology and organisational changes (so-called person-environment fit approaches). As a consequence, addressing the fundamental psychological needs of people in their work is not entirely achievable because these needs are affected by design choices with regard to the production process and their layout by people responsible for operation management. Of course, and again, it would help if work and organisational social scientists and operation management officers would be in a constructive dialogue with each other, for instance, in the case of developing, selecting and implementing new (digital) technology. Even if workers have job resources such as job carving and job crafting opportunities at their disposal (Scopetta et al., 2019), it might be merely scratching the surface if they cannot modify design and technology choices with regard to the production process.

While it may be correct to generally state that sociotechnical perspectives face limitations to guarantee the uptake of human-centred solutions, partly because these also lack fundamental design rules, there is one exception, and that is the Modern Sociotechnology approach (MST).

4. The many faces of sociotechnology

The common notion of sociotechnical approaches is to optimise technology and people in organisations jointly. It criticised a unilateral emphasis on either the technical or the social aspects (Van Eijnatten, 1993). The concept of sociotechnical systems emerged from the Tavistock Institute in London during the 1950s. Researchers such as Eric Trist and Fred Emery studied coal mining operations and observed that optimal organisational performance

resulted from jointly optimising social and technical components. This led to the development of the foundational principles of sociotechnical systems design (STSD), focusing on autonomous work groups and participative work design.

During the 1970s and 1980s, STSD principles were adopted and adapted across various countries. In the Netherlands, professor L.U. De Sitter played a pivotal role in advancing Modern Sociotechnical Design (MST), emphasising integral organisational renewal and the simplification of complex organisations into more adaptable structures. His work highlighted the importance of designing organisations that promote both efficiency and quality of working life. In the United Kingdom, Enid Mumford developed the ETHICS methodology (Effective Technical and Human Implementation of Computer Systems), which integrated ethical considerations into system design, promoting user participation and addressing human needs alongside technical requirements.

The 1990s and 2000s saw a convergence of STSD with systems engineering approaches. Researchers proposed frameworks that integrated work design, information systems, and cognitive systems engineering, aiming to create more holistic and user-centred design methodologies. This integration sought to address the complexities of modern organisational systems and the increasing reliance on information technology (Baxter & Sommerville, 2011). In recent years, 2010s until today, STSD has continued to evolve, addressing emerging challenges such as digital democracy, citizen participation, and the ethical implications of artificial intelligence. For instance, frameworks have been developed to design and evaluate digital platforms that facilitate democratic engagement, ensuring that technological solutions align with societal values and promote inclusive participation (Abdelnour-Nocera et al., 2024). Additionally, the concept of sociotechnical imaginaries has gained prominence, exploring how societies envision and enact futures involving complex interactions between technology and social structures. This perspective emphasises the role of collective imagination in shaping technological development and policy decisions (Jasanoff & Kim, 2009).

Modern Sociotechnical Theory

Modern Sociotechnical Systems Design or Modern Sociotechnical Theory (MST), particularly as developed by De Sitter in the Netherlands, presents a distinctive approach compared to other Sociotechnical Systems Design (STSD) methodologies (Kuipers et al., 2020; Van Eijnatten, 1993)[1].

De Sitter's MST emphasises an integral design methodology that concurrently addresses both the technical and social dimensions of an organisation. This contrasts with traditional STSD approaches, which often treat these aspects separately (Benders et al., 2000). A central tenet of De Sitter's philosophy is transforming complex organisations with simple jobs into simple

[1] This sociotechnical variant of the Low countries is often overlooked, even in sociological overviews of the link between sociotechnical systems thinking and quality of work (e.g. Guest et al., 2022). We think it is because it is 'too technical', as it has a strong relation with operation management. Another reason might be that publications in English are limited.

organisations with complex jobs. This involves designing job roles that are multifaceted and enriching, thereby enhancing employee engagement and reducing the need for extensive hierarchical control mechanisms (De Sitter et al., 1997). MST advocates for the creation of semi-autonomous work groups capable of self-regulation. This approach contrasts with other STSD methodologies that may rely more heavily on centralised control. By fostering self-regulating teams, MST enhances flexibility and responsiveness within the organisation (De Sitter et al., 1997). De Sitter's approach places significant emphasis on involving employees in the design process, ensuring that the resulting organisational structures align with the needs and insights of the workforce. This participative methodology contrasts with approaches observed in other STSD frameworks that, however, do support participation and democratic dialogue, but to a lesser extent, as it regards employee involvement in the design process as crucial (Van Eijnatten, 1993).

MST prioritises improving the quality of work life by designing jobs that are meaningful and provide opportunities for personal development. This human-centred focus distinguishes it from other approaches that may prioritise efficiency over employee well-being (Benders et al., 2000).

De Sitter's MST combines the mentioned elements to collectively contribute to creating organisations that are both efficient and responsive to the needs of their members.
MST of De Sitter bases its design rules on different principles and scope of application compared to other sociotechnical perspectives (Table 3).

Table 3. MST versus other sociotechnical perspectives

Aspect	De Sitter and The Lowlands	Other STSD Perspectives
Scope	Holistic, system-wide redesign	Localised, incremental changes
Simplification	Emphasis on reducing complexity	Focus on optimising existing structures
Work Group Autonomy	Self-regulating, autonomous groups	Hierarchical or semi-autonomous groups
Job Design	Enriched, multi-skilled, and meaningful jobs	Optimised for task efficiency
Coordination	Decentralised through self-regulation	Centralised or semi-centralised
Focus of Optimisation	Social-technical balance with integral renewal	Task and technical system optimisation

In MST, emphasis is placed on the joint optimisation of social and technical systems[2], but with a strong focus on simplification. De Sitter's rules aim to reduce complexity in organisational structures by designing simple organisations with complex jobs instead of complex organisations with simple jobs.

[2] MST does not make the distinction between social and technical systems, but posits that both are integrally connected to the functions (activities) that the system as a whole must perform (De Sitter, 1993, 1994).

The primary focus is on integral organisational renewal, where the entire system, including workflows, hierarchies, and technical systems, is redesigned together. Design rules advocate for functional decoupling of complexity, meaning that processes are structured to minimise interdependencies that lead to delays and errors. This results in modularised processes where units or teams are given autonomous control over their tasks, reducing the need for centralised coordination. The design rules promote self-regulating work groups as the foundation of organisational design. Work groups are given the autonomy to manage their tasks, monitor their performance, and make adjustments as needed. This decentralisation fosters adaptability and responsiveness. As criteria for work design, De Sitter's design rules incorporate principles like variance control at the source, meaning potential problems are addressed directly at their point of origin (i.e. autonomy to solve problems at the local level where problems occur and emerge). Job enrichment and multi-skilling (learning opportunities) are encouraged to ensure that employees experience a meaningful quality of work life. The design starts at the organisational level (macro) to identify bottlenecks and inefficiencies and then moves to the micro level (individual jobs and teams). In allocating executive and managing tasks to jobs this macro-to-micro approach is reversed into a micro-to-macro approach[3]. In other words, MST designs the production process top-down because it needs the complete overview of activities and interdependencies; then it designs the control structure bottom-up to ensure maximum autonomy at the lowest level while minimising unneeded interdependencies to minimise interferences (risks for disruptions and errors).

How does MST distinguish itself from the other sociotechnical variants? Generalising the 'other' sociotechnical perspectives, many approaches focus on joint optimisation, but their design choices are often applied to specific sub-systems or teams rather than at the organisational level. These approaches emphasise incremental changes rather than holistic organisational redesign. Other sociotechnical systems often use design principles focused on task-based modifications, like improving individual tasks or workflows, ensuring alignment with existing hierarchical structures. There is less emphasis on simplifying or reconfiguring the organisational structure as a whole. Or at least not a systemic analysis of the impact of inappropriate organisational design. Other perspectives may not stress the same level of functional decoupling or modularisation as De Sitter's approach. They often work within existing interdependencies rather than restructuring them. In contrast to the self-regulating groups advocated by De Sitter, other STSD frameworks often include more centralised coordination mechanisms or rely on formal managers to integrate activities. Other STSD methodologies, especially those influenced by cognitive systems engineering or IT-driven designs, place significant emphasis on the technical aspects, sometimes at the expense of social dimensions. Approaches tend to focus on optimising technical systems (e.g., software, hardware) and integrating them with human workflows. They are consequently depicted as slightly more technology-centric and slightly less human-centric (De Sitter et al., 1997; Kuipers et al., 2020; Van Eijnatten, 1993).

[3] MST also recognises the meso level of departments and units (Kuipers et al, 2020: 222).

Despite the commonalities, sociotechnical practice and sociotechnical theory developed differently depending on the region or continent. In Scandinavia, for example, emphasis has been placed on democratic dialogue between employers and employees in order to arrive at common starting points for organisational innovation. In Australia and America, the focus is mainly on participation in the design process. In the Lowland variants, the theoretical foundation for analysing and designing organisations has undergone thorough development (De Sitter, 1981; 1993; 1994).

The main distinction between MST and the other sociotechnical perspectives is that the first developed detailed design rules based on the mentioned characteristics and more fundamental principles that we will not treat here, as these are available in the textbook of Kuipers, Van Amelsvoort en Kramer (2020). It suffices to outline the main characteristics of the MST design rules and connect these to the SMART work design model. By doing this, we provide professionals who deal with job design and work design with tools to link the psychological needs and their higher-order factors of the SMART model to levers of the design of production processes. We, however, realise that the link between MST and SMART is still an intricate one to work with in practice. Therefore, we suggest an intermediate stage, which is performing a job analysis that connects MST and SMART criteria in an accessible way, and this can be done by applying the WEBA method (Dhondt & Vaas, 2001; Pot et al., 1994).

5. Linking the SMART model to organisational design and integral system characteristics

MST is an open systems approach to designing work processes (the process of producing goods or services) (Kuipers et al., 2020). The design of work processes of organisations follows from strategic choices that organisation members (often management) make. These choices deal with matters such as markets, customers, products, business models, and finance. The mix of those matters results in decisions on how the product can be produced to meet the needs of markets, customers, investors and so on. Thus, we have production criteria for the layout of the work process. The MST approach not only looks at economic values as an input for the design. Human values play a significant role in the MST principle to minimise the division of labour. This principle contributes to the quality of work in terms of meaningful jobs (see footnote 1) by the design of so-called 'complete jobs' (Hacker, 1986 and 2003), in which executive and managing tasks are not split up as in Tayloristic and Bureaucratic organisation designs. This principle allows to consider human-centric values that lead to work criteria that enable the inclusion of well-being-at-work criteria, such as reducing stress risks and enhancing learning and developmental opportunities.

MST design rules follow a certain sequence, namely to 1] first design the production layout top-down (called production structure), and 2] second, design the logic of combining or dividing managing and operational tasks bottom-up (called management structure). In line with minimising the division of labour, the MST principle aims to locate decision latitude at

the lowest organisational level where problems occur and where autonomous decisions can be made. Once these functional requirements of production and management are determined, as a 3] third step, the design of supporting systems follows, such as (additional) technological systems, information systems, management systems, and human resources systems.

To be clear, technology that is part of the production process is already taken into account in step 1. In the case of a redesign, like introducing new digital technology, a meticulous analysis is made of the functional allocation between humans and machines, taking into account both the interests of the production goals (like effectiveness, efficiency, flexibility and innovativeness) and the interest of employees in terms of quality of work, i.e. active jobs with learning opportunities and limited stress risks. In fact, designing the production structure reckons with the idea that the management structure benefits from a limited division of labour. This means the design process is never entirely linear but iterative. The fact that digital technology is immersive at every level of an organisation and is present in almost all primary and secondary processes requires designers to look at the possible interlinkages with digitalisation (Govers & Van Amelsvoort, 2023).

The sequence of the design is nonetheless crucial. All too often, organisations choose the application of technologies and IT systems that create a division of labour, omitting the quality of work criteria. In such instances, instead of implementing a complementary technology to augment workers in their jobs, technologies can steer and monitor what workers do.

Both sociotechnical researchers on the one hand and work and organisational, and occupational health psychologists on the other – as organisation designers - care about the well-being of people at work, and that is the reason why connecting the SMART work design model and sociotechnical design principles is a groundbreaking opportunity to improve organisational performance and the quality of work simultaneously. Table 4 shows the five factors of the SMART work design model in column 1. Column 2 shows organisational structural design goals, column 3 shows the organisational cultural goals, and finally, integral system characteristics are mentioned in column 4. We emphasise that these goals and characteristics are not similar to functional requirements or criteria for the sociotechnical design rules: these are more complex, abstract and systemic (Christis & Soepenberg, 2016; Kuipers et al., 2020). While MST does not emphasise organisational culture (column 3), so does workplace innovation. Workplace innovation is partly based on sociotechnical thinking and takes both structural and cultural characteristics into account in its purpose to simultaneously improve business performance and human performance and the quality of work (Oeij & Dhondt, 2017: 66). Workplace innovation aims to connect ‘organisational’ and ‘social innovation’, where ‘technological innovation’ is regarded as part of structural renewal.

SMART model Five factors and organisational conditions	Organisational structural design goals	Organisational cultural design goals	Integral system characteristics
Stimulating work characteristics Horizontal division of labour	•Minimise division of labour •Maximise learning new skills / job enrichment •Technology to augment work	•Opportunity of learning (new skills and on the job learning)	•The organisation as a system must have sufficient control capacity to adequately deal with environmental demands (Law of requite variety: external variety must be met by internal variety, i.e. internal control options / design active jobs with sufficient decision latitude)
Autonomous work characteristics (Agency) Vertical division of labour	•Decentralisation in division of labour / limited hierarchy / low formalisation •Autonomous teamwork •Artificial Intelligence / Machine Learning as a choice	•Presence of leadership and mentoring to learn new roles / growth in roles •Shared leadership •Options for self-management (self-regulation) and self-selection	•Reduction of structural complexity by reduction of interfaces (simplifying the organisation) •Parallelisation of order variety into homogeneous sub-streams (streamlining the orders) •Combine executive, preparatory, and managing tasks supporting of sub-streams, and allocate such 'whole tasks' (self-regulation) to autonomous groups (segmentation) •Decentralisation of authority whenever possible •Minimize critical specification / minimise monitoring and controlling Artificial Intelligence and Machine Learning
Mastery work characteristics Coordination and integration via information	•Maximise open information about company results and strategy	•Worker participation in organisational change / renewal •Contribute to innovation resulting in technology adoption •Democratic dialogue	•Teamwork implies control-capacity, coordination, collaboration, social support, uses of talents, enrichment, learning opportunities •Functional deconcentration of information (grouping of required information and data) /access to data / augmenting function of (information) systems / explainable Artificial Intelligence
Relational work characteristics Coordination and integration via social processes	•Maximise external control options •Maximise consultation at work / discussion of work progress (participation)	•Cooperation based on human(ist) respect (equality diversity and inclusiveness) / mature employment relationships / labour relations / commitment driven HR system	•Integrate control-cycles to minimise complexity in interactions (nodal network). A control cycle is a coherent 'loop' of import requirements (e.g. tasks and resources) and export requirements (e.g. product quality). Between input and output, the throughput determines how the work process is set up. This throughput (transformation) also regulates how the interactions take place. Think of effective cooperation without bureaucratic red tape.
Tolerable work characteristics Effort required to achieve shared organisational goals	•Maximise internal control options / decision latitude •Workload self-management (e.g. self-rostering)	•Task / assignments based on achievable (non-exploitative) production goals and human well-being •Fair reward system	•Taking into account the psychosocial and physiological boundaries of human functioning (in and outside work)

Table 4: SMART work design model organisational design goals and system characteristics

Parker and Knight (2023) have connected each of the five factors to organisational conditions, which are also mentioned in column 1. They connect stimulating work characteristics related to the horizontal division of labour. This can be associated with the integral system characteristic of developing the organisation as a system that is able to deal with turbulent environments[4]. This aligns with structural goals to minimise the division of labour and the creation of active jobs that enable learning new skills. The work characteristics of autonomy or agency align with integral system characteristics to keep organisations relatively simple, without too many interdependencies that require centralised steering. Instead, the structure should be decentralised with technology that augments people and enables an organisational culture with supporting leadership, shared leadership and much self-regulation. The related organisational condition is a vertical division of labour. Mastery work characteristics are associated with coordination and integration via information. The integral system characteristic related to this is having functionally required information at the lowest levels in the organisation, allowing people to use that information to uptake broad working roles, understand the technology they work with, and contribute to innovation. Relational work characteristics, with coordination and integration via social processes as the organisational condition, can be linked to control cycles as the integral system characteristic. In sociotechnical thinking, complex human relations within teams are preferred over complex interdependencies across teams and departments. Social relating based on intelligent cooperation and functional interhuman support, embedded in active job design, is the desired organisational behaviour enabled by a structure of largely decentralised control options. Finally, tolerable work characteristics, indicating an acceptable effort to achieve shared organisational goals as an organisational condition, can be paired with an integral system characteristic that considers the psychosocial and physiological boundaries of human function. The structural design goal is to maximise control and decision latitude with achievable workloads, allowing for organisational cultural design goals that respect human wellbeing and fair rewards.

In this way, sociotechnical thinking and the SMART design model are highly complementary, with SMART emphasising the fulfilment of psychological human needs at work and sociotechnical thinking connecting the production system, the management system and the information system to active jobs in which operators can fulfil these human needs. The alignment of the two can be realised by translating the organisational conditions (column 3 in Table 1 and column 1 in Table 4) into criteria for human needs and into functional requirements for sociotechnical design[5]. While this is theoretically quite well feasible (Oeij, Dhondt & Vaas, 2024), it is also rather complex and runs the risk of not being used and applied by practitioners. Especially since the ones who design the organisation and its

[4] Flexible and innovative organisations must deal with turbulent environments that are volatile, uncertain, complex, and ambiguous (Atanassova & Bednar, 2024). Such VUCA environments necessitate that organisation designs deal with that by making organisations less complex (less 'bureaucratic', thus eliminating unneeded interdependencies); the complexity should be designed into the jobs in teams so as to ensure that operators can effectively deal with complex job demands (De Sitter et al., 1997).

[5] Be aware that the organisational conditions are very similar to Mintzberg's coordinating mechanisms that lead to different organisational configurations: mutual adjustment, direct supervision, standardisation of skills, jobs and outputs / norms (Mintzberg, 1983).

technology and the ones who design jobs and skill people – decision managers, engineers, technicians on the one hand, and HR professionals and people managers on the other -are often not the same functionaries. With regard to the implementation of new technology and digitalisation, the question arises: Who looks at the interests of the quality of work of employees? HR professionals lack broad knowledge of operations management and technology design, while engineers want to make error-free technology and may not understand human needs sufficiently; most managers feel responsible for the business but not always for social aspects. The risks are that the implemented technology is not augmenting but controlling humans, that employees are unwilling to adopt innovations and technology, and that the production process and business performance are suboptimal.

It so happens that there exists a method that can function as an intermediary between MST and SMART, and, what is more, is relatively easy to work with for practitioners, which is called WEBA, an acronym in Dutch that can be translated as Well-being at Work (Dhondt & Vaas, 2001; Pot et al., 1994; Vaas et al., 1995). The method helps practitioners analyse jobs to identify control problems in their work and assess where the options are to eliminate such control problems in the design of the production structure and management structure. The WEBA;

- looks at control problems at work;
- is based on sociotechnical thinking, thus looks at the relation with the production process and workplaces;
- includes conditions of well-being at work, based on the Job-Demand-Control model (Karasek &Theorell, 1990), and conditions for learning and development through 'complete jobs' (Hacker, 1986; 2003).

6. Start with control problems and control options: the WEBA

The description of the SMART work design model and MST beg the question: Where should we start? Redesigning the organisation with MST is no easy task and not a short-term exercise. The application of the SMART philosophy is clearer. A possible objection, however, is that the consequences of problem situations are addressed, but not the structural causes of those problem situations. A more accessible way to connect both perspectives is to apply an approach that immediately puts the axe to the roots, namely, where control problems make it impossible to solve problems in the workplace. Because it causes stress risks and hinders learning and development in the workplace. This often has a cause in how the work is organised and results in employees experiencing *job dissatisfaction*, or worse, absenteeism and *burnout* in the longer term.

The WEBA method to analyse and redesign jobs

The WEBA method can describe how an organisation is designed as a work process, resulting in functions with tasks that include or exclude well-being risks. These risks are a feature of the job and employment situation, regardless of the experience of a person performing the work. However, the absence or presence of risks will impact the perceived fulfilment of human needs in the job performer. It is possible to assess control problems at the level of tasks and functions. A control problem is a disruption in the work process that can be solved with control options (i.e. decision-making space, regulatory authority, autonomy, peer support). A control problem can occur at the task level, for which the job operator may or may not have the control options to solve the disruption (this is the result of a choice in job design and division of labour). If there is a control problem, it means that there is a disruption or an interruption in the performance of a task or job. To solve the disruption, control options (i.e. decision-latitude, autonomy) are needed at the level of this job. It is not about *person-environment fit* but about (internal and external) control options in the job so that it is possible for the job operator to adapt the workload to his physical and psychosocial capacity. The motto is not to adapt the person to the job but to make the job requirements 'adaptable' for (and by) the job performer.

If the control options are lacking and the disruption cannot be resolved at the level of that job, the operator assigned to the job may feel incompetent or stressed. In such cases, it can be established that the task is confronted with an unfavourable 'well-being condition'. We discuss the seven well-being conditions of the WEBA (Dhondt & Vaas, 2001; Pot et al., 1994; Vaas et al., 1995). In doing so, we indicate the relationship with MST and with the SMART work design model (Oeij, Dhondt & Vaas, 2024: 16-17; Parker & Boeing, 2023: 94)[6]:

1. The completeness of a job: a 'complete range of tasks' implies the presence of all options for action (execution, preparation, support and management). This means that the function allows the operator to resolve disturbances (i.e. the result/ *output* is achieved qualitatively and quantitatively) with assigned autonomy and external control possibilities (i.e. some degree of control at both the level of the production structure and the management structure).
   -*MST*: this corresponds to the MST design criteria about autonomy over a completed part of the production process (the so-called micro-level of the production structure and control structure);
   -*SMART*: this corresponds to the S of Stimulating about task variation, skill variation, problem-solving requirements and information provision; and to the A of autonomy in work.

2. Non-short-cycle time tasks: Short cycle time tasks or short-cycle tasks indicate work that is repetitive, monotonous, and contains (physical/physiological) risks. The task

[6] Our own assessment deviates slightly from the one by Parker & Boeing, 2023.

does not offer learning opportunities and can cause one-sided physical strain. Such tasks should be limited in a job.
-*MST*: this corresponds to the MST design criteria about the autonomy over a completed part of the production process so that learning opportunities are available;
-*SMART*: this corresponds to the S of Stimulating about task variation, skill variation, problem-solving requirements and information provision;

3. Level of (cognitive) complexity: Within a job, there must be tasks that provide learning opportunities. The combination of high task demands and high autonomy ensures a combination of learning new things and the presence of control to deal with them (e.g. solving a malfunction) without high stress risks. A balanced mix of 'complex' tasks and 'routine' is desirable.
   -*MST*: this corresponds to the MST design criteria on the autonomy over a completed part of the production process;
   -*SMART*: this corresponds to the S of Stimulating about task variation, skill variation, problem-solving requirements and information provision; and the T of tolerable work brands about low role overload, low role conflict, and low work-home conflict (work-life imbalance).

4. Autonomy: the position must allow forms of autonomy in the execution of the tasks with regard to pace, method, (order) order and (work) place.
   -*MST*: this corresponds to the MST design criteria on the autonomy over a completed part of the production process with an absence of stress risks and the presence of learning opportunities;
   -*SMART*: this corresponds to the S of Stimulating about task variety, skill variety, problem-solving requirements and information processing; and with the A of autonomy in work; and the T of tolerable works brands about low role overload, low role conflict, and low work-home conflict.

5. Interaction network: the tasks should allow functional and social contacts with other people and the workplace should not be an isolated working environment.
   -*MST*: this corresponds to the MST design criteria on teamwork, information provision, and external control capacity;
   -*SMART*: this corresponds to the M for Mastery about feedback at work, feedback from others and role clarity, and to the R for Relational about job meaning, contact with beneficiaries, and social support.

6. Organising tasks: the tasks must make it possible, among other things, to organise functional contacts, work consultations and intervision (mutual consultation) and to arrange help and advice (by colleagues, staff, staff and management).
   -*MST*: this corresponds to the MST design criteria on full functions, teamwork and external control capacity;

-*SMART*: this corresponds to the R of Relational about task meaning, contact with beneficiaries, and social support, the T of tolerable works brands about low role overload, low role conflict, and low work-home conflict, and the M of Mastery which stress the understanding how work is organised and who is doing which tasks.

7. Information: there must be sufficient information and data available about the goals, the assignment and feedback on the results.
   -*MST*: this corresponds to the MST design criteria about the autonomy over a completed part of the production process for which sufficient information must be available;
   -*SMART*: this corresponds to the M of Mastery about feedback on work, feedback from others and role clarity.

If these well-being conditions are not met and intended results cannot be achieved, this will not only have consequences for the realisation of the intended goals of the organisation but also for human needs. However, MST is less concerned with human job satisfaction but with the absence of risks in tasks and functions. With the WEBA, the SMART work design model can take advantage of the sociotechnical design approach to identify risks in the organisation's design and jobs to improve the options to optimise human needs and job satisfaction. Equally, the MST can benefit from the relationship with the work of HR professionals to strengthen and validate the usefulness of MST. We think this can support the conversation between organisation designers, such as engineers, technicians and HR professionals. The pleasant feature of the WEBA method is that it can be applied easily by people who have a thorough knowledge of work, organisational processes and organisational behaviour.

Example of a WEBA job analysis: Operator production line

To show the connection between the SMART work design model and sociotechnical design rules, we present an example of a WEBA analysis of a concrete job, the operator on a production line (Vaas, 2023). This was part of research into the health and safety risks of short cycle time labour. Based on an expert assessment of the seven well-being conditions, a 'well-being profile' can be generated (Table 5).

Table 5. Well-being profile of 'operator production line' (Vaas, 2023)

Assessment	Unsatisfactory	Limited satisfactory	Satisfactory
1.Job completeness			
2.Non-short cycle time tasks			
3.Cognitive complexity			
4.Autonomy			
5.Interaction network			
6.Organising tasks			
7.Information			

Overall, the job profile of this operator does not look too bad but can be improved by enhancing cognitive difficulty to improve learning opportunities. To prevent, reduce and preferably structurally eliminate the risks that lead to unsatisfactory scores, the WEBA method – based on sociotechnical design rules- suggests adaptation measures, improvement measures, and restructuring measures (i.e. redesign). Adaptation measures are mainly measures that solve control problems, for example, by clearer work instructions and provision of more or better resources and materials. Note that this is 'only' an adaptation: it reduces the stress risks, but it also reduces the opportunities to learn from solving the problem in case. Improvement measures are aimed at improving task composition and introducing control opportunities as (social) contacts without requiring production-organisational and/or production-technical measures (i.e. restructuring measure): task rotation, task expansion, task enrichment (as examples of improving the horizontal division of labour), work consultation (functional dialogue).

The machine operator in the studied plant rotates across various workstations on the production line. At these workstations, the operator has to carry out preparatory tasks and quality control tasks. As a result, the job contains fewer short-cycle tasks as in the case of isolated workstations. This contributes to the job 'completeness'. Task enrichment here has little effect on cognitive difficulty (i.e. learning opportunities) or functional contacts because most tasks on the line are of an equally low cognitive level, and the workstations are isolated (the operators usually work there in pairs). A useful task enrichment in this job would be to have the machine operators (in rotation) make the daily schedule or introduce self-scheduling.

Introducing work meetings (functional consultation) for all operators on this production line would enable the machine operators to jointly address control issues in areas such as material supply or working conditions. A restructuring measure could be to make all operators on the production line function as a 'task group' or 'autonomous team'. Such a team is responsible for the daily planning and mutual distribution of work, does as much of the preparation, execution and support tasks in the work process as possible, establishes contacts with colleagues inside and outside the department independently when control problems arise, meets regularly for work consultations involving planning and logistics, product and process specifications, materials (i.e. what is processed by the machines), equipment, technology, working conditions, clean policy requirements, etc.
The formation of a task group /team requires a rearrangement of tasks and competencies, i.e. a change in the production structure and the management structure of the work organisation.

Why should involved agents want to use it? First of all, we think that the time is right. There is growing resistance against economic systems such as shareholder capitalism that does not put much effort into taking into account a fair sharing of the profits, and that benefits few at the cost of the health of workers. Also, outside the world of work, another wind is blowing. European policymakers suggest that technological deterministic Industry 4.0 should make

place for a more human-centric Industry 5.0 which also pays attention to sustainability, circularity and reduction of fossil energy resources (Breque et al., 2021). And thirdly, the threat of '*un*explainable AI' and autonomous technology demands to get back a sense of control and grip on our future (Prunkl, 2024; Rana et al., 2022).

With this in mind, the next step and challenge in connecting SMART and MST is to understand digital technology better and to implement it in a way that continues to ensure opportunities for good quality work in accordance with creating economic welfare and social well-being.

7. Summary and Concluding Observations

The aim of this contribution is to bring organisation designers into conversation about organisational design, technology choices and quality of work. In the first part of this article, the focus was on the relationship between the SMART work design model and the MST. If organisation designers want to apply this combination in practice, it is a complicated exercise, and that inevitably raises questions about its usability. In the second part, we added the WEBA method. In this way, not only does the picture become complete, but there is a guide to make the connection with the design of work organisations and functions based on the desire to improve the quality of work. We want to make the point that the results of a function analysis with the WEBA method lead to insights into control problems. These regulatory problems can be counteracted or eliminated by introducing measures based on MST design rules. It is possible to relate design rules to the five factors of the SMART work design model. No fewer than fifty sociotechnical design rules increase the quality of work from the perspective of MST (see Peeters & Mossink, 1995). We have summarised these elsewhere, establishing the relationship between the design rules and five factors of the SMART working design model (Oeij, Dhondt & Vaas, 2024).

This conceptual article examined how the SMART work design model can be linked to sociotechnical systems thinking to improve the quality of work. The article starts from two perspectives: the design of jobs from psychological human needs and from operational functional requirements of the organisational business goals. The conclusion is that the link is possible, at least in theory. The SMART work design model operationalised human needs in five factors and organisational conditions. The MST translated production requirements into functions that meet welfare conditions for which design rules were formulated. We emphasised that there is an order that we believe produces the best results. First, look at how the work is organised in the production process before interventions are proposed as solutions. Logically, one should first look at the organisation of work from a socio-technical perspective and only then possibly identify improvements for the psychological needs that people have in work from the five-factor model of SMART. Fortunately, the WEBA method offers the opportunity to analyse features and develop redesign recommendations that align with both MST and the SMART working design model.

Our contribution is primarily aimed at supporting organisation designers in developing organisations and functions that promote good organisational performance and good quality of work at the same time. In doing so, the approach is in line with the concept of *workplace innovation,* or social innovation (Oeij & Dhondt, 2017, p. 66; Parker & Boeing, 2023: 92). The next step is to translate our ideas into a concrete action plan with concrete steps.
A limitation of our contribution, therefore, is the lack of empirical testing this new combination of MST and SMART into a single approach. That is to say, the elements about human needs have been researched extensively and the SMART work design model did stand its first tests (Parker & Knight, 2023). Concerning the MST design rules and the WEBA method, there is quite some qualitative research carried out in the Lowlands (the Netherlands and Flanders in Belgium) that supports the viewpoints, but a systematic, quantitative evaluation has not been performed[7]. Nonetheless, there are numerous qualitative case descriptions available[8]. Moreover, there is serious concern that individual-level interventions (read psychological interventions) do not engage with working conditions (read organisational redesign) and that such interventions do not provide additional or appropriate resources in response to job demands (Fleming, 2023).

Secondly, we want to emphasise the importance of collaboration in the scientific field to develop this approach further. There is too little dialogue between different scientific disciplines, such as psychology, sociology, management science, computer and software technology and operations management. That makes sense because they are diverse fields. But where those disciplines come together in the world of work, digitalisation, and business results, there is also a loss. We estimate that at least some convergence of the organisational researchers with individual, group and organisational design expertise would be useful for people who work with new digital technology now and in the future to constrain the risk of harming human interests and align digital technology with human values (Bai & Vahedian, 2023; Christian, 2020; Kretschmer & Khashabi, 2020; Parker & Grote, 2020).

The future of work is one with more digitisation, robotisation, artificial intelligence and *machine learning* (Govers & Van Amelsvoort, 2023; Parker & Grote, 2020; 2022). We have learned that technological advances and their application and implementation tend to neglect the human factor too much. This needs to change; we can put people more at the centre (Breque et al., 2021; Oeij, Lenaerts, Dhondt, Van Dijk et al., 2024). "Industry 5.0 is characterised by going beyond producing goods and services for profit. It shifts the focus from shareholder value to stakeholder value and reinforces the role and the contribution of industry to society. It places the well-being of the worker at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet" (Breque et al., 2021: p. 14). Human centricity, therefore, as the social hallmark of Industry 5.0, implies taking human interests seriously, which, in sociotechnical terms and in line with the workplace innovation concept, suggests

[7] However, there is also a survey questionnaire version of the WEBA (called NOVA-WEBA) that has been tested and validated (Kraan et al., 2000) and has been partially included in the Netherlands Working Conditions Survey (NEA, https://www.cbs.nl/en-gb/our-services/methods/surveys/brief-survey-description/netherlands-working-conditions-survey--nea--).
[8] See for example the Knowledge Bank Workplace Innovation (https://www.workplaceinnovation.org/).

the presence of a management approach that is not fully top-down and offers at least some room for bottom-up dialogue). To this end, human interests are linked to humanist values in work (as in the quality of working life stream, human relations perspective). Such values are linked to the psychological human needs model (such as in SMART work design). These depend on organisational facilitation that is rooted in the operations design of working processes and production processes, according to the basic rule to keep the division of labour limited and to maximise employee decision latitude. This, then, finally leads to the notion that tools, instruments, software, IT, etc., should, as much as possible, augment and support the work of workers instead of controlling, monitoring and steering workers.

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Exclusion and inclusion through a discourse of equality – positioning the blue-collar worker in Industry 4.0

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Anette Hallin
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Abstract

Blue-collar steel industry workers have traditionally been engaged in hard, physical, manual labour, but with the transformation of Industry 4.0, the need for manual human labour is reduced. In this article we explore the consequences of this transformation for the constructions of discursive positioning of the blue-collar worker. Analysing the material from 89 interviews from five steel companies in Sweden we analyse the the linguistic constructions of concept: what the blue-collar worker is and might become in Industry 4.0, and the consequences this concept has for the blue-collar worker as object: who the blue-collar worker is, and who (s)he is not. This shows that blue-collar workers are constructed as skilled and equal to white-collar workers, but also as deskilled and standardized.

Furthermore, inclusion into this equal and standardized workforce is constructed as being based on abilities and experiences that are only shared by a fragment of the population; the young, well-versed, socially skilled, and fast learners, with permanent contracts. The study contributes with an understanding of how social polarization is taking place in contemporary industry and points to the need for management, labour unions and to take the constructions of social inclusion and exclusion in daily interactions in the workplace seriously, in order for the development towards an innovative, human-centric Industry 5.0 to become just and fair.

Keywords: blue-collar workers; Industry 4.0; upskilling; deskilling; equality

Introduction

Since the early 20th century, the distinction between "blue-collar" (dressed in chambray, dungaree or denim) and "white-collar" (dressed in white shirts) workers have been made between workers performing manual labour and workers performing clerical and administrative tasks (Wikman, 2012). Unlike white-collar work, blue-collar labour is traditionally performed in high-risk, dirty work environments (Lucas & Buzzanell, 2004) and blue-collar workers are commonly seen to constitute a vulnerable group in the industrial context (Lucas, 2006; Thomas, 1989). In addition, blue-collar workers have long occupied a subordinate hierarchal position in the organisation, under the close supervision of foremen and/or mechanical controls (Ashforth & Kreiner, 1999; Lucas & Buzzanell, 2004; Thomas, 1989). This position of the blue-collar worker is, however, changing with the development of automation technologies within that which has become known as Industry 4.0.

Industry 4.0 was coined in 2014 by the German government as part of a federal strategic action plan (Bundesministerium für bildung und Forschung, 2014) but has since spread to more broadly denote the development of a 'smart' factory where routinized work is automized by connecting machines and systems, improving quality by minimizing human labour and human error. Industry 4.0 involves the adoption of advanced ICTs, such as robots and AI, which are implemented with the purpose of increasing efficiency and productivity (Autor et al., 2003; Herzog et al., 2017; Xu et al., 2018).

It has been argued that the emergence of Industry 4.0 will change the organisation and nature of work, requiring workers to adopt new skill sets (Habraken & Bondarouk, 2017), in a way that will have major consequences for skills development (Acemoglu, 2002; Acemoglu & Restrepo, 2017; Brynjolfsson & McAfee, 2014). Previous research has described how the implementation of new technologies has led to processes of alienation and deskilling (Braverman, 1974; Haakestad & Friberg, 2020), and to a development of skills-polarization on the labour market (Martinaitis et al., 2021) with effects on workplace inequality (Baxter & Wallace, 2009; Schaupp, 2022).

Others claim that the use of technologies in various industrial settings is explored mainly as a matter of organisational effectiveness and employee performance, where the social effects on equity, diversity and inclusion has been limited to consequences of the tools themselves, and that further studies are needed to "understand how employees perceive and behave in response to technological advancements" (Budhwar et al., 2022, p 1087). To advance such knowledge, studies on the use of discourses in organisational settings are promising, since individuals through language can adopt and resist positions that construct them as included or excluded in certain societal contexts (Wetherell & Potter, 1993). Previous research in this journal has pointed to a need for critical discourse studies exploring embedded conflicts and the effects on humans in the Industry 4.0-transformation (Johansson & Abrahamsson, 2021, p. 194). To amend this, the purpose of this study is to examine how blue-collar workers are discursively repositioned in the transition towards Industry 4.0.

Drawing on a large interview study in five Swedish steel companies, the article sheds light on the discursive mechanisms that construct workers as included or excluded in Industry 4.0. By contributing to the understanding of the discourses that reposition the blue-collar workers in the contemporary industrial setting, the study contributes with an understanding of how social polarization (Martinaitis et al., 2021) is taking place through the use of discourse. The conclusion is that management, labour unions and policymakers need to take the constructions of social inclusion and exclusion in daily interactions in the workplace seriously, in order for the digital development in industry to evolve just and fairly.

The debate on deskilling and upskilling, the polarization of skills and consequences for (in)equality

In the contemporary implementation of new technologies in the transformation towards Industry 4.0, historical social relations in the industry are challenged and renegotiated through parallel ideals of workers' deskilling and upskilling (Abrahamsson & Johansson, 2006). The concepts of *deskilling* and *upskilling* has a long history within the study of labour and relates to the question of if and how the skills of the worker changes with the implementation of new technology. Seminal here is the work of Braverman (1974) who argued that the implementation of new technology leads to de-skilling among blue-collar workers and therefore to an alienation from work. This, according to Braverman leaves the blue-collar worker in an even more vulnerable position than previously since he (sic) is made replaceable. More recently, the deskilling trend is predicted to lead to job losses on a large scale, as routinized manual labour is replaced by automated digital technologies (Pfeiffer & Suphan, 2015). With this development, skills related to craft work will no longer be needed or appreciated in the workplace (Haakestad & Friberg, 2020), which must be presumed as likely to have effect on the collective of blue-collar employees in the metal industry.

Other seminal works, however, counter the deskilling claims and plead for higher skills demands on industrial workers (Blauner, 1964). Scholars argue that the implementation of new technology does, in fact, lead to upskilling, as well as to increased autonomy for workers (Acemoglu, 2002; Acemoglu & Autor, 2011; Machin, 2001). The complexity of skilling in relation to implementations of artificial intelligence (AI) in industry is stated by Jaiswal et al. (2022, p. 1184, p. 1184) as "individuals need to be adept in various skills such as social, emotional, technological and physical skills to exhibit good performance or demonstrate appropriate behaviour depending upon the context or situation", in order to "remain employable and competitive" (p. 1185) on the labour market in general. The World Economic Forum specifies that the need for upskilling in the Mining and Metals industry as related to Big Data Analytics, Cloud computing, robotisation and the Internet of Things (Schwab & Zahidi, 2020). These studies confirm the need for upskilling in areas such as critical thinking, complex cognitive problem-solving, self-management, and data analysis learning skills (Jaiswal et al., 2022; Schwab & Zahidi, 2020).

Whereas less skilled workers seem to become less in-demand with the advancement of new technology, highly skilled workers seem to become more attractive (Acemoglu, 2002). This leads to what has been called the *polarization of skills*, i.e. an increased polarization between highly skilled and deskilled workers. Goos et al. (2014) describe this development as the result of machines taking over mid-skilled occupations, constructing a skills' void among workers, leading to wage polarization, and more generally changing the conditions for employment. The phenomena of skills-polarisation are especially noted in the Nordic countries where industry has undergone rapid technological change during the past few decades (Adermon & Gustavsson, 2015; Asplund et al., 2011).

As companies in the transformation towards Industry 4.0 workplaces grapple for skilled, innovative and creative talents, the social effects of the polarization of skills in the industrial process towards Industry 4.0 is an urgent matter. We know that the development of new technologies may be understood as driving agents of economic and social inequalities in society at large (e.g. Peters, 2013) and that technology in itself is "created, harnessed and reproduced" through societal drivers of power (Spencer, 2017, p. 145). Extant research furthermore shows that polarization of labour is changing relational prerequisites between different groups, hereby challenging the quest for what has been called the 'inclusion turn' (Adamson et al., 2021) in organisations. Hence, it may be argued that everyday practices and use of discourses in skills demands *seem* neutral and non-exclusionary, but that they in reality operate *against* inclusion (Dobusch, 2021; Nkomo, 2013). But how does this happen? To unpack "the processes and dynamics related to issues of inequality in blue-collar workplaces" (Lønsmann & Kraft, 2017, p. 146), a focus on language use provides a promising avenue, since a close focus on discursive constructions allows for a problematization of common understandings of technological change (Abrahamsson & Johansson, 2021; Pfeiffer & Suphan, 2015).

Theoretical and analytical approach

As humans use language in everyday conversations as a way to make sense of their experiences, paying attention to language-use makes it possible to understand how their selves are constructed (Edwards & Potter, 1992; Wetherell & Potter, 1993). Here, we mobilize the theoretical notion of *subject positioning*, as used in discursive psychology (Wetherell, 1998). Subject positioning is closely related to ideas of personality or identity. However, as stated by Parker (2015, p. 130) "This is where we can connect with a wider critical approach to the discipline [of psychology], for we treat the variety of things that psychologists tell us they have found inside us and among us as forms of discourse." This means that when describing experiences, skills, or traits, as normal, desirable, abnormal, or undesirable such statements can be explored as discursive constructions embedded in both a specific organisational as well as wider Western culture. The linguistic constructions of humans in

text and talk can thus be understood as "a particular 'regime of truth' which makes our talk and experience about 'the self', 'personality' and 'attitudes' make sense." (Parker, 2015, p 132) in the particular time, place and context. Context here is thus viewed as multi-layered, contestable, locally achieved and co-created through ongoing human interaction (Fairhurst, 2009). This makes discursive positioning a suitable analytical framework when aiming at understanding the consequences of one-on-one conversations, such as interview settings, for larger social contexts, since the positioning process does not merely say something about the (interviewed) individual but enables the analysis of larger societal processes (Harré & Moghaddam, 2003). Finally, unlike other discursive theories, discursive psychology recognizes individual agency by emphasizing that even if the social context stipulates certain positions as those are that are available, individuals can still select them deliberately – or not – and thus resistance towards social change is possible (Harré & Moghaddam, 2003; Wetherell & Potter, 1988, 1993; Parker, 2015).

Subject positioning posits that the qualities of subjects (individuals/groups of individuals) are brought about through the discursive locating of individuals within a set of linguistic repertoires (Wetherell, 1998). It should be noted that a *subject* here is not to be understood as denoting a fixed identity. Instead, subjects are undergoing a constant process of becoming constituted and reconstituted through the use of the discursive repertoire that are available.

Discursive repertoires are used in human interaction to produce how a role, a group or how individuals within such a group should be or become. Through interaction we can discuss, debate and agree on a *concept* that can be used to speculate how this role, group or individual should be, behave, know or act (Phillips & Hardy, 1997). Furthermore, through this interactive process of defining the *concept*, individuals as *objects* become included or excluded in particular ways, which then also means that some people are constructed as not belonging to the particular group of individuals that are objected to the repertoire mobilized. In the realm of discursive psychology, Parker (2015) describes the matter of *object* in two different ways: either as a matter of reality, i.e. that language refers to an object by the use of a noun (a cat, a blue-collar worker), or as something that is constantly given new meaning through discourse. In this later case, our analysis rests on the notion of discourses as objects. A further way to approach the matter of subject-object is that "The object that a discourse refers to may have an independent reality outside discourse but is given *another* reality by discourse. An example of such an object is the subject who speaks, writes, hears, or reads the texts where discourses live." (Parker, 2015, p. 158, italics in original). To conclude, the subject positioning of the blue-collar worker in Industry 4.0 is explored through the linguistic construction of *concept* (Phillips & Hardy, 1997) – what the blue-collar worker is and might become, and the consequences for the blue-collar worker as *object* (Parker, 2015): who the blue-collar worker is, and who (s)he is not.

Study design

The study was part of a larger 1-year research project, the Digitalized Work and Organisation (DAO) project where ten researchers (the authors plus additional colleagues), performed interviews at seven Swedish steel companies. For this article, five companies were selected since they (companies A-E in Table 1) represent a cross-section of the Swedish steel industry with regards of production processes, with in total 89 semi-structured interviews[1]. Most respondents were men, which reflects the gender structure of the industry at large. The ages of the respondents varied from 26 to 65.

Table 1. Characteristics of the companies studied

	Production process	Type of product	Degree of automation/digitalization	Number of interviews, female (F) and male (M)
Company A	Flow	Raw material	Mainly manual and automated units	21 (4 F, 17 M)
Respondents' roles: 12 operators (incl. 1 local union representative), 4 production managers, 1 technician, 1 head of production, 1 head of logistics, 1 HR manager, 1 CEO				
Company B	Batch	Manufacturing	Mainly robotized units	20 (4 F, 16 M)
Respondents' roles: 11 operators (incl. 1 local union representative and 3 with shift manager responsibilities), 3 technicians, 1 production technology manager, 1 production unit manager, 1 site manager, 1 product manager, 1 HR business partner, 1 IT site operations manager				
Company C	Flow	Raw material	Units that are manual, automated and robotized	13 (4 F, 9 M)
Respondents' roles: 9 operators (incl. 1 local union representative), 1 HR administrator, 1 technology manager, 1 head of operations, 1 HR director				
Company D	Production maintenance	Raw material	Units that are manual, automated and robotized	11 (1 F, 10 M)
Respondents' roles: 1 operator and local union representative, 2 technicians, 4 technology coordinators, 2 maintenance managers, 1 section manager, 1 HR partner				
Company E	Batch	Raw material	Units that are manual, automated and robotized	24 (4 F, 20 M)
Respondents' roles: 15 operators (incl. 2 local union representatives), 3 production managers, 2 flow managers, 2 unit managers, 1 technician, 1 HR manager				

Workers, engineers and management share historical memories of organisational and technical change, blurring the boundaries between professional identity and organisational memory within an industry (McLachlan et al., 2019). Therefore, interviews were performed across the companies with blue-collar workers (entitled 'operators' or technicians), HR-professionals, on-site union representatives and managers at various levels. All interviews were recorded and subsequently transcribed. The variation within the empirical context strengthens the transferability to other contexts (Larsson, 2009). In the *findings* section below, respondents from all five companies are represented.

Without neglecting the risk of imbalanced and complex power relations between researchers and informants (Merriam et al., 2001), when approaching respondents we explicitly presented ourselves as outsiders, not paid by, or following orders from management in the particular industry, in order to gain trust from workers who might have been less informed about the research project taking place (e.g. Lønsmann, 2016; Lønsmann & Kraft, 2017, p. 145).

For the interviews a common template was used with the themes (with corresponding keywords): *Work* (work tasks; competence; requirements for a good job; change; future; relationships within the team); *Culture* (a good employee; the climate; influence; the feeling of communality); *Technology/Digitalization/Automatization* (development then-now; new technology and new organising); *Organising* (which part of the organisation; meetings; relations to other teams); *The Boss at work* (the role of managers; information; leadership); *You at work* (your role; your responsibility; your contribution; expectations; rights; relations between boss and co-workers); and *The future in 5-10 years* (what will it look like?; how do you get there?). All respondents were informed and approved consent before the interviews. As this was a non-interventional study, no ethics approval was needed according to Swedish regulation.

The first approach towards the material involved individually reading the interview transcripts by the three authors, focusing on the multitude of linguistic clusters, tropes or figures of speech (Wetherell & Potter, 1988), that were negotiated within the interview material (Hallin et al., 2022). In this first round of analysis, the use of a discourse of promoting equality in the Industry 4.0 workplace in the empirical material became apparent. This discourse was in no way unexpected, as increasing equality is a frequently mentioned topic in Swedish Steel industry official documents and webpages (see for instance Jernkontoret, 2022).

In a second step the authors jointly read and reread the interview transcripts searching for first (enacting identities and relationships), second (responding or rejecting positioning) and third order (arguments referring to other conversations) positioning made in relation to the role of blue-collar workers. These three levels of positioning often occur in parallel in the same conversation (van Langenhoven & Harré, 1999). All coding was done manually. After discussing and comparing our separate readings, we extracted quotes into a shared excel document, trying to be as inclusive as possible, to get an overview of the (extensive) empirical

material. This overview reflected arguments supporting the discursive construction of the blue-collar worker as *concept* (Phillips & Hardy, 1997); what the blue-collar was, is and might become in Industry 4.0.

In a third step we went back from the extracted quotes of interest to the full interview transcripts to understand the respondent´s workplace role and the previous conversation between the respondent and the interviewer, paying particular attention to tensions and contradictions through the empirical material (Burr, 2003). The construction of the discourse of equality grew detailed and nuanced through inclusion of extracts regarding co-workers as interchangeable (and thus required to be equal) in everyday work and the construction of equality between different professions (such as between blue and white-collar workers).

To explore the discursive constructions taking place in the interviews further, in a fourth step we actively searched for examples of constructions of workers as not suitable. In this way we were able to explore the question of the blue-collar worker as *object* (Parker, 2015)*;* who the blue-collar worker is, and who (s)he is not.

In the *Findings* section below, extracts from the interview transcripts have been carefully selected to reflect the original transcripts, including the tensions and variations within the empirical material. As all interviews were conducted in Swedish, translation into English is a challenge when aiming to be true to both exact wording and cultural meaning (Berger & Luckmann, 1966). The delicate matter of multilingual research is highlighted by Steyaert and Janssens (2013, p. 132) who, in response to "the unreflected and unreflexive use of English as the language of publication", urge scholars to take seriously the visualization of multilingual research in translated publications. Furthermore, Temple (2008) summarizes that "narrative identities are formed using languages, so it matters which languages are used, in what contexts and for what purposes" (p 362). Thus, we humbly conclude that even though we took great care in translating the empirical material, we acknowledge that the exact details of Swedish melody and pronunciation are lost. The quotes presented in the *Findings* section are, nonetheless, carefully selected to display as much as possible of the material, including the tensions and variations within it. Quotations have been carefully translated from Swedish by the authors and thereafter proofread by a native English-speaking translator.

Findings

In this section the construction of the blue-collar worker in Industry 4.0 explores the discursive production of *concept* (Phillips & Hardy, 1997): what the blue-collar worker is and might become, and *object* (Parker, 2015): who the blue-collar worker is, and who (s)he is not.

What the blue-collar worker is – and might become – in Industry 4.0

In the empirical material, the blue-collar worker is simultaneously positioned as deskilled and standardized, but also as highly skilled and equal to the white-collar worker.

Positioning the deskilled, and standardized worker

Several accounts were found in the material where the importance of the blue-collar workers having streamlined skills was put forward. For example, Oscar, a 59 year-old HR-director, described the blue-collar worker of the future in the following way:

> *You need another breadth in competence, so someone who has little to do can go in and do other things. The planning and these flows and to really be able to hit the optimal staffing at each specific moment, that is hard. But I think that is a success factor that you need to get to. I think you don´t have any alternative really.*

Here, the blue-collar worker in the digitalized industry is constructed as they need to be equally skilled as his/her peers and able to replace other workers, being able to adapt to each other. Even as this points to broader competence requirements, former requirements of craftsmanship and specialized skills are no longer sought for among workers. Likewise, Robert, a 53-year-old operator at a robotised unit said: "Well, you need the ability to work in a team, because we are dependent on each other. Especially now when there are so few of us." This constructs dependence as essential for building social equality within the team.

Freddy, a 26-year-old operator described a "good operator" as someone "eager to learn". He continued: "The old way was more of craftmanship. The new way [...] is more like the same [way to work] for everyone". In this quote, learning to become a "good" operator is constructed as working in the same manner as everyone else. Another example of this is found in an interview with Allan, a 50-years-old operator at a robotized unit:

> *Interviewer: What do you think are the benefits of this [digitalization](...)?*
>
> *Allan: Well, it's easier to teach people to do the same. Because I mean before we did more by hand and it was more individual how you approached work. Now you see that there is something wrong in this row, I have to do this to make it right.*
>
> *Interviewer: And that is good because?*
> *Allan: It´s easier to learn. It's more like: 'this is right, this is wrong'.*

deskilled blue-collar workers as mutually equal in the sense that they are interchangeable with a presumed equal level of skills.

Positioning the blue-collar workers as highly skilled and equal to white-collar workers

We were told that due to increased digitalisation, the difference between blue-collar workers (with bodies that endure dangerous and dirty work) and white-collar workers (behind screens in clean, safe work environments), would be disappearing. This was addressed by the 59-year old HR-director Oscar (who earlier on in the interview pointed to blue-collar workers of the future as interchangeable). Preceding the quote below, Oscar described the balancing act of the company's generous salaries in parallel with cost savings during hard economic times. Replying to this, the interviewer posed a question related to information obtained in an earlier interview that the company today only employed about 20% of the number of employees as in the 20th century. Oscar's first response was to position himself as new at the plant, and hence not as personally to blame for the decreased number of operators. Thereafter, he initiated a shift in the conversation, away from the topic of the numbers of employees, to the company culture, which he depicted as displaying eroding differences between white and blue-collar workers:

> *The line between what a white-collar worker is and what a blue-collar worker is has been blurred. […] We used to say that a blue-collar worker was someone that worked with his hands, at least 50% of the time, while a white-collar worker sat in front of a screen and typed, but [addressing the researcher] you've seen this when you've walked around, there are very few people that work with their hands now.*

This extract displays a managerial response to the apparently provocative conversation related to the threat towards blue-collar workers manual labour when robotizing industry. In his response, Oscar positions blue-collar workers and white-collar workers using the discourse of enhancing equality to describe the relationship between different professions in an organisational hierarchy that is presumed to soon be part of the past. In this quote, the transition towards Industry 4.0 is thus constructed as holding a promise of the traditional separation between employees based on types of labour disappearing.

In line with Oscar's construction of the organisationally equal worker, Jonas, a 32-year-old operator, responded to the question of his expectations on blue-collar work in the coming ten years, saying: "my boss had talked to someone that said that it [blue-collar work] could be more like the work of engineers". Likewise, Ralf, a 42-year-old technology coordinator described the blue-collar worker in the digitalized plant as in need of "more analytical and engineering knowledge". Gert, a 54-year-old operator described how a good operator must "be independent and you need to know math (…) you need to be able to read between the lines (…) able to collaborate with management (…) [and] have well-developed social skills".

These are examples of how operators produce the concept of the blue-collar worker in Industry 4.0 as socially and intellectually highly skilled in a work role characterized by equality between blue-collar workers and white-collar workers (such as engineers and management).

Who the blue-collar worker is – and who is *not* a blue-collar worker – in Industry 4.0

In the empirical material, the *object* (Parker, 2015) i.e. constructions of who counts as a blue-collar worker – and who (he) is not – is analyzed to explore the discursive negotiations of boundaries for being an equal blue-collar worker in Industry 4.0. These boundaries are in the empirical material drawn in relation to older workers, immigrant workers, mentally challenged workers, and temporary workers.

Exclusion of the deviant worker

Using the two constructions of the de-skilled and the highly skilled blue-collar worker, one of the interviewers proposed these as a matter of either-or, when talking to Jenny, a 40-year-old HR-business partner at a robotized plant:

> *Interviewer: If you look at blue-collar workers, you are interchangeable because you no longer need the craftsman's skills. So, what is the difference between the really, really skilled and competent operator [...] and the one that is deskilled and interchangeable?*
>
> *Jenny: I would say that it's of course about competence, but it´s about your personal ability as well; the ability to structure, ability to communicate, ability to engage with others [...] so it's really all about your personality [...][The company] has changed so much over the past years that I have been here. [...] We used to have some people we called '1%-people'. [...] They emptied waste baskets and stuff. There is no place for them here anymore.*

First, in this response, the responsibility for being included as object in relation to the concept of blue-collar worker was constructed as depending on "your personality"; the ability to be positioned as a blue-collar worker depended on how the worker displayed and acted his/her social skills. Second, the skilled mind was constructed as a barrier to be included as a blue collar worker in Industry 4.0; to the extent that those without the required level of mental ability were constructed as un-abled in the workforce of equal (ly deskilled/skilled) workers.

Another example related to ableism was 60-year-old operator and local union representative Keith who said: "Today the teams have harsher requirements for who gets employed. So, they can be mean to each other too, some have less ability and others more. That makes you mean to each other." Here, the responsibility for equality in the collective of blue-collar workers was not placed on management, but on the blue-collar worker "team", and bullying of those with "'less ability" was constructed as a normalised consequence in every-day work.

The two quotes above are examples of how the responsibility of being standardized *and* highly skilled was discursively placed on the individual, as well as on the collective of blue-collar workers, not on management or on technological or societal change.

A second boundary was related to ageism, where a generational divide was constructed in the interviews in relation to the (un)able worker. For instance, Curt, a 50 year-old technology coordinator said: "It´s frightening, this shift in generations. We have a fairly high number of middle-aged workers here, and those that have worked here the longest, they weren't on the train from the beginning [...] they can´t get a grip". The inability of older workers was even constructed as a cause of illness and social exclusion, as operator Keith explained: "The older ones, those that can´t keep up. [...] They sort of become rehab cases. What are they to do? [...The older workers] can work in a spare room, become an oddjobber, but we don't have many of them at all." This was an example of how old workers were positioned as both nonskilled *and* non-standardized, to the extent of affecting their personal health, becoming "rehab cases".

A third boundary was constructed through accounts of racism. For instance, Flavio, an operator with a non-Swedish background, described an incident where he became engaged in a fistfight with another operator due to insults based on his ethnic background. In Flavio's account this incident was overlooked by management as "normal" and part of the "industry culture" today, positioning himself as deviant towards the organsational norm. Other employees described how the rise of the (far) right-wing political party known as the Swedish National Democrats (SND) had contributed to xenophobia among colleagues. For instance, union leader Keith explained a current conflict: when the union tried to employ immigrant workers, SND members opposed and left the union. Keith decaled that this was weakening the collective power of blue-collar workers and left his hands tied, as the conflict around immigrant workers had become a source of tension in the workplace.

A fourth boundary, related to the tension described above, was related to temporary workers. These workers were described with derogatory words like "just temps". 38-year-old operator Manuel, who today works at a robotized unit described his own skills development in relation to temporary workers:

> *There are other machines that are more manual, but I only stayed there two years, because no one wanted to run those machines. Only temps ended up there. Because you must develop yourself, it's a step forward to run the more advanced machines with robots and programming.*

This account separates the "us" and "you" in "no one", from "they" in "the temps". Manuel is aligning his self-positioning with the highly skilled and equal worker in relation to white-collar workers (engineers and programmers), while positioning temporary workers as deskilled and stuck at manual machines. On the contrary, 56-year-old operator and local union representative Lennart said "It's really important that they [the temps] don´t learn everything,

because then they will be really hard to get rid of, I dare say. They might learn two or three job tasks, but not, like, ten." Here, temporary workers were constructed as needed to stay non-standardized and non-interchangeable (non-equal) through not learning several tasks, thus positioning the temporary worker as deviant from both the position of the skilled and equal worker, and likewise from the deskilled and standardised worker.

The constructions of "un-abling" through ableism, ageism, racism, and forms of employment would overlap between themselves in the interview material. One such example was made by the operator and union representative Lennart who later in the interview continued:

> *Lennart: They [the immigrants] are among the temporary employees. Not because [the company] are searching for them, that's the way it is.*
>
> *Interviewer: They [the temp agencies] engage them?*
> *Lennart: Yes, for equality, or diversity. So that way we get it for free.*

The presence of the immigrant blue-collar worker was here directly related to equality, but as seen in previous quotes simultaneously positioning immigrants, as temporary workers, as unable and deviant in relation to both the skilled and equal to white-collar workers, and the deskilled and standardized workers.

Consequences for inclusion among blue-collar workers in Industry 4.0

The analysis of the extensive empirical material displays how the repertoires mobilized of seems to promote equality while actually reinforcing tensions between social groups at the workplace. As the findings indicate, the blue-collar worker is positioned as *performing equal* (low skilled, interchangeable) *tasks;* as *equal to other professions* (white collar; engineers and managerial positions); and as being *equally young, socially skilled and native language speaking*. However, this use of discourse displays a dilemmatic discursive construction that appears to be non-excluding, while, in fact, having contradictory consequences (Dobusch, 2021; Nkomo, 2013). In fact, the discourse of equality is constructed based on abilities and experiences that are only shared by a fragment of this collective; the young, well-versed, socially skilled, and fast learners, who have permanent contracts.

Even though older, immigrant, and socially, analytically, linguistically less skilled, or temporary, workers are present as humans in the industrial plant during the transition towards Industry 4.0, they fail to be defined within the subject positioning of the blue-collar worker as object in this context. This finding not only highlights the embedded conflicts in the social shifts that come with the transformation towards Industry 4.0 (see Abrahamsson & Johansson, 2021); it also showcases how the use of discourse is important, as mistreatment of subordinate groups tends to become muted in organisational narratives (Meares et al., 2004). Only by

exploring the fluctuating and relational aspects of the deviant-from-the norm workers we are able to discuss and act on unintended social exclusion (Dobusch, 2021, p. 380).

The official claims of Industry 4.0 points to a shortage of skills in Swedish industry and argues for skills validation for immigrants as well as continuing education for older workers (Ministry of Enterprise and Innovation, 2016). This could potentially provide underrepresented groups, as well as older blue-collar workers, the possibility to enter and remain employed. However, previous research on Swedish workplaces displays structural mistreatment of immigrants (Rosander & Blomberg, 2022). As seen in the analysis, the discursive negotiations of the concept and object of the blue-collar worker correspond to socially prevailing discriminating mechanisms of, for instance, ageism, racism, and ableism on an ideational level of societal norms. It could even be argued that the exclusion of immigrants (of whom there was a large-scale influx during the 21st century) in the transition towards Industry 4.0 reproduces the extreme right-wing political messages that are progressing in Sweden, as in many European countries, in the 21st century.

The analysis displays that the individual's personality is constructed as crucial in fitting with the concept of the Industry 4.0 blue-collar worker. This corresponds to previous studies in other digitalized work settings where the individual's personality (her way of being, feeling and thus behaving) becomes discursively constructed as a prerequisite for being an appropriate worker in digitalized workplaces (Lindell et al., 2022). Brynjolfsson and McAfee (2014) described the link between digital technology and social polarization as a matter of the individual's own responsibility for (and possible neglect of) her employability. Therefore, adopting an active position for the blue-collar worker is only conditionally possible when he/she as an individual accepts and adapts to the discursive constructions of subject positioning used to explain the role of humans in industrial change. By adopting the discourse of equality, individuals become positioned as morally responsible for their own competence development and inclusion in the collective of equals, but morally non-responsible for the social exclusion that inevitably seems to be the consequence. As stated by Phillips and Hardy (1997, p. 166): 'Discourses do not reveal some hidden, pre-constituted reality, but rather provide concepts, objects and subject positions that actors use to fashion a social world'. This study confirms such an observation, nuancing the deskilling and upskilling and polarization of skills debates (Blauner, 1964; Braverman, 1974; Budhwar et al., 2022; Haakestad & Friberg, 2020; Martinaitis et al., 2021), and previous claims of preferred skills for employability in Industry 4.0 (Jaiswal et al., 2022; Schwab & Zahidi, 2020). The study highlights that if only a few blue-collar jobs are left as Industry 4.0 progresses, the criteria for being positioned as a blue-collar worker is discursively narrowed down to only fit those that have the right attitude, experience, background, and mind that match this development.

Practical implications

The existence of inequalities is often silenced in relation to technological development (Spencer, 2017), which might make processes of exclusion difficult to detect and track by managers and HR-professionals in practice. The discourse analysis approach adopted here allows us to make visible how inequalities between groups persist and evolve, despite eager attempts among managers and HR-professionals to follow the 'inclusion turn' (Adamson et al., 2021) in developing industry. Even though the exclusion of, for instance, immigrant workers is known both in practice and in previous research (Baxter & Wallace, 2009; Rosander & Blomberg, 2022), this article points to the need to take the discourse of equality, and the exclusion that seems to evolve in the transition not only towards Industry 4.0, but towards Industry 5.0, seriously, also by HR-professionals and managers in order for a more heterogenous *and* equal workplace, where unknown skills are taken advantage of, to emerge. In the emergence of Industry 5.0 human-centric, up- and re-skilling among workers is denoted as important for a resilient European industry (European Commission, 2023).

Theoretical implications

Theoretically, this article provides an explanation to the delicate relationship between construction of concept (Phillips & Hard, 1997) and object (Parker, 2015) into the framework of critical discursive psychology. The originality of our study lies in applying an understanding of the contradictory construction of the blue-collar worker in Industry 4.0 (Herzog et al., 2017; Xu et al., 2018; Autor et al., 2003). Focusing on the discursive constructions of the *concept* of the blue-collar worker (Phillips & Hardy, 1997); i.e. on what the blue-collar *was*, *is* and *might become* in Industry 4.0, and the *object* of the blue-collar worker (Parker, 2015)*;* i.e. *who* the blue-collar worker is, and who (s)he is not. This detailed investigation of language use add to the insights of how technological change not only alters power relations (Ibrahim, 2012), but serves to reproduce, and recast, existing social structures (Schou & Hjelholt, 2019). The focus on discursive positioning makes it possible to explore the dynamic aspects of how employees, managers and HR use discourses when describing their work, allowing for close investigations of negotiations of societal and organisational change (Whittle et al., 2008). The empirical material in this study is neither merely reproducing managerial discourse, nor is it merely reactive or resistant to technological change. Instead, it displays discursive negotiations in relation to the societal and technological change that is taking place (Golden & Geisler, 2007; Whittle et al., 2008).

Limitations and future directions

The limitations of our study point to the need for further studies. Demands of continuous learning may increase due to ongoing changes (Jaiswal et al., 2022). The discursive construction taking place implies a resolution of the traditionally strong blue-collar worker collective; when everyone is equal, as borders are floating and disappearing, a collective is no longer possible, or even needed. As individualization is taking place, and as the individual

worker's personality and employability is placed at the center of the blue-collar worker concept. This development is likely to enhance the vulnerability of the worker. Future studies on the development of Industry 4.0 should be added to previous research on the use of discourses among unions and policy makers, to explore the consequences of individualization as the power of the union collective might dissolve in the wake of Industry 4.0.

Conclusion

Critical thinkers of digitalisation claim that digital development is a driving agent of economic and social inequalities in society (eg Peters, 2013). As the need for steel industry workers is declining in contemporary industry, discourses of equality might be used to explain and legitimize industrial transformation under the notion that the roboticized industry is safer, cleaner and in many ways better for human bodies and further require a more skilled individual. Digital and technological development is *perceived* as inevitable and therefore without political intentions. Therefore, adopting an active position for the blue-collar worker is only conditionally possible when he/she as an individual accepts and adapts to industrial change. As an individual he/she needs to develop and keep up with the speed of digital development, conditioned to the right criterions of inclusion. By adopting the linguistic constructions explored in this study, individuals become positioned as morally responsible for their own competence development and inclusion, but morally unresponsible for the social exclusion that inevitably seems to be a consequence of the construction of digitalization. Thus, the article adds to the insights of the symbiotic relationship between technological change and discourses as well as to how technological change serves to reproduce existing social structures (Schou & Hjelholt, 2019) in Industry 4.0.

The theoretical framework used in this article points to the capability of humans to exercise choice in language use (Wetherell, 1988) as a way to master ongoing social changes. Even if dominant, repetitive use of discourse is powerful, since it sets the horizon for what can be said and which positions can be constructed in a certain setting, repeated resistance holds the power to modify and change social consequences (Wetherell & Potter, 1993). This article thus points to the need for managers, labour unions, and policymakers, to take seriously the construction of inclusion and exclusion expressed in this study; the homogenization that is taking place in the Industry 4.0 workforce deserves further attention. Through this conclusion, this study contributes to understandings of changes of employees´ working conditions, which puts "research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry" for the advancement of a truly human-centric Industry 5.0 (European Commission, 2023).

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1 Data is available upon reasonable request from the authors.

Jobs and Skills of Production Workers at Manufacturing SMEs

An empirical exploration of smart technology adoption

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Abstract

The skillsets of production workers are crucial for the effective adoption of smart technologies which are largely shaped by work design. However, current literature lacks comprehensive insights into the skills and work designs of production workers, hindering the adoption of Industry 5.0. Grounded in work design and skills literature this study explores the required skills of employees and perceived work design characteristics for adoption of AI, AR/VR, and Robotics in Dutch Manufacturing SMEs. This qualitative study involved semi-structured interviews with experts, managers and production workers. Results reveal a need to reassess traditional job profiles, as two distinct production workers roles emerge from AI, AR/VR and robotics adoption. Machine operators face potential deskilling through low feedback from the job, low task variety and low job complexity. Foreman-production workers require additional skills due to job enlargement and enrichment. However, they seem to be put in this job role due to the lack of various professional and transversal skills to fully utilize smart technologies, and to accommodate a viable return on the technology investment. This highlights the importance of balancing job resources and requirements in work design, training programs for I5.0 skill development, and understanding contextual design elements of manufacturing systems contributing to viable I5.0 adoption in SMEs. Finally, sustainability, self-awareness, and self-reflection skills are not considered by professionals, displaying unawareness of its importance for I5.0 implementation practices.

Keywords: Industry 5.0, SMEs, production workers, smart technology, workplace innovation, work design, skills

Introduction

In the last decade, a lot of attention has been paid to Industry 4.0 (I4.0) which was predominantly focused on digitalization and the implementation of smart technologies (e.g., Robots, AR/VR, AI) to create more efficient and flexible factories (Ammirato et al., 2023; Meindl et al., 2021; Müller, 2021). Recently, a new concept has emerged: Industry 5.0 (I5.0). This concept represents the next wave in manufacturing, promoting the integration of advanced digital technologies while prioritizing employee well-being and job quality (Breque et al., 2021; Ghobakhloo et al., 2023). I5.0 advocates that technology adoption should ensure sustainability, human-centricity, and resilience toward industry, the economy, and society including its members (Breque et al., 2021; Xu et al., 2021). In this feat, the evolution from I4.0 to I5.0 does not seem to change what smart technologies are used. Instead, it predominantly changes how smart technologies are adopted, and the level of digitalization required in SMEs to accommodate sustainability, resilience, and human centricity requirements of smart technologies (Akundi et al., 2022; Alojaiman, 2023; Ammirato et al., 2023; Barata & Kayser, 2023; Leng et al., 2022). Moreover, I5.0 shifts from I4.0's technological determinism to a more inclusive approach based on technology appropriation. Technology appropriation emphasizes adoption, modification and customization of technology and manufacturing processes to meet user requirements and needs (Carroll et. al., 2003; Dix, 2007). Therefore, true adoption of technology in I5.0 automatically implies appropriation of these technologies by definition (Oeij et al., 2024).

Meanwhile, AI, AR/VR, and Robotics are smart technologies that have become rapidly available to manufacturing organizations (Maddikunta et al., 2022, Noghabaei et al., 2020, Zhang et al., 2021). These technologies present opportunities for SMEs in areas such as production planning and control, energy management, quality management, and maintenance management (Zheng et al., 2021). The integration of smart technologies into everyday business allows SMEs to shift towards more efficient, agile, and competitive production processes (Chavez et al., 2023). In addition, example cases emerge that show benefits of AI, AR/VR and robotics in terms of more resilient production systems (Bortolini et al., 2018; Dohale et al., 2024), enhanced understanding of sustainability in production (e.g., Daut et al., 2017; Liu et al., 2019), and enhanced well-being and performance through human-centered use of smart technologies (e.g., Bal et al., 2021; Kim et al., 2019; Mark et al., 2021; Vukicevic et al., 2019). Hence SMEs, who account for 4 million jobs in the Dutch economy, are increasingly implementing these technologies to reap the benefits (European Commission, 2023a; Frank et al., 2019).

The adoption of AI, AR/VR, and robotics also brings about significant challenges, especially for Small and Medium-sized enterprises (SMEs) (Maddikunta et al., 2022). These challenges encompass (1) increased job complexity (Hecklau et al., 2016), (2) the need to learn new skills (Müller, 2021), (3) new job profiles being required (Wilson et al., 2017), and (4) a potential decrease in job quality (Spencer, 2018). Production workers are at the core of I5.0 and require specific skills to fully leverage smart technologies (Nair et al., 2024). However, these skills seem scarce across Europe (Büth et al., 2017; European Commission, 2023b; George & George,

2023). In response to this skills scarcity, SMEs are focusing on developing their existing workforce (European Commission, 2023b). In this vein, workplace innovation (WPI) gained attention, as it explores practices for effective integration of smart technologies while also ensuring the well-being and development of their production workers (Dhondt et al., 2015; Kopp et al., 2019; Oeij et al., 2017; Oeij, Preenen, & Dhondt, 2021). More specifically, WPI refers to practices that structurally (division of labour) and/or culturally (empowerment) enable employees to participate in organizational renewal and improvement to enhance the quality of working life and organizational outcomes (Oeij et al., 2017). This means that manufacturing processes can be adapted to the (development) needs and current capabilities of production workers (Breque et al., 2021) and work designs can be shaped such that they facilitate the exhibition and development of required skills (Eurofound & Cedefop, 2020; Humphrey et al., 2007; Parker & Knight, 2024).

Despite these initiatives, successful adoption of I5.0 is lacking at SMEs (Maisiri et al., 2019; Mavrikios et al., 2018). This seems to be due to various challenges such as data security, required investments, and human resource requirements in terms of time and effort invested and skills required to work with smart technologies (Adel, 2022; Leng et al., 2022; Lewandowska et al., 2023). In this paper, the focus is on the skills challenge. The novelty of I5.0 concept has resulted in limited understanding of skills that are required to work with smart technologies in an I5.0 context (European Commission, 2023c; Oeij et al., 2024).

Additionally, whilst technology affects jobs (Parker et al., 2017) research on how these changed jobs look like is lacking (Pejic-Bacht et al., 2019). In particular for production workers, as they are traditionally underrepresented in research on jobs and learning (Koen et al., 2013; Preenen et al., 2015). Moreover, although research on the jobs and skills of production workers in I4.0 can provide a foundation, skills and jobs are context-specific and vary from organization to organization, depending on different factors, including the maturity of the implemented technologies (Dalenogare et al., 2018; Parker et al., 2017). For instance, the extent to which a decision support technology can support increasingly complex decisions is reliant on the technological maturity and can impact the job complexity of a production worker. Further empirical data on skills and work design is necessary (European Commission, 2023c; Oeij et al., 2023; Rus et al., 2019). Therefore, to bridge the skills gap for SMEs, there is a need to specify the required skills and current work design of production workers into the context of specific smart technologies in a manufacturing system.

Overall, a comprehensive understanding of the current skills landscape could facilitate a smooth transition to I5.0. To achieve this, a review of existing literature has been conducted to identify the spectrum of skills in I4.0 that are relevant to I5.0. The skills identified are often broad categories (i.e., technical skills, personal skills) that necessitate interpretation within specific contexts (Dalenogare et al., 2018). Production workers, defined as those directly involved in the operational processes of manufacturing and handling technology daily, are experiencing and adapting to I5.0 in their daily work. Understanding their perspective is crucial, as they are not just users of technology but are also significantly impacted by its

integration in their work environment. To further enhance comprehension of this perspective it is important to understand the context within which a smart technology is adopted. In this sense, it is critical to model the manufacturing processes (Havey, 2005). In this study, it is explored how production workers can be fostered to adopt three smart technologies: (1) AI, (2), AR/VR, and (3) Robotics. Striving for achieving the I5.0 vision, the identification of specific skills, and how jobs look like dependent on the manufacturing processes that they work on has become crucial. These two challenges result in the following two main research questions:
Which skills do production workers need to work with AI, AR/VR and Robotics within manufacturing SMEs that strive for I5.0?
How do production workers experience work design characteristics when working with AI, AR/VR and Robotics within manufacturing SMEs that strive for I5.0?

Theoretical foundations for smart technology adoption

This study is grounded in skills (e.g., van Laar et al., 2020) and work design theory (Humphrey et al., 2007) in the context of I5.0 manufacturing. Given the limited literature specific to I5.0, this study draws primarily from I4.0 research, adapting these insights to the I5.0 context. The European Commission highlighted human-centricity, sustainability, and resilience as the core principles of the I5.0 concept (Breque et al., 2021). Human-centric technology adoption means that technology is used to adapt production processes to the needs of the worker whilst ensuring smart technologies do not impinge on workers' fundamental rights to privacy, autonomy, and human dignity (Breque et al., 2021). Sustainability requires technology adoption to enhance circular processes, reduce waste, and decrease environmental impact of manufacturing systems such that energy consumption and greenhouse emissions are reduced. Finally, smart technology adoption should contribute to the resilience of organisations through increased robustness in industrial production. Manufacturing systems should be armed better against disruptions and provide better security for critical industrial infrastructures in times of crisis (Breque et al., 2021)

This chapter outlines the key concepts of work design and skills that are crucial for innovating manufacturing workplaces with smart technologies. To select these concepts we specifically looked at scientific and grey literature that fulfil the predetermined selection criteria: (1) production workers, (2) level of abstraction, and (3) duplicates.

1. Skills and work design characteristics that are specifically relevant to production workers in manufacturing SMEs. This means identifying skills and work design characteristics that are important for people who work directly in manufacturing processes.
2. Skills and work design characteristics that are described in a more concrete and practical way. In particular, skills and work design characteristics that are more directly related to the actual tasks and activities carried out by production workers.
3. If there are skills or work design characteristics that appear multiple times in the papers or overlap with each other, duplicates are removed. This means if a skill is mentioned more than once, it is included once in the skills synthesis.

Work design and smart technology adoption

Work Design can be defined as the process of structuring work and defining the roles and responsibilities within an organization. It involves determining the division of work tasks assigned to individuals, specifying not only what workers do but also how and why these tasks are performed. Designing jobs encompasses the analysis of task requirements, the methods used to complete these tasks, and the relationships involved in the job (Morgeson & Humphrey, 2006). This analysis is done on the level of work design characteristics which can be defined as "the attributes of the task, job, and social and organizational environment" (Humphrey et al., 2007, P. 1333).

In general, Humphrey et al. (2007) distinguish three categories of work design that contain several work design characteristics. First, motivational characteristics refer to individual job components such as the skill, task and knowledge demands of work. Second, social characteristics pertain to interactional components of work such as interdependence, feedback, and social support from others. Third, work context relates to contextual elements of a job which can be physical demands, ergonomics of the workplace, and noise in the surrounding workplace (Humphrey et al., 2007).

The introduction of smart technology can have various effects on work design depending on the context. Industry 4.0 is associated with more job variety and an increase in the cognitive predominance of the tasks executed. However, Industry 4.0 can also lead to deskilling and lower autonomy due to changes in job content (Shaba et al., 2019). While Industry 4.0 has been associated with affecting job enlargement and job enrichment by pushing workers at the shopfloor level to constantly monitor the production processes (Lagorio et al., 2021), Waschull et al. (2022) highlight a trend in job simplification for production workers, mainly from a technological push perspective. These contrasting findings highlight the context-specific nature of technology effects on the workforce. Shaba et al. (2019) found that these effects are dependent on a control-oriented organizational design or a commitment-oriented organizational design.

In the same vein, Parker et al. (2017) claim that the implementation of smart technologies affects work design both positively and negatively. In the context of Industry 4.0, the level of implementation has different effects on job complexity, skill variety, and job autonomy (Waschull et al., 2019). Hirsch-Kreinsen (2016) distinguishes between polarized organizations, where there are simple tasks and a need for highly skilled professionals for the execution of complex tasks. On the other hand, there are large groups of organizations where simple activities are completely automated. Lastly, as a result of new technologies, several job profiles are modified or newly created: industrial engineers (Cimini et al., 2020), data scientists (Pejic-Bach, 2020), AI engineers, cloud services managers, data security administrators (Pontes et al., 2021), cybersecurity managers, cobot programmers, cobot users, additive manufacturing experts, human-machine interface programmers & users (Leitao et al., 2020), augmented reality experts (Ras et al., 2017), robot coordinators, maintenance of smart

systems, software engineers for CPS, process analysts, bionics experts, and programmers (Jerman et al., 2019).

In conclusion, extant literature focused mainly on the impact of I4.0 technologies on work design of production workers. Automation, as opposed to augmentation, seems to be the preferred use by manufacturing SMEs and other sectors such as logistics (Hosseini et al., 2023). In addition, human-centricity has been limitedly applied to technology adoption (Kwiotkowska, 2022) which is integral to both the socio-technical approach (Trist, 1980) and the I5.0 concept (Beque et al., 2021). Despite the growing interest in the he social system, it represents a very marginal amount of the literature (Kadir & Broberg, 2021). The lack of attention to the social component aspect of this system is partially related to the failure to recognize the complexity of technology adoption (Schumacher et al., 2016). Table 1 provides an overview of the job characteristics that are considered within the three identified work design categories. These allow for further investigation of the effect of smart technology adoption for the work designs of production workers in an I5.0 context.

Table 1. Work design categories, characteristics, and their definitions adopted from Humphrey et al. (2007)

Category	Job characteristic	Definition
Motivational characteristics	Autonomy: • Work scheduling autonomy • Work methods autonomy • Decision making autonomy	The freedom to control the schedule and timing of work. The freedom to control which methods and procedures are utilized. The freedom to make decisions at work.
	Skill variety	The knowledge and skills necessary to perform a job.
	Task variety	The extent to which an individual performs different tasks at his/her job.
	Task significance	The extent to which a job impact's others' lives.
	Task identity	The extent to which an individual can complete a whole piece of work.
	Feedback from the job	The extent to which a job imparts information about an individual's performance.
	Information processing	The extent to which the job necessitates an incumbent to focus on and manage information.
	Job complexity	The extent to which a job is multifaceted and difficult to perform.
	Specialization	The extent to which the job involves the performance of tasks requiring specific knowledge and skill.
	Problem solving	The extent to which a job requires the production of unique solutions or ideas.
Social characteristics	Interdependence	The extent to which a job is contingent on others' work.
	Feedback from others	The extent to which other organisational members provide performance information.
	Social support	The extent to which a job provides opportunities for getting assistance and advice from either supervisors and co-workers.

	Interaction outside the organization	The extent to which a job requires and incumbent to communicate with people external to the organisation.
Work context characteristics	Physical demands	The amount of physical activity or effort necessary for a job.
	Work conditions	Aspect of the work environment such as health hazards, temperature, and noise.
	Ergonomics	The extent to which the work permits appropriate posture and movement.

Skills for smart technology adoption

The current study is based on the definition of skills given by Peterson and Van Fleet (2004) who define skills as "the ability either to perform some specific behavioural task or the ability to perform some specific cognitive process that is functionally related to some particular task" (P. 1298). Tasks are units of activity that produce output (Autor, 2013). While literature often distinguishes between competencies and skills, this study treats them as synonyms, reflecting their interchangeable use in I4.0 and I5.0 research.

One stream of research sees the change of work as so extensive that authors label new production workers as "Operator 4.0" (Bousdekis et al., 2020; Romero et al., 2016, 2020). Such Operator 4.0, or "smart worker," is skilled enough to perform not only "cooperative work" with robots but also work aided by machines. Hence, the relevance of acquiring a set of skills to cope with cyber-physical systems. Studies on the Operator 4.0 (e.g., Hecklau et al., 2016) have identified personal skills, social and interpersonal skills, technical skills, and methodological skills as important for the new workforce. Moreover, the significance of interpersonal skills lies in the fact that it is a crucial domain where humans can outperform machines, and they will be required in all the new job profiles (Alhoul & Kiss, 2022). The prominence of technical skills is also emphasized by Pinzone et al. (2017), who focused on the technological skills needed to operate in I4.0, particularly in areas where the most attention is needed (i.e., operations management, supply chain, product-service innovation management, data science management, IT-OT integration management).

The World Economic Forum has investigated the skills required on more than one occasion (2017, 2020, 2023) and identified some of the most important skills: analytical thinking, active learning, complex problem solving, critical thinking and analysis, creativity, leadership and social influence, technology use, technology design, resilience, stress tolerance, flexibility, and reasoning. Similarly, Islam (2022) found that business skills, such as critical thinking, cognitive flexibility, complex problem-solving, adaptive thinking abilities, qualitative skills, and communication skills, as well as technical skills, including programming, quantitative skills, data interpretation, data visualization, and virtual collaboration, are also essential for employability in Industry 4.0. According to Karacay (2018), all employees in an Industry 4.0-based system must have information and communications technology (ICT) skills and soft skills, such as collaboration, communication, and autonomy. According to Mudzar et al. (2022), three skills are crucial: high-level technical skills (e.g., deep understanding of

technologies), higher-order cognitive skills (e.g., problem-solving and critical thinking), and human and interpersonal skills (e.g., interpersonal and leadership).

The aforementioned paragraphs highlight either technical skills, non-technical skills (soft skills), or both. Janis and Alias (2018) have made a clear distinction between these two types of skills. A similar distinction has been made by Rampelt et al. (2019), who identify specific skills and general skills. The former is concerned with content-specific skills required to carry out a job, and the latter is concerned with a broader spectrum (e.g., literacy). Similarly, Maisiri (2021) distinguishes between technical skills (technological, programming, digital skills) and soft skills (thinking, digital, social). Praj et al. (2022) have investigated the crucial competencies for Industry 4.0, making a distinction between must-have skills (e.g., ability to interact with modern equipment), should-have skills (e.g., knowledge management), and could-have skills (e.g., programming skills). However, despite this overview, no distinction has been made or attention paid to the different roles and technologies independently. This specification to roles and technologies was also missing in the overview of Prifti et al. (2017) who identified eight critical areas and the associated skills required to effectively perform in I4.0 companies.

Finally, after a literature review, Kohlgrüber et al. (2021) propose a new classification of the skills needed for the future of work. This classification consists of five primary areas: digital skills, personal skills, social skills, methodological skills, and professional skills.
In conclusion, early literature focused mainly on the technological skills of the workforce to operate with Industry 4.0 technologies. More recent publications are focusing to a greater extent on non-technical skills. These align well with tasks of workers in the human-centric, sustainability, and resiliency views of I5.0 (Oeij et al., 2024). However, the dimensions identified as being of interest tend to be broad categories that require interpretation in specific contexts. A summary of the main skills associated with smart technologies can be found in appendix 1.

To achieve a comprehensive list of skills, the starting point is the skillset identified by Kohlgrüber et al. (2021) due to the notable effort in mapping many studies comprehensively about skills and the seeming relevancy of the study in an I5.0 context. Further understanding of skills in the I5.0 context is derived from a study done by Oeij et al. (2024) who proposed a categorization for skills according to general, human-centric, resilient, or sustainable abilities of production workers. Human-centricity in I5.0 requires production workers to work with assistive technologies, communicate in participation processes, participate in (re)design / change processes, and make use of learning opportunities and being empowered (Oej et al., 2024). This aligns with digital- and technical skills that enable production workers to engage in human-machine interaction and tailor technology to their needs for task support and interaction needs. Examples of these skills could be human machine interface skills and process management. Resilience requires production workers to engage in lifelong learning, develop the ability to adapt and be creative, reflect on and respond to the resilience of work processes, analyse and solve resilience-related problems at system-level, and be self-organising and manage yourself (Oeij et al., 2024). This production work in I5.0 can be

implicitly attributed to some personal skills such as flexibility and cognitive flexibility, learning skills and self-awareness. Finally, sustainability requires production workers to understand circularity, conduct lifecycle and environmental impact assessments, evaluate contributions of smart technologies to sustainability goals, and elaborates resources efficiency (Oeij et al., 2024). These tasks could be attributed to both green and personal skills. In sum, although most literature has focused on an I4.0 context, the skills derived from main skills literature seem to cover elements of the production work in I5.0 described by Oeij et al. (2024).

Overall, a synthesis of the skills was created that clearly distinguishes between Transversal skills and Professional skills. Transversal skills are not limited to a specific job or domain but are generally required in the digital transformation. This category includes digital skills, personal skills, social skills, methodological skills, and green skills. Professional skills are specific and specialized skills relevant to a particular field of work, discipline, or occupation. They contrast with general skills as they pertain to the application of specific knowledge. Professional skills refer to the technical skills specific to the context under investigation and are needed to conduct the tasks associated with the job. Table 2 allows for analysis of the skills that production workers require to work with smart technologies in an I5.0 context.

Table 2. Skills synthesis of skills for I5.0

Skill Category	Skill subcategory	Skills	References
Transversal (generally required)	Personal	Self-reflection, self-awareness; Learning skills / lifelong learning; Integrity / ethics; Responsibility, attitude (individual values); Flexibility & Cognitive flexibility; Emotional Intelligence.	(Behrend et al., 2022; Büth et al., 2017; Corporaal et al., 2021; Hecklau et al., 2016; Islam, 2022; Janis & Alias, 2018; Prifti et al., 2017; Probst et al., 2019; van Laar et al., 2020)
	Social	Teamwork; Collaboration; Intercultural skills; Mediating, Negotiating and persuasion.	(Behrend et al., 2022; Büth et al., 2017; Hecklau et al., 2016; Janis & Alias, 2018; Maisiri et al., 2019; Mudzar et al., 2022; Prifti et al., 2017)
	Methodological	Problem-solving skills; Creative thinking; Analytical thinking; Critical thinking; Decision making.	(Behrend et al., 2022; Büth et al., 2017; Hecklau et al., 2016; Islam, 2022; Mudzar et al., 2022; Prifti et al., 2017)
	Green / Sustainability	Environmental awareness; Energy efficiency; Water reduction; Waste reduction and management; Resource re use/ recycling.	(Hecklau et al., 2016; Schröder et al., 2024)

	Digital	Basic digital skills (use of PC, browse Internet, finding information, storing data); Moderate digital skills (Word-processing, working on documents, working on spreadsheets); Advanced digital skills (Programming).	(Behrend et al., 2022; Bouwmans et al., 2024; Kohlgrüber, 2021; Maisiri, 2021; Schröder et al., 2024)
Professional (subject related)	Technical (subject related)	Specialized and expert knowledge; Process management; Human machine interface; Trouble shooting and maintenance; Analysis, modelling and simulation of production based on big data from sensors and devices; Use of digital devices (e.g. tablets, smartphones, smartwatches) for production monitoring and control; Programming and use of relevant technology (e.g. Collaborative robots, VR); Use of additive manufacturing technologies; Remote system monitoring and supervision of maintenance interventions; Use of virtual and augmented reality for instruction and support of maintenance interventions.	(Acatech, 2016; Büth et al., 2017; Kohlgrüber et al., 2021; Mudzar et al., 2022; Pinzone et al., 2017; Prifti et al., 2017)

Methodology

To answer the research questions, this study adopted a qualitative research approach, because firstly, interviews allow for in-depth exploration of interactions between production workers and advanced technologies which are needed given the novelty and rapid evolution of the I5.0 concept. Secondly, a qualitative method allows capture of the variability in job roles and manufacturing processes that typifies SMEs operating in I5.0.

Sample and research design

The research involved 19 semi-structured interviews with two respondent groups: work design or technological experts (e.g., senior researchers, professors, and a technology supplier, N = 7X), and professionals from 6 SMEs (managers as well as production workers, N

= 12). The four semi-structured interviews with work design experts focused on all three technology contexts. Additionally, one interview with a technological expert focused on the AI context, one interview was conducted on the AR/VR context, and one interview addressed the AI and robotics context. The combinations of insights from the expert interviews with the 6 SME cases has allowed for a multi-perspective view.

The inclusion criteria for experts were threefold: (1) distinguished academics in related fields of work design, sociology of work, AI, AR/VR or Robotics, (2) actively engaged with research on I5.0, (3) familiar with the technical aspects of the technologies. Manufacturing SMEs were included in the sample if (1) the company adhered to SME size requirements defined by *OPOCE* (n.d.), and (2) if professionals use AI, AR/VR or Robotics technologies in a smart manufacturing system. It was assessed which smartness characteristics the technology of interest contributes to the manufacturing system through an adaptation of the smart manufacturing characteristics by Mittal et al. (2019). Below, table 3 describes which expert interviewees relate to which SME case, the smartness characteristics of the manufacturing system, and the application of smart technology.

Table 3. SME sample including Smart technology applications

Organisation ID	Respondent ID	Related Expert	Smartness characteristics	Technology application
SME1	PM1 PW1	WDE1-WDE4 TE3	Connectivity	Bending bench robot: Automation of picking up, bending, and depositing products CO_2 laser cutting robot: Automation of the laser cutting process
SME2	PM2 PW2	WDE1-WDE4 TE3	Decision-support, connectivity, and Monitoring and interpretation through sensors	Fiber and CO^2 laser cutting robot: Automation of the laser cutting process Maintenance monitoring support Quality control of end products Decision support for final product quality
SME3	PM3 PW3	WDE1-WDE4 TE3	Connectivity, monitoring and interpretation through sensors	Fiber and CO^2 laser cutting robot: Automation of the laser cutting process Maintenance monitoring support Quality control of end products

SME4	PM4 PW4	WDE1-WDE4 TE1 TE3	Connectivity and interoperability	AI-enabled Planning and control system: Automation of production control in robot cell Pallet-loading and spark robot: Automation of pallet loading Automation of sparking process Quality control of end products
SME5	PM5 PM5	WDE1-WDE4 TE1 TE2	Connectivity and interoperability, monitoring at distance	AI-enabled Work scheduling system: Automation of order scheduling Digital work schedule Digital work instructions
SME6	PM6 PW6	WDE1-WDE4 TE1 TE3	Monitoring and interpretation through sensors	Robotics and AI: Automation of substantive production processes such as milling Automation of production control in robot cell Automation of pallet loading

Based on a synthesis of literature from Work design (Morgeson & Humphrey, 2006) and skills (e.g., Kohlgrüber et al., 2021; van Laar et al., 2017) two semi-structured interview protocols have been developed: one for experts, and one for production workers and managers. The exploration of Work Design and required skills included an investigation of the manufacturing context in which production workers adopted smart technologies. In order to achieve this, the measurement instrument was enriched with elements drawing from business Process Modeling (Havey, 2005) and Technology Appropriation (Caroll et al., 2002). Business processes modelling was utilized through the creation of a flowchart that visualizes the detailed production steps, responsible person or machine, and flow of information and materials when producing a typical product for which they utilize the respective smart technology. Finally, elements of technology appropriation are utilized to capture required skills for modification and customization of technology and manufacturing processes to meet user requirements and needs.

The expert interview protocol assessed their views on two main elements: (1) Industry 5.0 and work design, and (2) skills for appropriation of technology. An example of a question targeting work design in I5.0 is: "*How has [the work design characteristic mentioned by the expert] evolved during one or two critical stages of implementing technologies like AI, VR, or Robotics in (I5.0) manufacturing*?"

The production workers interview protocol assessed three elements: (1) the current manufacturing process, and an assessment of (2) required skills and (3) current work design characteristics in the current manufacturing process. This focus on current processes is crucial because it establishes a baseline for understanding how I5.0 adoption may necessitate

new skills or changes in how workers interact with the manufacturing system. An example of a question is: "*What did you already need to be able to do before you first started to collaborate with the technology?*"

The data was collected through a combination of on-site (professionals) and online interviews (experts). The interviews with the professionals were supplemented by a workplace visit of the production workers and managers to further enhance understanding of the manufacturing process and work design. All interviews were recorded, with professional interviews transcribed in full and expert interviews transcribed selectively. Data analysis employed a deductive thematic analysis approach, utilizing both detailed transcripts and summaries. This variation in transcription allowed for in-depth analysis while balancing resource constraints based on the interviewee's role and the depth of technical process insights.

Results

Results indicate several insights which are structured according to the two research questions in the following sections: (1) required skills, and (2) work designs.

Required skills by production workers

Although green/sustainability skills are recognized as significant in the I5.0 literature, they were notably absent in the perspectives of interviewees. Similar results are shown for self-reflection and self-awareness which could be attributed as a skill for resilience. Instead, interviewees highlight the critical importance of digital skills, and technical skills such as human-machine interface skills. For instance, professionals indicated that manufacturing could be halted if production workers are unable to interact with the robot (interface). Experts further highlighted the importance of human-machine interaction for obtaining feedback from the job, maintaining job complexity, and maintaining task variety. Table 4 summarizes the perceived importance of skills in an I5.0 context.

Table 4. Composed list of required skills and their importance indicated in the interviews

Skill Category	Skill sub-category	Skills	Importance
Transversal (generally required)	Personal	Integrity / ethics; Learning skill; Self-reflection, self-awareness; Responsibility, attitude (individual values); Flexibility & Cognitive flexibility; Emotional Intelligence.	+ +++ 0 + ++ +
	Social	Collaboration; Teamwork; Intercultural skills;	+ ++ 0 +

		Mediating, Negotiating and persuasion.	
	Methodological	Creative thinking; Problem-solving skills; Analytical thinking; Critical thinking; Decision making.	+++ + +++ +++ +
	Green / Sustainability	Environmental awareness; Can identify appropriate approaches to mitigate, adapt and potentially solve sustainability problems; Challenge the status quo, and reflect on how personal, social and cultural backgrounds influence thinking and conclusions; Identify responsibility and accountability for unsustainable behaviour, and demand effective policies for sustainability.	0 0 0 0
	Digital	Basic digital skills (Use of PC, Browse Internet, Finding Information, Storing data); Moderate digital skills (Word-processing; Working on documents; Working on spreadsheets); Advanced digital skills (Programming).	+++ +++ ++
Professional (subject related)	Technical (subject related)	Process management; Human machine interface; Troubleshooting and maintenance; Analysis, modelling and simulation of production based on big data from sensors and devices; Use of digital devices (e.g. tablets, smartphones, smartwatches) for production monitoring and control; Programming and use of relevant technology (e.g. Collaborative robots, VR); Use of additive manufacturing technologies; Remote system monitoring and supervision of maintenance interventions; Use of virtual and augmented reality for instruction and support of maintenance interventions.	+++ +++ ++ +++ +++ ++ + + 0

Note. '0' indicates that the skill is not mentioned in the interviews.

Perceived work designs by production workers

Within the companies of this exploration, the gradual adoption of smart technologies has led to an incremental increase in technological sophistication. Consequently, distinctions between 'smart technology' and just 'technology in general' are not always salient for

production workers and managers. Some production workers have difficulties pinpointing changes in their jobs due to smart technology, given that they have been using the technology at hand for a prolonged period. This phenomenon is exemplified by the perception among production workers that smart robots do not seem to have not caused drastic changes to the work design compared to previous technologies, in the perception of these production workers:

> *"No, I think the tasks are pretty much the same as they were before. Only the process becomes much faster, and more products are created, when compared to ten years ago." – PW1*

Although human-technology collaboration and augmentation are dominant pillars in I5.0 that give direction to desired work designs of production workers, the manufacturing SMEs mainly utilized smart technologies for automation purposes. Robotics and AI are the two main smart technologies that are adopted with various applications and levels of technological capabilities. Most notably AR/VR was absent in the SMEs under study.

Interviews with managers highlighted the crucial role of Total Productive Maintenance. Automated tasks by robots enable the possibility of almost 24/7 activity in the manufacturing process. For instance, workers are often asked to start large orders near the end of the working day such that these larger orders can be performed by robots throughout the night. The next day, production workers perform control measures on the completed tasks. In this way, sequential interdependence is established in the human-machine interaction. In addition, AI-applications suggest work schedules and work instruction to production workers. In this vein, job autonomy seems to be contingent on the design of the manufacturing system. Generally, there is a high degree of autonomy between manufacturing processes, and a low degree of autonomy within manufacturing processes. Finally, interviewees unanimously agreed that task automation with Robotics alleviate the physical strain on humans through physical support.

Two clearly distinct main job profiles emerge, namely 'foreman-production workers' and 'machine operators'. Typically, organizations have a few foreman-production workers as opposed to a larger group of machine operators. Professionals indicate that this results from the current skills gap that SMEs are faced with in relation to skills such as programming, work process overview and troubleshooting. Foreman-production workers are characterized by their expertise in programming, understanding of work process, and troubleshooting. The responsibility for addressing machine failures and programming machines has shifted away from machine operators to foreman-production workers. Otherwise, with more complicated errors, the manufacturer of the machines is contacted; they will attempt to solve the problem via the telephone, but if this does not work, they will visit the company themselves. The production workers' hierarchy as mentioned here is illustrated by the following quote:

> *"If a problem arises, not all production workers will be able to tackle it. […] We definitely need the top layer for that." – PM3*

The criteria for advancing machine operators to supervisory positions emphasize both domain-specific expertise and cross-functional skills such as digital skills, learning skills, cognitive flexibility, analytical thinking, and critical thinking. Professionals indicated plenty of social support, within and outside the company, for machine operators that want to learn to work with smart technology. However, upskilling is required if machine operators are tasked with performing the work of a foreman-production worker. Experts indicate that upskilling requires practices such as user participation, user-centered design of smart technologies, on-the-job feedback, and possibility to customize work processes. However, these practices are rarely indicated by the professionals under study. Overall, the effect of smart technologies seems contingent on the job role of production workers and mainly distinct in the task and knowledge characteristics category. Table 5 provides an overview of the perceived work design of production workers who adopted smart technologies.

Table 5. Perceived work design characteristics subdivided by job role indicated by professionals

Work design category	Work design characteristic	Machine operators	Foreman-production workers
Task characteristics	Autonomy – within a manufacturing process	–	–
	Autonomy – between manufacturing processes	+ / –	+
	Task identity	–	+
	Task variety	–	+
	Feedback from the job	–	+
Knowledge characteristics	Job complexity	–	+
	Problem solving	–	+
	Specialization	–	+ / –
Social characteristics	Interdependence	+ / –	+ / –
	Interaction outside the organization	+/-	+
	Feedback from others	+	+
Contextual characteristics	Physical load	–	–

Note. ' + ' indicating high, ' + / – ' moderate, and ' – ' low perceived level.

Discussion

This study offers valuable insights into the implications that smart technology adoption has on the required skills and the work designs of production workers. The following discussion highlights key points for practitioners, policymakers, and workplace innovation scholars that emerged from the analysis.

Implications for practitioners

While the effect of technologies on work design has been long established (Hirsch-Kreinsen, 2016; Parker et al., 2017; Waschull et al., 2019; Waschull et al., 2022), professionals experience difficulty in assessing the direct impact of smart technologies on their work. Although all precautions were established to have all interviewees fully grasp the content, machine operators remain a challenging group when discussing complicated topics such as work design, skill requirements, and smart technology adoption. This may be further complicated by the gradual adoption of smart technologies.

Moreover, the context-specific effect of smart technologies on different job profiles remains an open challenge for practitioners. Implications for machine operators can be detrimental as low levels of task and knowledge characteristics, as indicated by professionals, is associated with various deskilling (Shaba et al., 2019) and motivational challenges (Humphrey et al., 2007). At the same time, the foreman-production worker experienced job enlargement and job enrichment. Consequently, they run similar risks for motivational challenges if their skillset and additional job resources do not suffice for the additional job requirements they experience (Humphrey et al., 2007). This highlights the importance of practitioners that integrate job quality, productivity, and well-being of production workers evenly when adopting technology. In this feat, practitioners could consider a SMART work design for their production workers as a starting point when adopting human-centric technologies (Parker & Knight, 2024). Finally, the consideration of human-centric technologies such as assistance systems present another opportunity for practitioners as it 'supports the production worker during manufacturing or assembly work tasks without replacing him, without overruling him and without posing any danger to the worker' (p. 228) (Mark et al., 2021). This could contribute to enhanced capabilities of production workers to perform their job.

Another important observation is the absence of explicit discussion around green and sustainable skills, despite their growing importance in literature (Hecklau et al., 2016; Schröder et al., 2024). As organizations strive to adopt smart technologies, practitioners should recognize the criticality of equipping production workers with the necessary skills to contribute to sustainable manufacturing practices. Integrating green and sustainable skills into workforce development strategies and training programs should be a priority (de Sousa Jabbour et al., 2018; Schröder et al., 2024).

The study's findings on the return on investment (ROI) of technology for SMEs highlight a practical consideration that warrants attention. While the human-centered approach to smart

technologies is desirable, it must align with a viable business case for these organizations (Borchardt et al., 2022). The focus on maximizing the utilization of available technologies, rather than extending human capabilities, suggests that practitioners must carefully balance the investment in technological solutions with the need to maintain a sustainable and competitive operation. To make human-centered adoption of these technologies financially viable and more accessible to SMEs, practitioners could explore innovative business models (Waheed et al., 2022), lean manufacturing principles (Bittencourt et al., 2019), skills development in interorganizational learning communities (Schipper et al., 2023), learning factories (Büth et al., 2020), or government incentives (Mukherjee et al., 2023). Overall, the wide variety in different directions highlights the complexity and multidimensionality of the challenge that practitioners face.

Implications for workplace innovation scholars

The results of this study underscored divergent skill requirements and perceptions of work design between machine operators and foreman-production workers, once again, challenging a one-size-fits-all approach to WPI in the I5.0 era (De Spiegelaere et al., 2012; Putnik et al., 2019). This differentiation could lead to positive effects for foreman-production workers due to job enlargement, but potentially negative effects such as deskilling for machine operators. These varying effects call attention to a contingent approach to WPI such as various scholars have highlighted (Oeij, Dhondt, & McMurray, 2021; Oeij et al., 2023). Practitioners and researchers must recognize the diverse implications of smart technologies on various job profiles and develop customized strategies to address the unique challenges and opportunities faced by each group of workers.

One key implication for workplace innovation scholars to consider is the potential impact on the job quality of machine operators. The findings suggest that the introduction of smart technologies may have led to a reduction in the task and knowledge characteristics of the work. These changes could potentially lead to deskilling (Shaba et al., 2019) and eventually a reduction in perceived job quality (Bakker & Demerouti, 2007). This is an important consideration, as maintaining or improving job quality should be a critical goal when implementing workplace innovation practices for I5.0 adoption (Oeij et al., 2017; Oeij et al., 2019).

Avenues for future research

The insights from this exploratory study point to several promising avenues for future research.

Firstly, addressing the methodological challenges of assessing the direct impact of smart technologies on work design characteristics is critical. This study considered context aspects in which the effect of smart technology on work design is assessed. For instance, the study considers a healthy mix of different manufacturing types used in SMEs, such as line manufacturing and cellular manufacturing. However, these differences were not considered

in the analysis of this study. Future research should explore how these manufacturing approaches influence the relationship between I5.0 adoption and work design, given the significant differences in work design between line manufacturing and cellular manufacturing (Sengupta & Jacobs, 2004). Moreover, other contextual elements in the manufacturing system such as technological maturity (Zizic et al., 2022), technology type (Dhondt et al., 2020), existing production workers skills (Nair et al., 2024), and the design and capabilities of the technology itself (Mark et al., 2021) should be considered when investigating context-specific adoption of smart technologies in manufacturing systems. Longitudinal studies and comparative analyses can provide a more comprehensive understanding of the dynamic and evolving nature of these relationships across specific contexts. For example, AR/VR applications were ultimately not utilized in the SMEs under study despite rigorous efforts. This warrants further exploration in terms of technology type.

Secondly, the role of green and sustainable skills when innovating workplaces warrants deeper exploration. Researchers should investigate the integration of sustainability skills and work design elements that support environmentally conscious manufacturing processes and examine how organizations are adapting their training and development programs to address this emerging need. This research could contribute to a more holistic understanding of the evolving skill landscape in smart manufacturing environments.
Thirdly, the study's findings on the affordability of smart technologies for SMEs and their focus on maximizing technology utilization rather than extending human capabilities open up new research questions. Future studies could investigate how an I5.0 approach to technology adoption can provide a viable business case for manufacturing SMEs. Such research requires a system-approach that includes a thorough understanding of contextual elements in manufacturing systems and their outcomes.

To achieve this, scholars could explore specific strategies and interventions to improve job quality for production workers with human-centric smart technology. Human-centric technologies such as assistance system could be a potential solution for both machine operators and foreman-production workers (e.g., Pacaux-Lemoine et al., 2022; Wotschack et al., 2023). However, much uncertainty remains regarding the context-specific adoption in which assistance systems contribute and which additional strategies and interventions support the positive effects of these human-centric technologies (Kleineberg et al., 2017; Mark et al., 2022; Oestreich et al., 2020; Romero et al., 2016). Future research could examine how job roles and responsibilities can be restructured to increase task variety, autonomy, and skill utilization, evaluating the effectiveness of upskilling and reskilling programs to equip machine operators and foreman-production workers with necessary competencies, assessing the role of worker involvement in the design and implementation of assistance systems, and exploring the influence of organizational policies, practices, and the physical work environment on the job quality and well-being of machine operators. Conducting longitudinal studies to track the long-term effects of assistance system adoption and performing comparative analyses across different organisations, industries and regions could help identify best practices and contextual factors that influence job quality outcomes for

production workers, contributing to the development of evidence-based strategies to maintain or enhance their job quality in the face of technological change.

Finally, researchers should investigate the specific mechanisms by which the job role of machine operators may have been affected. This could involve examining changes in task variety, autonomy, skill utilization, and other key job characteristics that contribute to overall job quality. Understanding these underlying drivers will be crucial in identifying ways to mitigate potential negative impacts. Given the challenging nature of doing research with machine operators, researchers should consider strengthening co-creation of business process models, and semi-structured interviews with observations and think-aloud protocols to get a more reliable view of mechanisms by which the jobs of machine operators may have been affected.

Conclusion

This study offers insights into work designs and required skills for production workers in manufacturing SMEs striving for I5.0 adoption. This research suggests that whilst machine operators can experience deskilling due to reported low feedback from the job, task variety and job complexity (Shaba et al., 2019), foreman-production workers require additional skills due to job enlargement and job enrichment (Lagorio et al., 2021). Moreover, both job roles required a combination of transversal and professional skills to effectively leverage these smart technologies. On the contrary, the absence of sustainability, self-reflection, and self-awareness skills in the perspectives of production workers and managers signals a potential blind spot in current I5.0 implementation practices. This, once again, highlights the importance of practices for fostering autonomy, collaboration, and continuous learning in the workplace to ensure a successful I5.0 transition (Oeij et al., 2017; Prus et al., 2017).

In addition, the observed shift towards more cognitively demanding tasks and increased job variety necessitates (1) a re-evaluation of traditional job profiles (e.g. Wilson et al., 2017), (2) training programs (Leesakul et al., 2022), (3) and a balance between job demands and resources within SMEs (Bakker & Demerouti, 2007). Human-centric technologies such as assistance systems show great promise regarding the latter point through physical, sensorial, or cognitive assistance (Mark et al., 2021).

Moreover, capturing context-specific elements has proven to be crucial for a comprehensive analysis of current work designs and required skills of production workers that adopted smart technologies. Technological maturity (Zizic et al., 2022), type of technology (Dhondt et al., 2020), existing skills of production workers (Nair et al., 2024), and the design and capabilities of the technology itself (Mark et al., 2021) could contribute to enhanced understanding of the creation of a viable business case for human-centric smart technology adoption at SMEs.
In conclusion, while smart technologies offer significant potential for enhancing productivity in manufacturing SMEs, their successful implementation requires careful consideration of skill

development, work design across different job roles, and contextual elements of the manufacturing system at hand.

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Appendix 1: Overview of main skills literature associated with smart technologies

Author	Title	Skills area (or category)
Acatech (2016)	Kompetenzentwicklungsstudie Industrie 4.0	• Technical skills (e.g., data analysis); • Process skills (e.g., process management); • Organizational skills (e.g., leadership, autonomy, decision making).
Behrend et al. (2022)	Understanding future skills and enriching the skills debate	• Digital; • Social; • Methodological; • Personal; • Job-specific.
Bouwmans et al. (2024)	Developing the digital transformation skills framework: A systematic literature review approach	• Digital working; • Communication; • Adaptation; • Collaboration; • Evidence based working; • Entrepreneurial.
Büth et al. (2017)	Bridging the qualification gap between academia and industry	• Professional (e.g., specific technical skills); • Methodological (e.g., problem solving); • Social (e.g., communication); • Personal (e.g., self-discipline).
Corporaal et al. (2018)	Werken in de nieuwe industriële revolutie	• Analytical capabilities; • Reflecting and accurate working; • Communication; • Collaboration; • Creativity / innovativeness; • Commercial skills.
Gronau et al. (2017)	Development of the Industrial IoT Competences in the Areas of Organization, Process, and Interaction based on the Learning Factory Concept	• Professional; • Personal; • Cultural; • Methodological; • Leadership; • Social; • Process; • Organization; • Interaction.
Hecklau et al, (2016)	Holistic approach for human resource management in Industry 4.0	• Technical; • Methodological; • Social; • Personal.
Islam (2022)	Industry 4.0: Skill set for employability	• Business Skills; • Technical Skills.
Janis and Alias (2018)	A systematic literature review: human roles, competencies and skills in industry 4.0	• Technical skills (knowledge, manufacturing, IT, computer science, Robotics, Automation); • Non-technical skills (personal, social, professional, methodological).
Kohlgrüber (2021)	Beyond 4.0	• Digital; • Personal; • Social; • Methodological; • Professional.

Maisiri (2021)	Industry 4.0 skills: A perspective of the South African manufacturing industry.	• Digital Skills (e.g., advanced Robotics); • Soft Skills (e.g., social); • Domain Skills.
Mudzar et al. (2022)	Change in Labour Force Skillset for the Fourth Industrial Revolution: A Literature Review	• High-level technical skills (e.g., data analysis); • Higher-order cognitive skills (e.g., problem solving); • Human or interpersonal skills (e.g., leadership).
Müller-Frommeyer et al. (2017)	Introducing competency models as a tool for holistic competency development in learning factories: Challenges, example and future application	• Professional & Methodological Skills (e.g., presentation skills, analytical skills); • Social skills (e.g., teamwork, communication); • Personal Skills (e.g., motivation, openness).
Pinzone et al. (2017)	Jobs and skills in Industry 4.0: an exploratory research	• Technical skills associated with: Operations Management (e.g., Simulation modeling), Supply chain (e.g., virtual design), Product-Service Innovation Management (e.g., smart product design), Data Science Management (e.g., big data analysis), IT-OT Integration Management (e.g., integration of embedded devices).
Prift et al. (2017)	A Competency Model for "Industrie 4.0" Employees	• Leading & Deciding; • Supporting and cooperating; • Interacting and presenting; • Analysing & interpreting; • Creating and conceptualizing; • Organizing and executing; • Adapting and coping; • Enterprising and Performing.
Probst et al. (2019)	Skills for smart industrial specialisation and digital transformation	• Technical; • Quality, Risk and Safety; • Management, leadership & entrepreneurship; • Communication; • Innovation; • Emotional Intelligence; • Ethics.
Schröder et al. (2014)	From Industry 4.0 to Industry 5.0: The Triple Transition Digital, Green and Social	• Digital; • Green; • Social; • Individual; • Personal; • Methodological; • Technical (subject specific)
Van Laar et al. (2017)	The relation between 21 -century skills and digital skills or literacy: A systematic literature review	• Core skills (technical, information management, communication, collaboration, creativity, critical thinking, problem solving); • Contextual skills (ethical and cultural awareness, flexibility, self-direction, lifelong learning).

Van Laar et al. (2020)	Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers: A Systematic Literature Review	• Technical; • Information; • Communication; • Collaboration; • Critical thinking; • Creativity; • Problem-solving skills.

About the authors

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A Pilot Study on the Effects of a Task Analysis Training Program on Self-Efficacy and Work Engagement in Disability Welfare Facility Staff

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Abstract

This study examined the effects of a task analysis training program on Organizational-Based Self-Esteem (OBSE) and Work Engagement (WE) among staff at disability welfare facilities. The training program consisted of two interactive sessions, workplace implementation phases, and a follow-up evaluation. Participants selected a workplace task for improvement, documented current workflows, and identified areas for enhancement. The first session introduced task analysis techniques, incorporating practical exercises and peer feedback. Participants then implemented their proposed improvements and reconvened for the second session to refine their strategies. A five-week implementation phase followed, during which participants documented the impact of their changes. WE, OBSE, personal attributes, and workplace resources were assessed using validated scales, and statistical analyses were conducted using IBM SPSS Statistics 27. The results indicated that task analysis training enhanced self-efficacy and significantly increased OBSE; however, its effect on WE remained inconclusive. These findings underscore the importance of structured training programs in addressing both the practical and emotional challenges faced by staff. Furthermore, when embedded in a supportive organizational environment, such training may serve as a catalyst for employee-driven workplace innovation, contributing to both individual development and broader organizational learning.

Key words: Task Analysis Training Program, Work Engagement, Disability Welfare Facility Staff, Organizational-Based Self-Esteem

1 Introduction

1.1 Work & Job Demands in Disability Welfare Facilities

Staff at disability welfare facilities provide direct care, addressing individuals' health, personal needs, behavioral issues, and overall well-being. They also assist with vocational and daily activities, develop support plans, and coordinate facility operations (Azih et al., 2023). Supporting individuals with intellectual, physical, or developmental disabilities requires staff to acquire appropriate techniques, manage risks, and make informed care decisions.

However, the demanding work environment poses significant challenges, including high emotional and physical stress, job dissatisfaction, and burnout, which negatively affect both staff well-being and service quality (Azih et al., 2023). Role ambiguity and limited organizational support further contribute to workplace stress, making it difficult for staff to provide effective and consistent care (Moran et al., 2024). Studies have shown that disability support workers often experience high levels of work-related stress and burnout, impacting their professional quality of life and job performance (Harries et al., 2015; Holding et al., 2024; Mutkins et al., 2011). Addressing these challenges requires adequate staffing and structured training programs aimed at enhancing staff competencies and optimizing facility management (Moran et al., 2024; Rathmann et al., 2020).

One essential competency for staff is the ability to systematically analyze work processes and implement improvements. Task analysis provides a structured approach to breaking down tasks, optimizing workflows, and allocating responsibilities effectively. Developing these skills can help staff facilitate more effective vocational training for service users while also improving their Organizational-Based Self-Esteem (OBSE) and Work Engagement (WE).

In response to these challenges, this study examines the effects of a task analysis training program on OBSE and WE among disability welfare staff, focusing on how training influences staff perceptions of their work abilities and engagement, rather than directly measuring its impact on service users.

1.2 Task Analysis in Workplace Training

Task analysis is a systematic methodology employed to deconstruct work processes into smaller, manageable components. This approach enables staff to comprehend each stage of a task, identify potential areas for optimization, and allocate

responsibilities with greater precision. In the context of disability welfare facilities, task analysis is particularly advantageous as it provides a structured framework for staff to enhance workflow efficiency and improve the quality of care delivered to service users.

Empirical research has demonstrated that task analysis can substantially enhance staff performance and job satisfaction. For instance, systematic task analysis facilitates a clearer understanding of roles and responsibilities among staff, thereby mitigating role ambiguity and its associated stress. Additionally, this method assists in identifying specific training needs, thereby facilitating the development of targeted training programs aimed at addressing skill gaps (Ferreira et al., 2015; Bansal & Tripathi, 2017). Training in task analysis has been shown to enhance self-efficacy and professional quality of life among disability support workers by equipping them with the requisite skills to manage their tasks more effectively (Bansal & Tripathi, 2017).

The implementation of task analysis enables staff to develop a more comprehensive understanding of their roles and responsibilities, which contributes to the reduction of role ambiguity and work-related stress. Moreover, task analysis fosters a culture of continuous improvement, encouraging staff to engage in systematic evaluation and refinement of their work processes.

The integration of task analysis into workplace training programs has been linked to significant improvements in both staff performance and job satisfaction. Employees who have undergone task analysis training report higher levels of job satisfaction and lower levels of occupational stress (Bansal & Tripathi, 2017). By providing staff with the methodological tools to systematically analyze and enhance their work processes, task analysis serves to reinforce both confidence and professional competence. Consequently, this approach fosters increased staff engagement and motivation, ultimately contributing to a more positive and productive work environment.

Moreover, task analysis training aligns with the principles of workplace innovation (WPI), which emphasizes participatory practices, reflective learning, and employee-driven improvements. As defined by Totterdill et al. (2016), WPI involves "new and combined interventions in work organization, human resource management and supportive technologies," aimed at improving both organizational performance and quality of working life. By engaging staff in analyzing and improving their own work processes, task analysis training contributes to a bottom-up innovation model that fosters employee autonomy, organizational learning, and sustainable change.

1.3 The Relationship Between Task Analysis Training, Self-Efficacy, and Work Engagement

Task analysis training has a significant impact on staff self-efficacy and WE . Self-efficacy refers to an individual's belief in their ability to successfully perform tasks. Task analysis training enhances self-efficacy by equipping staff with the necessary skills to systematically deconstruct tasks and develop effective support strategies. This improvement in skill acquisition fosters greater confidence in their professional capabilities, thereby increasing motivation and engagement in their work.

Empirical research suggests a strong association between self-efficacy and WE. For instance, Bandura (1997) posited that individuals with high self-efficacy exhibit greater motivation and proactivity in their professional roles. Similarly, Schaufeli and Bakker (2004) demonstrated that self-efficacy positively correlates with job satisfaction and performance, ultimately contributing to a more productive work environment.

The implementation of task analysis training enables staff to develop a clearer understanding of their roles and responsibilities, thereby mitigating role ambiguity and its associated stress. This increased role clarity, coupled with an enhanced skill set, fosters a sense of professional competence and confidence, leading to heightened levels of WE. Consequently, staff are more likely to remain motivated, satisfied, and effective in their roles, leading to sustained improvements in service quality and organizational stability.

1.4 The Need for Structured Training Programs in Disability Welfare Work

Staff at disability welfare facilities face numerous stress factors, including heavy workloads, emotional burdens, role ambiguity, and insufficient organizational support. These stressors significantly impact staff well-being and the quality of services provided, often leading to job dissatisfaction and burnout (Harries et al., 2015). Traditional training programs, which typically focus on basic caregiving skills and regulatory compliance, aim to enhance staff capabilities and reduce stress. However, these programs frequently fall short in addressing the practical and emotional challenges encountered by staff. Key limitations include a lack of practical skill development, insufficient ongoing support, and an inability to meet individual staff needs (Holding et al., 2024).

Given these identified stress factors and the limitations of traditional training, there is a clear necessity for structured training programs. Such programs offer a systematic approach to improving staff skills, clarifying roles, and reducing workplace stress.

Additionally, they provide a more comprehensive and practical framework for staff development, addressing both the technical and emotional aspects of their roles. Research has shown that structured training programs can significantly enhance staff competencies and job satisfaction (Ferreira et al., 2015). For example, such programs have been found to reduce role ambiguity and increase job satisfaction among disability support workers (DeOnna, 2002).

In summary, the implementation of structured training programs is essential for improving the well-being and performance of staff at disability welfare facilities. These programs equip staff with the necessary tools and support to manage their work more effectively, ultimately leading to better outcomes for both staff and service users.

1.5 Aim of this study

The aim of this study was to examine the potential effects of a task analysis training program on OBSE and WE among staff at disability welfare facilities. This study was designed as a pilot investigation, assessing both the effectiveness of task analysis-based education in workplace training and its psychological impact on professional confidence and job involvement. We hypothesized that the training program would enhance self-efficacy by improving participants' ability to systematically deconstruct tasks and develop structured support strategies. While we hypothesize that the training program will enhance self-efficacy, its direct impact on WE remains uncertain due to various contextual factors, such as organizational culture, social dynamics, and job autonomy. Investigating these influences is crucial for designing effective training interventions in disability welfare facilities.

2 Methods

2.1 Study design

The study was designed as a within-subjects pre-post study, where participants completed a questionnaire before and after the training (Fig. 1). The training sessions took place over a period of approximately six weeks, and the pre- and post-training surveys were administered in the weeks immediately before and after the training, respectively. To maintain consistency in data collection, all participants completed the surveys on the same scheduled days within each period.

In addition to the quantitative assessments, participants submitted follow-up reports five weeks after the training. These reports were reviewed to extract key themes related to workflow improvements, training effectiveness, and perceived changes in job performance. Thematic patterns were summarized to complement the quantitative findings.

Participants' self-efficacy, WE, and workplace resources were measured before and after the training. Additionally, a follow-up discussion was conducted five weeks after the second session via an open chat platform. This qualitative evaluation aimed to capture participants' reflections on the application of task analysis techniques in their workplace, their perceived effectiveness, and any remaining challenges. Participants were encouraged to share their insights in an open-ended manner to provide a more comprehensive understanding of the training's long-term impact.

The study aimed to assess whether training in task analysis techniques could enhance self-efficacy and WE among disability welfare facility staff.

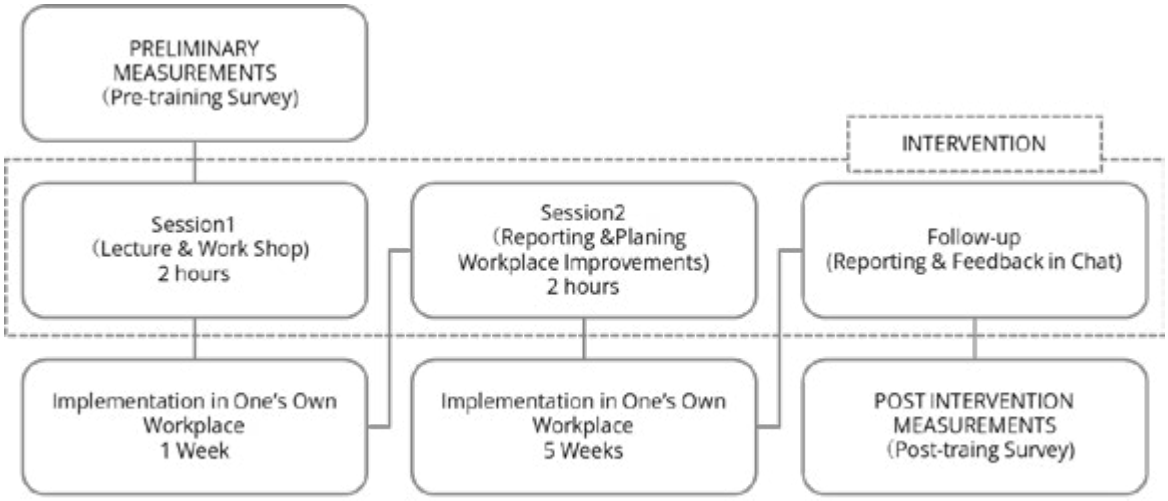

Fig.1 Study design.

2.2 Recruitment and participants

An invitation to participate in the study was sent via e-mail to 11 individuals who had registered for a training program targeted at disability welfare facility staff, organized by the Shiga Prefecture Social Employment Promotion Center. Of these, nine individuals agreed to participate in the study.

To be included in the final analysis, participants were required to attend both training sessions and complete both the pre- and post-training questionnaires. Those who were unable to attend all training sessions or failed to complete either questionnaire was excluded from the study. Additionally, participation in a follow-up discussion held five weeks after the second session was encouraged but not set as a strict inclusion criterion, as all participants took part in this phase. After applying these criteria, seven participants were included in the final analysis.

The participants had an average age of 38.9 ± 10.7 years, consisting of four males and three females. Their roles in disability welfare facilities varied, including one managerial staff member, three life support staff members, two vocational support staff members, and one other staff member.

Before participation, all individuals provided informed consent after being briefed on the study's benefits and potential risks. The study was approved by the Kyoto Tachibana University Research Ethics Committee (24-56).

2.3 Intervention

The intervention was conducted as a training program aimed at enhancing the competencies of disability welfare facility staff through task analysis-based education. The primary goal of this training program was to equip staff with task analysis skills, enabling them to support service users in receiving more effective vocational training. By systematically breaking down tasks and structuring support strategies, staff members were expected to improve the quality of vocational training provided at disability welfare facilities.

The researchers collaborated with the Shiga Prefecture Social Employment Promotion Center to design and implement the program. The intervention consisted of two training sessions held over a one-week period, with participants engaging in workplace implementation between and after the sessions. A follow-up discussion was conducted five weeks after the second session via an open chat platform.

Throughout the sessions, participants were actively engaged in discussions, hands-on exercises, and peer feedback. The training emphasized collaborative learning, requiring participants to present their analyses and actively contribute to the refinement of workplace improvement plans. Rather than passively receiving instruction, participants took an active role in evaluating their workplace tasks, identifying inefficiencies, and

proposing solutions. This interactive approach was designed to enhance their ability to apply task analysis techniques in real-world settings.

In the first session, participants attended a lecture and engaged in practical exercises on task analysis. They learned how to systematically break down tasks and developed initial job improvement plans based on task analysis principles. After this session, they were instructed to implement their job improvement plans in their respective workplaces and document their observations.

A week later, participants reconvened for the second session, where they shared their experiences from the workplace implementation phase. They discussed challenges faced during implementation and refined their job improvement plans based on feedback and further analysis. Following this session, they conducted another round of workplace implementation, applying their revised plans over a five-week period.

A follow-up discussion was conducted via an open chat platform five weeks after the second session. Participants reported on the results of their workplace implementation and received additional feedback from facilitators and peers.

The detailed structure and content of the training sessions are described in the following section.

2.4 Task Analysis Training Program

This program aimed to equip disability welfare facility staff with practical task analysis skills to enhance vocational training effectiveness. Task analysis has been widely applied in industrial and healthcare fields to optimize workflows and support structured learning (DeOnna, 2002; Lee, 2018). The training program consisted of two interactive sessions, two workplace implementation phases, and a follow-up evaluation conducted five weeks after the second session.

Before attending the first session, participants were required to select a workplace task they wished to improve. The selection process was guided by relevance to vocational training, existing challenges in efficiency, clarity, or execution, and the potential for improvement through task analysis. Participants documented the current workflow of the selected task and identified specific areas they aimed to enhance. This preparatory assignment ensured that participants engaged with the training content in a way that directly related to their daily work.

The first session, a two-hour workshop, introduced participants to task analysis and work process optimization. It began with a lecture covering the definition, importance, and applications of task analysis in vocational training settings. Participants learned techniques for breaking down tasks into step-by-step processes and identifying inefficiencies. They then watched a recorded vocational task performed by service users and applied task analysis techniques to evaluate workflow efficiency and identify areas for improvement. This exercise helped participants develop an objective perspective on task efficiency before analyzing their own workplace tasks.

Following the video-based exercise, participants conducted a detailed analysis of the workplace task they had selected prior to the session. In small groups, they discussed their findings, suggested improvement strategies, and provided peer feedback. Each group presented their results, and a certified occupational therapist offered expert feedback. At the end of the session, participants were instructed to implement their proposed task improvements in their workplaces over the following week, documenting their implementation process, observed challenges, and any necessary modifications.

A week later, participants reconvened for the second session, which focused on reflection, refinement, and advanced application of task analysis. They began by sharing their experiences from the initial workplace implementation, discussing both the successes and challenges they encountered. Through group discussions, they analyzed the effectiveness of their modifications and considered further refinements. Participants then assessed the impact of their task modifications based on predefined criteria, including task completion time, reduction of unnecessary steps, service user comprehension, and overall feasibility in daily practice. Each group worked collaboratively to refine their strategies for further improvement, with the occupational therapist providing targeted feedback and additional recommendations.

To reinforce the learning process, participants were required to implement their revised task analysis strategies over a five-week period following the second session. During this phase, they documented the impact of their changes, focusing on user adaptation, workflow efficiency, and staff workload.

Five weeks after the second session, participants submitted a final report summarizing their task improvement efforts. These reports included a description of the implemented modifications, observed outcomes, reflections on the changes, and challenges encountered. The instructor provided individualized feedback and comments on each report, marking the conclusion of the training program.

2.5 Measurements

To evaluate the effects of the intervention, this study measured WE, OBSE, personal attributes, and workplace resources using validated Japanese versions of standardized scales. WE were assessed using the Japanese version of the Utrecht Work Engagement Scale (UWES-9) (Shimazu et al., 2008), while OBSE was measured using the Japanese version of the OBSE scale (OBSE-J) (Matsuda et al., 2011). In addition, personal attributes and career-related factors, including age, gender, highest educational attainment, employment status, years of experience in the current workplace, job position, and role, were collected.

To assess workplace resources, this study adopted 21 items comprising 53 questions from the New Brief Job Stress Questionnaire (New BJSQ), an updated version of the Brief Job Stress Questionnaire (BJSQ). Originally developed through research commissioned by the former Ministry of Labor, Japan, the BJSQ is based on the NIOSH occupational stress model and is widely used to assess occupational stress factors, stress responses, and modifying factors across various job sectors.

The New BJSQ was selected for its ability to provide a more detailed assessment of workplace resources, including workload, job control, social support, job satisfaction, and organizational characteristics. Compared to the original BJSQ, it refines certain subscales and incorporates additional workplace resource factors, making it particularly useful for evaluating the impact of training on staff well-being and engagement.

The reliability and validity of the New BJSQ have been confirmed in previous studies, with Cronbach's alpha coefficients demonstrating the consistency of its subscales (Inoue et al., 2014). All items were rated on a four-point Likert scale, where lower scores generally indicate more favorable conditions. For example, job satisfaction responses ranged from 1 ("Satisfied") to 4 ("Dissatisfied"), while
social support responses ranged from 1 ("Very much") to 4 ("Not at all"). The subscales used in this study are listed in Table 1.

Table 1. Overview of the 21 Items and 53 Questions Extracted from the New Brief Job Stress Questionnaire (New BJSQ)

Scales	Question Item	Number of Items
Job Demands		
Quantitative job overload	"I have to handle an excessive amount of work."	3
Qualitative job overload	"My work requires advanced knowledge and skills."	3

Physical demands	"My job requires significant physical exertion."	1
Job resouces: Task level		
Job control	"I can decide the order and method of my tasks."	3
Suitable jobs	"My job content is well suited to me."	1
Skill utilization	"I rarely use my skills and knowledge at work."	1
Role clarity	"I understand my duties and responsibilities."	3
Meaningfulness of work	"My job is rewarding and fulfilling."	3
Career opportunities	"I have opportunities to learn new things at work."	3
Job resources: workgroup-level		
Supervisor support	"How easily can you talk to your supervisor?"	3
Coworker support	"How easily can you talk to your coworkers?"	3
Support from family and friends	"How easily can you talk to your family?"	3
Monetary / status reward	"I am in a position that matches my abilities and experience."	2
Esteem reward	"I am treated appropriately by my supervisor."	2
Leadership	"My supervisor provides feedback on my work performance."	3
Workplace where people complement each other	"I receive praise when I do my job well."	3
Workplace where mistakes are acceptable	"I have a chance to recover even if I make a mistake."	2
Job resources: organisational-level		
Respect for individuals	"My workplace values each employee's individuality."	3
Career development	"My workplace provides training and education that enhances career growth."	5
Outcomes		

Job satisfaction	"Are you satisfied with your current job?"	1
Work-self balance (positive)	"What I learn at work helps enrich my personal life."	2
Most items were rated on a four-point Likert scale (1 = "Strongly agree" to 4 = "Strongly disagree"), with lower scores generally representing more favorable conditions.		

2.6 Statistics

All statistical analyses were conducted using IBM SPSS Statistics 27. Descriptive statistics were calculated for all variables. Due to the small sample size and potential non-normal distribution, the Wilcoxon signed-rank test was applied to compare pre- and post-training measurements. Effect sizes for the Wilcoxon test were calculated using rank-biserial correlation (r_b). Spearman's rank correlation coefficient (ρ) was used to explore relationships between changes in WE, OBSE, and workplace resources. Missing data was handled using listwise deletion. Statistical significance was set at $p \leq 0.05$, and effect sizes were interpreted based on standard guidelines (small: 0.10, medium: 0.30, large: 0.50 for rank-biserial correlation).

3 Results

Table 1 presents the demographic, educational, and employment characteristics of the participants. The final sample consisted of seven individuals (four males and three females) with an average age of 38.9 ± 10.7 years. The participants had varying levels of experience in their current workplace, with the majority (57.2%) having three years or less of experience. In terms of educational background, three participants had completed vocational school, one had graduated from junior college, and three held a university degree. Most participants (85.7%) were employed as full-time staff.

Table.2 Participant Characteristics

Variable	Mean ± SD / n (%)
Age (years)	38.9 ± 10.7
Gender	
・Male	4 (57.1%)
・Female	3 (42.9%)
Years of experience in current workplace	
・Less than 1 year	1 (14.3%)

▪ 1–3 years	3 (42.9%)
▪ 4–6 years	1 (14.3%)
▪ 7–10 years	2 (28.6%)
Educational background	
▪ Vocational school	3 (42.9%)
▪ Junior college	1 (14.3%)
▪ University	3 (42.9%)
Employment status	
▪ Full-time employee	6 (85.7%)
▪ Non-regular employee	1 (14.3%)
Job position	
▪ Managerial staff	1 (14.3%)
▪ Life support staff	3 (42.9%)
▪ Vocational support staff	2 (28.6%)
▪ Other	1 (14.3%)

3.1 Changes in Work Engagement and Organizational-Based Self-Esteem

Table 3 presents the changes in WE and OBSE before and after the training. Although WE scores showed a slight increase from 3.00 (IQR: 2.78–4.00) to 3.11 (IQR: 2.11–3.78), the change was not statistically significant (p = 0.31). In contrast, OBSE scores increased significantly from 3.13 (IQR: 2.88–3.75) to 3.25 (IQR: 3.00–4.00), with a notable effect size (r = -0.86, p = 0.02). These findings suggest that the training may have contributed to improvements in OBSE, although its impact on WE remains unclear.

Table. 3 Comparison of Work Engagement and Organizational-Based Self-Esteem Before and After Training (n = 7)

Variable	Pre-training Median [IQR]	Post-training Median [IQR]	Z	r_b	p
Work Engagement (UWES-J)	3.00 [2.78, 4.00]	3.11 [2.11, 3.78]	-1.014	-0.38	n.s
Organizational-Based Self-Esteem (OBSE-J)	3.13 [2.88, 3.75]	3.25 [3.00, 4.00]	-2.264	-0.86	0.02*

*p < 0.05, Wilcoxon signed-rank test

3.2 Changes in Job Characteristics

Table 4 presents a comparison of job characteristics before and after the training. The Quantitative job overload significantly decreased after the training (Z = -2.04, r = -0.77, p = 0.04). Given that a lower score indicates a higher workload, this result suggests that the workload increased after the training. In contrast, there were no significant changes in Qualitative job overload (p = 0.78) or Physical demands (p = 0.16). Regarding job resources at the task level, a decreasing trend was observed in skill utilization after the training (Z = -1.41, r = -0.53, p = 0.16), suggesting a potential reduction in opportunities to apply one's skills. However, this change was not statistically significant. For job resources at the department level, coworker support (Z = -1.36, r = -0.51, p = 0.18) and Esteem reward (Z = -1.89, r = -0.71, p = 0.06) showed some improvement, but these changes were not statistically significant. Similarly, there were no significant changes in job satisfaction (p = 0.66) or career development opportunities (p = 0.40) before and after the training. Overall, these results indicate that while the training led to a significant increase in Quantitative job overload, no statistically significant changes were observed in other job characteristics, including job resources and job satisfaction.

Table.4 Comparison of Job Characteristics Before and After Training (n = 7)

Variable	Pre-training Median [IQR]	Post-training Median [IQR]	Z	r_b	P	
Job Demands						
Quantitative job overload (3)	2.33 [2.33, 2.67]	2.00 [1.33, 2.33]	-2.04	-0.77	0.04	*
Qualitative job overload (3)	2.33 [2.00, 2.67]	2.33 [2.00, 3.00]	-0.28	-0.1	0.78	
Physical demands (1)	2.00 [2.00, 3.00]	2.00 [1.00, 3.00]	-1.41	-0.53	0.16	
Job Resources (Task level)						
Job control (3)	2.33 [2.00, 3.00]	2.33 [2.00, 2.67]	-0.14	-0.05	0.89	
Suitable jobs (1)	2.00 [2.00, 2.00]	2.00 [2.00, 3.00]	-1.41	-0.53	0.16	
Skill utilization (1)	3.00 [2.00, 3.00]	2.00 [2.00, 3.00]	-1.41	-0.53	0.16	
Role clarity (3)	2.00 [1.00, 2.33]	2.00 [1.00, 2.33]	-1.06	-0.4	0.29	
Meaningfulness of work (3)	2.00 [1.33, 2.00]	2.00 [1.33, 2.00]	-0.18	-0.07	0.85	
Career opportunities (3)	2.00 [1.67, 2.67]	2.33 [1.67, 3.00]	-0.6	-0.23	0.55	
Job Resources (workgroup-level)						
Supervisor support (3)	2.00 [1.67, 2.67]	3.00 [1.00, 3.00]	-0.82	-0.31	0.41	
Coworker support (3)	1.67 [1.00, 2.33]	3.00 [1.00, 3.33]	-1.36	-0.51	0.18	

Family & friend support (3)	1.67 [1.00, 2.33]	1.67 [1.00, 2.33]	-0.74	-0.28	0.46	
Monetary / status rewards (2)	2.50 [2.00, 3.00]	2.50 [2.00, 3.00]	-1.63	-0.62	0.10	
Esteem reward (2)	2.00 [2.00, 2.50]	2.50 [2.00, 3.50]	-1.89	-0.71	0.06	
Leadership (3)	2.33 [1.67, 3.00]	2.33 [2.00, 3.00]	-1.00	-0.38	0.32	
Workplace where people complement each other (3)	2.33 [2.00, 3.33]	2.67 [2.00, 3.33]	-0.27	-0.1	0.79	
Workplace where mistakes are acceptable (2)	2.00 [1.50, 2.50]	2.50 [2.00, 3.00]	-1.41	-0.53	0.16	
Job Resources (Organization level)						
Respect for individuals (3)	2.00 [1.67, 2.33]	2.00 [2.00, 2.33]	-0.82	-0.31	0.41	
Career development (5)	2.20 [2.00, 2.40]	2.40 [1.80, 3.00]	-0.85	-0.32	0.40	
Outcomes	2.00 [2.00, 2.00]					
Job satisfaction (1)	2.50 [1.50, 3.00]	2.00 [2.00, 3.00]	-0.18	-0.07	0.66	
Work-self balance (positive) (2)	2.50 [1.50, 3.00]	2.00 [2.00, 3.00]	-0.75	-0.28	0.45	

3.3 Relationship Between Changes in Work Engagement and Job-Related Factors

Table 5 presents the correlation coefficients between changes in WE and OBSE-J and various job-related factors. Regarding changes in WE, a significant negative correlation was observed with Physical demands (ρ = -0.79, p = .03), indicating that as Physical demands increased, WE also tended to increase. Other factors, including Meaningfulness of work (ρ = -0.48, p = .27), Supervisor Support (ρ = -0.61, p = .15), and Career Development (ρ = -0.36, p = .43), showed moderate to weak negative correlations with changes in WE, but these were not statistically significant.

For changes in OBSE-J, no statistically significant correlations were found with any of the job-related factors. However, Workplace Tolerance for Failure (ρ = 0.61, p = .15) and Workplace where people complement each other (ρ = -0.46, p = .30) showed moderate correlations, suggesting a possible trend that requires further investigation.

Overall, these findings suggest that an increase in Physical demands may be associated with higher WE, while changes in OBSE-J do not appear to be strongly related to the examined job-related factors.

3.4 Qualitative Results

To complement the quantitative findings, follow-up reports submitted by participants five weeks after the training were analyzed to identify key themes related to workflow improvements, training effectiveness, and perceived changes in job performance. Several common themes emerged, highlighting the impact of task analysis training on workplace organization, communication, and operational efficiency.

One prominent theme was the importance of workplace organization and efficiency. Participants reported that streamlining task workflows and improving workspace organization led to greater productivity and reduced physical strain. For example, some participants noted that reorganizing storage areas and optimizing material placement minimized unnecessary movement, thereby improving efficiency and reducing fatigue.

Table.5 Correlation Matrix of Work Engagement and OBSE-J with Job-Related Factors (Spearman's ρ)

Variable	Change in Work Engagement (Post - Pre)	*p*	Change in OBSE-J (Post - Pre)	*p*
Quantitative job overload	-0.33	0.47	-0.63	0.13
Qualitative job overload	-0.02	0.97	-0.36	0.43
Physical demands	-0.79	0.03	0.17	0.71
Job Control	-0.20	0.67	0.07	0.88
Suitable job	-0.63	0.13	0.26	0.57
Skill Utilization	0.63	0.13	-0.26	0.57
Role clarity	-0.20	0.67	-0.18	0.70
Job Meaningfulness	-0.48	0.27	-0.12	0.79
Career opportunities	-0.46	0.29	0.02	0.97
Supervisor Support	-0.61	0.15	0.30	0.51
Coworker Support	-0.56	0.19	0.45	0.31
Family & Friend Support	0.07	0.88	0.43	0.34
Esteem reward	-0.23	0.62	0.13	0.79
Monetary / Status Rewards	0.54	0.21	0.23	0.62
Leadership	-0.52	0.23	-0.40	0.37

Workplace where people complement each other	-0.12	0.80	-0.46	0.30
Workplace where mistakes are acceptable	-0.28	0.54	0.61	0.15
Respect for individuals	-0.53	0.22	0.30	0.51
Career Development	-0.36	0.43	0.12	0.80
Job Satisfaction	-0.40	0.37	0.37	0.42
Work-Self Balance (Positive)	-0.46	0.31	-0.07	0.88

*Correlations are calculated using Spearman's ρ. Bold values indicate statistically significant correlations ($p < .05$). WE = Work Engagement; OBSE-J = Organization-Based Self-Esteem (Japanese version).

Another recurring theme was the role of communication and collaboration. Participants observed that reducing physical distance between workstations not only improved workflow efficiency but also enhanced interpersonal communication. This, in turn, helped reduce errors, facilitated teamwork, and increased overall job satisfaction. Some participants implemented additional measures such as whiteboards to visually share task progress, reducing miscommunication and improving task coordination among staff members.

Additionally, several participants noted improvements in task awareness and proactive problem-solving. By applying task analysis techniques, they became more conscious of inefficiencies and were able to proactively suggest improvements. This heightened awareness extended beyond the immediate training period, with participants expressing a continued interest in refining their work processes and supporting colleagues in similar efforts.

While most participants found the training beneficial, some challenges remained. A few reported that certain process improvements did not yield expected efficiency gains, requiring further adjustments. Others highlighted the difficulty of sustaining changes over time, particularly when faced with fluctuating workload demands and varying levels of staff engagement.

Overall, the qualitative findings suggest that task analysis training fostered a mindset of continuous improvement, encouraging staff to take a more structured approach to problem-solving, improve workplace organization, and enhance communication within their teams. However, the long-term sustainability of these changes requires further support and reinforcement at the organizational level.

4. Discussion

The findings of this study offer valuable insights into the effects of task analysis training on WE, OBSE, and various job characteristics.

4.1 Work Engagement and Organizational-Based Self-Esteem

The training resulted in a significant increase in OBSE scores, suggesting that participants felt more valued and confident within their organization after completing the program. This improvement in OBSE may be attributed to the structured approach and skill development fostered by the training, which likely enhanced participants' perceptions of their roles and contributions. Previous research has shown that OBSE is positively related to in-role performance and can be enhanced through formal training and development-focused feedback (Hahn & Mathews, 2022). However, the slight increase in WE scores was not statistically significant, indicating that while participants experienced a greater sense of esteem, this did not necessarily translate into higher engagement levels. This discrepancy underscores the complexity of factors influencing WE and suggests that additional interventions may be required to enhance engagement more effectively (Phuong & Thi Ngoc Quynh, 2022).

4.2 Job Characteristics

The significant increase in quantitative job overload after training was an unexpected outcome, given that the program aimed to streamline workflows and reduce physical strain. This finding suggests that while the training may have enhanced organizational efficiency, it also contributed to a heavier workload—possibly due to heightened expectations or more efficient task completion leading to additional responsibilities. Previous studies have shown that task analysis can improve productivity and optimize work processes; however, if not properly managed, it may inadvertently increase workload (Keiser & Arthur, 2022; Grant, 2008). The lack of significant changes in qualitative and physical demands, as well as in job satisfaction and career development opportunities, further highlights the need for a balanced approach that not only enhances efficiency but also effectively regulates workload and supports employee well-being (Huang, 2019; Kanuto, 2024).

4.3 Correlation Between Work Engagement and Job-Related Factors

The negative correlation between physical demands and WE suggests that as physical demands increased, participants' engagement also tended to rise. This counterintuitive finding may indicate that participants felt more engaged when physically active or

challenged, possibly due to a sense of accomplishment or the dynamic nature of their tasks. Previous studies have shown that engaging in physically demanding or challenging tasks can enhance WE by fostering a sense of achievement and dynamism (Shimazu et al., 2008; Schaufeli & Bakker, 2004). However, the moderate to weak correlations with other job-related factors, such as job meaningfulness and supervisor support, were not statistically significant, suggesting that these factors alone may not strongly influence changes in WE. This finding aligns with prior research indicating that while job resources like supervisor support and job meaningfulness are important, they may not be sufficient on their own to significantly impact WE without the presence of additional motivating factors (Tanuwijaya et al., 2022; Alshurideh, 2023).

4.4 Qualitative Insights

The qualitative findings complement the quantitative results by highlighting key themes related to workflow improvements, training effectiveness, and perceived changes in job performance. Participants reported enhanced workplace organization and efficiency, improved communication and collaboration, and increased task awareness and proactive problem-solving. These improvements suggest that the training fostered a mindset of continuous improvement and encouraged participants to adopt a structured approach to problem-solving. However, challenges such as sustaining changes over time and managing fluctuating workload demands indicate that ongoing support and reinforcement at the organizational level are essential for the long-term success of such training programs.

Furthermore, the successful application of task analysis practices by participants may be attributed not only to individual motivation, but also to a pre-existing organizational climate that supported collaborative learning and staff initiative. Such an environment—characterized by trust, open communication, and leadership receptivity—reflects what workplace innovation (WPI) literature identifies as “innovation-conducive conditions” (Pot, 2011; Borrás & Edquist, 2013). These conditions enable bottom-up change to take root and evolve into broader organizational learning. Although the training lasted only five weeks, its perceived benefits suggest that the intervention was embedded in a workplace culture that allowed experimentation, reflection, and shared improvement. This underscores the importance of aligning individual-level interventions with supportive organizational structures to achieve sustainable innovation.

Conclusion

Overall, this study demonstrates that task analysis training can significantly enhance OBSE while improving workplace organization and efficiency. However, the increase in quantitative job overload, along with the lack of significant changes in WE and other job characteristics, highlights the need for a more balanced approach that prioritizes both efficiency and employee well-being. Future research should explore additional interventions to enhance WE and examine the long-term sustainability of training outcomes.

In addition, this study suggests that task analysis training may serve as a practical example of employee-driven workplace innovation. By empowering frontline staff to analyze and improve their own work processes, the program exemplifies bottom-up approaches that align with the principles of participatory innovation (Totterdill et al., 2016; Pot, 2011). Embedding such practices within supportive organizational environments may contribute not only to individual development but also to sustainable organizational learning and adaptability.

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Appropriation of SMART Glasses

A Qualitative Study on the Long-term Use of SMART Glasses in Healthcare

Niek Zuidhof, Oscar Peters, Peter-Paul Verbeek, Somaya Ben Allouch

Abstract

Smart glasses could revolutionize healthcare workplaces. Despite pilot studies, long-term use insights are limited. This study examines nurses using smart glasses (Vuzix M400) for wound care over several years. In the use case presented in this study, nurses visit patients at home, consult remote experts via smart glasses, and treat patients accordingly. However, since knowledge about the long-term use and appropriation of smart glasses is scarce, this study aims to understand long-term use experiences through interviews with home care nurses (n=7), remote wound care nurses (n=7), and hospital managers (n=3). Data were analysed using directed content analysis, revealing four main themes: personal experience, collaborative experiences, unanticipated consequences, and future needs. Respondents reported personal habits, emotional aspects, and experiences when working with smart glasses. In collaboration through smart glasses, respondents mentioned the increased quality of care and the change in interdependencies.

Furthermore, working together via smart glasses had an impact on care at home as well. The consequences of the long-term use of smart glasses led to more feedback between nurses and patients, and to shifts in tasks between stakeholders. Future needs for smart glasses lie in further coordination with various stakeholders: patients, colleagues, IT, management, and developers of smart glasses. In conclusion smart glasses enable hands-free, high-quality home care, where an expert advises with a first-person perspective, the nurse learns new skills and a vulnerable patient can remain in the comfort of their environment. Despite it is currently cost increasing, it also saves time and space in the hospital.

Keywords: smart glases, appropriation, healthcare, workplace innovation

Introduction

Increased use of smart technologies can play an important role in addressing the ageing population (Liu et al., 2016) but also in working during a pandemic like COVID-19 (Martínez-Galdámez et al., 2021). On the one hand, it offers the opportunity to provide care to vulnerable elderly people at home, on the other hand, expertise can be provided remotely and may contribute to dealing with staff shortages. Wearable technology such as smart glasses is promising for distinct market segments in professional settings such as engineering and technical fields but also in specialized settings for instance in firefighting or the medical field (Kress, 2014). There is a growing body of literature describing first experiences with smart glasses (Han et al., 2019; Mason, 2016; Mitrasinovic et al., 2015; Mühlematter & Donno, 2016; Sobieraj et al., 2023; Zuidhof et al., 2022), but very little is known about experiences in long-term use and even less is known for the specific target group of nursing.

In healthcare, there are several use cases for smart glasses that have been experimented with, for instance in surgery (Muensterer et al., 2014; Singh & Klein, 2014), emergencies (Schaer et al., 2015) or wound care (Ye et al., 2016). Google Glass (see Figure 1) is a type of smart glasses that is both famous and infamous. Although there are privacy issues with smart glasses in general (Basu, 2014; Hofmann et al., 2017; Hong, 2013), it was suggested to have less impact on the potential user, but possibly more on the outsider who is confronted with a user of smart glasses (Rauschnabel et al., 2018). Turning back to the healthcare context, this does not seem to play a role for the patient (Odenheimer et al., 2018). However, what has not yet emerged here is that also more stakeholders besides the nurse and the patient can be involved in the use of smart glasses. For instance, smart glasses are used in wound care, and in that use case, a nurse (user), a patient (Wüller et al., 2018), but also a remote expert are involved. The use of smart glasses might lead to situations of task shifting and task sharing between stakeholders.

Figure 1. Image illustrating as a general example how smart glasses can be used by a nurse in the home environment for wound care (published with permission)

Whether or not people want to use smart glasses is examined by technology adoption models (Goken et al., 2016; Özdemir-Güngör et al., 2020). Although acceptance models are

continuously adapted to the use case and context, a limitation is that research in this way remains a snapshot of technology diffusion, for instance, whether someone wants to use it or not. Beyond the scope of these models, it is also known that people and technology continuously shape each other (Bijker & Law, 1992) and by viewing smart glasses as a mediator between humans and the outside world (Verbeek, 2015), it is possible to gain insight into a broader perspective of not only smart glasses acceptance but also of sustained use concerning the interaction with the environment. Knowledge about appropriation may provide new information about how we experience adoption, use and how we interact with smart glasses and each other (Zuidhof et al., 2019) see Figure 2. This study aims to gain insight into influences on sustained use and future needs in the workplace by long-term users such as nurses and stakeholders of smart glasses in healthcare. The research question of this study was: *what influences does the long-term use of smart glasses have on peer collaboration in patient care?*

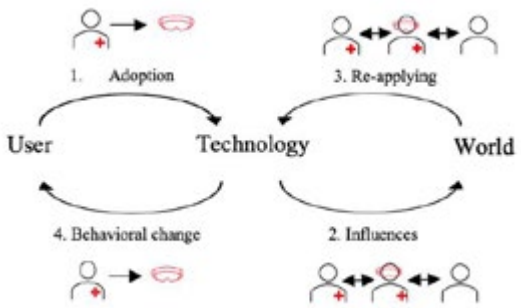

Figure 2. The theoretical framework to study the long-term use of smart glasses derived and adapted from Zuidhof et al. 2019

Methods

The current study included interviews with healthcare professionals involved in smart glasses use from three perspectives, the smart glasses user, the remote expert, and the manager. Interviews offer an effective way to obtain in-depth information. In addition, themes can be made transparent in analysis in this way. This study was reviewed and approved by the Ethics Committee of the Behavioural, Management, and Social Sciences of the University of Twente, The Netherlands (approval number: 200946). All participants provided written informed consent.

Participants

Interviews were carried out (n=17) with nurses as users of smart glasses (n=seven) from a Dutch healthcare organization, wound care nurses working as remote experts (n=seven), and managers (n=three) of a Dutch hospital. One wound care nurse was excluded because the

inclusion criterium of minimum experience of three months of smart glasses usage was not met. The average experience with smart glass usage was over three years (m=45.9 months, sd=29.3 months). The respondent group consisted mainly of women (88%) and the mean age was 47.17 years old (sd=11.46).

The participants were interviewed about the following use case for smart glasses. Before smart glasses were introduced, a patient with a complex wound had to return to the hospital regularly for a check-up by the wound care nurse. Due to physical limitations, a patient may be brought by a caregiver or taxi. In the situation of using smart glasses, a nurse visits the patient at home and after unpacking and cleaning the wound, she puts on the smart glasses (Vuzix M400) and connects with the wound care nurse in the hospital. Then they discuss the cure on the spot and the nurse at the patient's home receives treatment instructions from the remote expert.

Procedures

To identify relevant insights into the long-term use of smart glasses and workplace needs, the theoretical framework was used as a basis for semi-structured interviews (see Figure 2) and is based on the knowledge of technology adoption and technology mediation (Zuidhof et al., 2019).

Data collection

Data was collected with semi-structured interviews with the following topics: experience of use, social influences during use, behavioural changes, technology acceptance, and the future of healthcare.

Data analysis

The interviews were transcribed verbatim and anonymized, analysed with directed content analysis, and coded with an inductive approach since only broad topics regarding adoption, use, and consequences were known. Approximately 10% of the data were independently coded and discussed by two researchers with an intercoder agreement in two rounds (Cohen's Kappa .71).

Results

Themes derived from the analysis can be divided into four main groups: personal experiences in the use of smart glasses, the experiences in peer collaboration, consequences of sustained use, and needs for future use of smart glasses in the workplace.

Personal experiences in the use of smart glasses

"Very positive because I think it's a really good development. It is for older people, usually the group we work with, that it is often so difficult to come to the hospital. Then you have to arrange a taxi because the children live far away. It's all tricky. How nice is it that you can just do the check at home? (...) There is contact between the wound clinic and the patient. I think it's great. It is a bit more work for us, but in the end, it will inevitably save time and money. In the planning, but also the healthcare costs. If you work that out properly and start working with it much more, that is simply a very positive development." (Respondent nine)

Table 1. Demographic characteristics of the participants (n=17)

Category	Specification	Number of respondents
Gender	Male	2
	Female	15
	Prefer not to say	
Year of birth	<1950	
	1950-1959	2
	1960-1969	4
	1970-1979	7
	1980-1989	2
	1990-1999	2
Highest degree	High school or less	2
	Some college but no degree	2
	Associate degree	
	Bachelor's degree	14
	Master's degree	
	Professional or Doctoral degree	1
Years of work experience	3 months – 1 year	2
	1-3 years	6
	3-6 years	9
Relationship with smart glasses	User (nurse)	7
	Distant user (remote expert)	7
	Manager	3

The nurse uses smart glasses directly at the patient's home and the wound nurse is indirectly involved, remotely in the hospital. Both return that *habit* plays an important role in their experience. Over time, they have become more accustomed to using smart glasses, with the nurse at the patient's home becoming increasingly skilled in using them and the remote expert saying that it was mainly a matter of time to get used to them. this way of working. There were also *emotional aspects* to the personal experience, both are enthusiastic about their tasks, although the work can now be a bit more stressful for the user, and that sometimes creates some tension. This can be understood by how the experience of *working with smart glasses* is perceived. Important aspects were the stability of technology in the context and the number of steps that must be taken before a connection is established. For

example, the success of a dial-up moment via smart glasses is determined by whether the connection is stable. Mobile use of internet connections and visiting rural or more remote areas can sometimes lead to connection problems. If there is a weak connection, a consultation is not successful and has cost the patient, nurse, and remote nurse time and frustration. Furthermore, issues can arise in the wearing comfort for the user, for example in combination with wearing eyeglasses.

Table 1. Themes regarding personal experiences in the use of smart glasses from a user and remote expert perspective

Perspective	User of smart glasses (Nurse)	Remote expert in hospital (Wound care nurse)
Theme		
Habit	More skilful in the use	Takes time to get used to
Emotional aspects	Tension before use	
	Enthusiasm	Enthusiasm
Work with smart glasses	Multiple actions before use	One action to use
	Weight and fit issues	Connectivity issues

Experiences in peer collaboration using smart glasses

"People are now in the hospital for a shorter time, but they go home more complex. You do have to improve the quality of district nurses, of course, you must provide relatively much care in the home situation" (Respondent 11).

The experiences of working together with smart glasses are described from four perspectives, see Table 2. The interviewees were the nurse working with smart glasses working, the nurse working as a remote expert, and the manager. Patients were not interviewed because of COVID-19 lockdowns, but they were asked about their experiences as perceived by the nurses.

All four stakeholders showed that the *quality of care* has increased by working with smart glasses. This is primarily due to better and synchronous contact in the coordination between different healthcare providers that would otherwise not have been possible because it is normally asynchronous. The user and manager also indicate that in this way learning is also done while working, directly in patient contact. For example, the nurse at the patient's home can consult with the remote expert and receive guidance where necessary. Another aspect that contributes to better coordination is that the remote expert better understands the situation. Normally, the patient comes to the hospital neatly dressed for a check-up for example, but now there is an image of the home situation, in addition, there is also the patient who indicates that he is allowed to participate in the conversation and therefore feels seen and involved in the treatment. For instance, it may happen that a cat is lying on the

patient's lap near a complex wound, this situation provides an opportunity to discuss wound healing and hygiene and is something that might be less likely to be discussed in the hospital this way.

The use of smart glasses also entails *interdependencies between stakeholders*. A good relationship with the remote expert is important for the nurse to function properly with smart glasses. All parties are enthusiastic about working together via smart glasses, provided the technology works well. In line with this, another important condition for good cooperation is that there is mutual trust and that there is the possibility of low threshold contact for asking a short question or for peer consultation about a situation in which a nurse would like to share responsibility for patient care. The course of the consultation with smart glasses depends on the expertise of the remote expert on the complex wound on the one hand and on the user's ability to both work with smart glasses and translate the advice of the remote expert on the other hand to practice. This may mean that certain actions must be performed under the supervision of the remote expert or that certain advice in wound care must be discussed with the patient. There are also dependencies outside the care providers, namely those of informal carers. The pressure on informal care is reduced because the patient can stay at home and does not have to travel, which in some cases an informal caregiver would accompany.

Table 2. Themes regarding peer collaboration using smart glasses

Perspective Theme	User (Nurse)	Remote expert (Wound care nurse)	Patient at home	Manager (Hospital)
Raised quality of care	Better coordination			
	Learn from specialist	Better understanding		Bedside teaching
Interdependencies between stakeholders	Good relationship	Positive communication	Surprised Enthusiasm	Enthusiasm if it works out for everyone
	Low-threshold contact	Trust in relationship	Trust in both caregivers	More insight into process
	Added value depends on remote expert	Dependent on skills of district nurse	Less intensive for informal carers	Attention from others outside the organization
Care at home	More personal	Personal touch	Prefer home / Prefer hospital	
	Vulnerability (privacy), awareness of privacy	Faster policy Hospital is responsible Less inpatient care	No privacy issues reported Fewer travels	More space in the hospital for emergencies

"People are in their home environment, see other opportunities in the video call and say, for example: "Look, this is my dog I was talking about", or "You should see my front yard". This makes care more personal." (Respondent one)

Care that can be provided at home through smart glasses support is experienced in different ways, namely more personal, with additional vulnerabilities and consequences for hospital occupancy. For the nurse, working in this way is more personal because of the direct and synchronous contact with both the patient and the remote expert. This also applies to the

Table 3. Unanticipated consequences of sustained smart glasses usage

Perspective Theme	User (Nurse)	Remote expert (Wound care nurse)	Patient at home	Manager (Hospital)
Feedback	Receive more feedback	Give more feedback to nurse, patient	More involvement in the conversation	More interdisciplinary discussions
Preparation	Checks needed before use (batteries) More scheduling	Ask additional questions to clarify	Less hassle	Mediate between nurses and patients
Training	Aiming the camera at the wound takes practice	Taking turns takes practice		

remote expert because, due to the home environment, there is also a more personal touch to the contact with the patient, whether through contact with smart glasses. In addition, there are patients with a strong preference to receive care at home, on the other hand, there are also patients who see a visit to the hospital as an activity in the day and experience it as an 'outing'. The home situation in combination with technology also entails vulnerabilities, the nurse is very aware of this and discusses how the patient's privacy is guaranteed by, for example, not showing what is unnecessary, setting up a mobile connection, and discussing safety with the organizations involved. Until now, patients have never expressed any concerns regarding their privacy according to the respondents. It is also important for the remote expert they communicate clearly that they remain responsible for the treatment. This home care results in a faster policy for the remote expert and more space for the hospital at the location because this care has been relocated (see Table 2).

Unanticipated consequences of sustained smart glasses usage

“It is true that in the beginning, we said: gee, are you not wearing an apron or are you not wearing gloves or are you still wearing the jewellery? They are things that you can see

someone working on at home. Now you see that they no longer have sleeves underneath and they don't wear jewellery, even when we take pictures that they have gloves on. I think that something has changed in that sense if they have done something with the tips that we have given. Normally you have no control over someone who works in a home situation. (...) If you see that it also happens at home, you can point it out. Those things will change." (Respondent two)

Some aspects were not foreseen by the respondents, but looking back on their experiences, these have become an integral part of their work when they were not before. As mentioned earlier, there is therefore more synchronous contact between nurses, while at the same time, *feedback* is also given by the remote expert during the consultation and received by the nurse at the patient's home. Examples of this can be not having taken off a scarf or wearing and changing gloves. In addition, the patient is also involved in the conversation and the feedback sometimes also focuses on the patient about hygiene such as contact with pets. These interdisciplinary discussions have also been noticed by management and are perceived as positive for the quality of care and the patient's self-reliance. Another part is the necessary *preparations*. The nurse who works at the patient's home has been given extra tasks, such as checking whether the battery is sufficient, whether the device works properly and does not need to be updated, for example, but also the proper management of the agenda, after all, the contact moments must be coordinated with the patient and the hospital. Few additional tasks are required for the remote expert, other than carefully asking what is seen on the screen. For example, the colour of the wound must be checked and can be influenced by the quality of the camera or the incidence of light on the patient. For the patients, the preparations for a check-up are considerably reduced because they can stay at home. At an organizational level, coordination between institutions is often required for proper operation with smart glasses. Finally, a consequence is that *training* is needed for a smooth contact moment. Due to the position of the camera on the glasses, the nurse must practice aiming the camera in such a way that the remote expert can get a good picture. Another consequence for both the nurse and the remote expert is that because of the connection, it is sometimes difficult not to talk at the same time (see Table 3).

Future needs for smart glasses usage

"I'm thinking in the direction of privacy. We talked this morning about how scary it is right now. You now have the cookies that you find everywhere on the internet. That I am now discussing this subject with you, and I will come across this subject two hours later. That is apparently eavesdropped by an app. I find that frightening because (...) I tell something intimate. (...). In terms of privacy, I assume that all this is guaranteed, but I could be concerned about that."(Respondent three).

To continue working with smart glasses there are several *needs from the stakeholders*, the respondents consider it important that privacy and security are as optimal as possible. Although they are aware of this and comply with laws and regulations, this is also an area

that is difficult to trust. Good cooperation with other specialists in the field of IT and human resources is important to keep checking this. Another point is the loss of human contact, which remains of great importance to the nurse who works at the patient's home and is also a reason to do this work. They find it important that, despite working with smart glasses, attention is also paid to personal contact and see opportunities to tailor this to the wishes of the patient, because we have seen that one patient prefers to stay at home and the other just like that. love to visit a hospital. Optimal interaction is an important theme for the remote expert, how can you communicate well at a distance, deal with the possibilities and limitations of smart glasses and be and remain responsible for the treatment? For example, what tasks can you have a nurse perform under supervision and when do you call a patient back to the hospital? This requires further exploration. At the organizational level, scaling up is complicated. After a subsidy, the question arises who can and should bear the costs, and who benefits most from this intervention? At the moment it costs money because the hospital manages the glasses and buys software support from a supplier, at the same time there is a saving in the time that the remote expert spends on a check, which needs further investigation. Other *needs that come into play specifically for smart glasses* are possibilities that lie in integration with the electronic patient file, so that reports can be made at the same time, for example. For the remote expert, a detachable camera would be useful for a better view of a complex wound in a dark environment or a location that is difficult to capture, for example with a deep wound. Coordination with designers and developers is necessary to better integrate the smart glasses into the work and to appropriate them even better (see Table 4).

Table 4. Needs for future use in the workplace

Perspective	User (Nurse)	Remote expert (Wound care nurse)	Manager (Hospital)
Theme			
Needs from the stakeholders	Privacy and security must be optimal		
	Loss of human touch: keep face-to-face, tailor, to needs	Optimal interaction between nurse and expert	Scale up but the business case is difficult, dependency on fees
Needs towards smart glasses	Integration of electronic health record	Detachable camera for close-ups	Collaboration with designers/developers

Discussion

This study aimed to gain insight into the influences of long-term use and future needs regarding the use of smart glasses in healthcare. Although studies regarding long-term users with a clear use case are scarce, the present study investigated how different stakeholders reflect on their use, how the collaboration between user and remote expert is represented and which needs arise for continued use in the context of wound care.

As the most important conclusion in personal experiences of the nurse and the remote nurse in working with smart glasses, the increase of skills and enthusiasm in use is central. This finding contradicts earlier findings of potential users who presented many concerns when anticipating use (Due, 2015; Honan, 2013; Hong, 2013; Lawler, 2014; Zuidhof et al., 2022). The reason for this difference may be that the previous studies mainly focused on Google glass and the use of the current glasses (Vuzix M400) offers more possibilities to handle data safely in accordance with European laws and regulations. Due to the use of different type of smart glasses and also different use case, more positive evaluations were seen in this study compared to other studies (Yu et al., 2016). Furthermore, in working together via smart glasses, the nurse at the patient's home and the wound care nurse can coordinate better and learn from each other, which ultimately increases the quality of care. An important interdependence in cooperation is the relationship and the quality of the contact through trust and constructive feedback. A result of providing care at home is creating a more complete picture of the patient, which also potentially will save on hospital staffing and reduces travel movements.

Subsequently, unanticipated consequences that have changed the work lie in the collaboration and especially direct communication between the user, remote expert, and the patient. Other skills are also important, such as proper preparation and planning of daily work activities with smart glasses. Needs for continued use again lie in collaboration where privacy and safety must be paramount and coordination between all stakeholders can be improved, also considering the needs of patients. Patients do not appear to be concerned about privacy, which is in line with previous research (Odenheimer et al., 2018). This may be due to the trust of the patients in the healthcare provider. That the need for optimal privacy and security must be and remain present is in line with other studies on smart glasses and is confirmed by these studies (Adenuga et al., 2019; Hong, 2013; Kudina & Verbeek, 2018; Przegalinska, 2019). Furthermore, smart glasses can be improved in terms of software and hardware for every stakeholder, and involving the stakeholder in the development of smart glasses is essential. There is also a role here for an organizational role for instance in management and human resources to facilitate collaboration across institutions, collaboration with IT to tailor security and technology to users and train users for optimal alignment, communication skills, and efficient planning of work with smart glasses for the optimal use of technology.

An interesting outcome is that the theoretical framework (Figure 2) focused on behavioural changes and they were also partly found, but respondents also looked ahead and stated their needs for continued use. This result is in line with both the diffusion of innovations (Rogers, 1983) but also with the theoretical framework (Figure 2) in which it is assumed that appropriations fit into an infinite lemniscate in which humans and technology gradually shape each other (Bijker & Law, 1992; Pinch & Bijker, 1984). The theoretical framework used in this study (see Figure 2) was based on a combination of adoption and interaction with technologies from the perspective of appropriation (Zuidhof et al., 2019). Previous work on the adoption and appropriation of mobile technologies has been conducted in other

contexts such as with young people or in the household. The attractors and appropriation criteria that were found for young people (Carroll, Howard, Vetere, Peck, & Murphy, 2002) do not seem applicable to this professional setting in healthcare except for safety and security. The same applies to the domestication approach, which distinguishes four elements: appropriation, objectification, incorporation, and conversion (Silverstone & Hirsch, 2003). In this professional context, there is no personal purchase or ownership (appropriation in the domestication approach), or it takes up a place in the household (objectification in the domestication approach), but there is incorporation and conversion that can best be compared with the theme found in this study on the influences in the collaboration with others, namely how smart glasses are used over time and what unanticipated consequences the use of smart glasses has.

Regarding the different scope and therefore absence of the workplace in influential theory on appropriation (Silverstone & Hirsch, 2003), appropriation in mandatory settings provide valuable insights for organizational support and to better understand the findings in this, such as found in the use of IT in mandatory settings. In Engelbert's proposed model of appropriation, cognitive, social, and technical aspects shape the attitude towards appropriation and the resulting appropriation itself (Engelbert & Graeml, 2013). This study confirms the perceived differences in time and experience with smart glasses. However, objective appropriation as the ultimate endpoint of this process does not seem to have been achieved. Rather, as stated above, it can be perceived to be a mutual and ongoing process that continues to evolve over time, as suggested in the framework of long-term adoption (Figure 2). In the present study, the identified needs for future use indicate that further development may be necessary, particularly concerning technical aspects (e.g., detachable camera), social aspects (e.g., optimizing the feedback culture among professionals through smart glasses), and an element not explicitly covered in Engelbert's model: the revised business case informed by previous experiences.

Furthermore, workplace innovation offers recent research on augmented telework (Watanabe, 2023) and a useful framework within which to situate the experiences of professionals and managers reported in this study, especially regarding the impact on skill development, social and functional support, autonomy in nursing, and task variety. The concept of hospitality for telework appears to be relevant, as the unanticipated consequences in giving and receiving of feedback was a surprising finding in this study. Little evidence was found in the experiences described of increased work pressure or physical strain, which seems to be largely attributable to the specific use case in this study (short-term use of smart glasses) and the healthcare context in which this study was conducted, where the inherent variety of tasks is already substantial. The context-dependence and the continuous evolution of workplace dynamics highlight the need for ongoing implementation and appropriation research into such innovations, especially considering the inherent limitations of each individual study.

Limitations and future directions

This study was limited by the absence of input from a key stakeholder, namely the patient. The focus of this study was aimed at nurses and managers, but the patient is an indispensable stakeholder. However, this study was conducted during the COVID-19 pandemic and lockdowns, it was therefore impossible and irresponsible to ask vulnerable patients to participate in this study. The primary reason why patients could not be included in this study was that, during the COVID-19 pandemic, many nurses were deployed to intensive care units, and appointments for other types of care were postponed wherever possible. Despite this we recognize that, from the perspective of workplace innovation, the lack of patient voices limits our ability to fully evaluate the socio-technical dynamics involved. Another limitation is that the interviews were conducted digitally via video calls due to COVID-19 lockdowns. Despite a good connection and satisfaction with the researcher, an interview might have gone differently if it had been conducted face-to-face.

In terms of methodology, this study has demonstrated how different stakeholders experience innovation and what is needed for further development. Given that patients are central to this context, they should now be included as restrictions related to COVID-19 have eased. Additionally, HR emerges as an important stakeholder to consider, alongside insurers (or other actors responsible for funding), to enable a more comprehensive integration at the managerial, strategic, and systemic levels. From both a theoretical and practice-oriented perspective, the themes and job characteristics of SMART work design could provide an interesting lens for organizational conditions and psychological processes (Parker & Knight, 2024), complementing the framework for long-term adoption (Figure 2). Together, they offer valuable insights into how workplace innovation and technological innovation can be optimally aligned with the needs and experiences of each stakeholder.

In summary, by looking at the appropriation of smart glasses, we found that initial concerns about use, such as privacy, are much less prominent than previously thought in anticipated adoption. Possibly the benefits after long-term use outweigh the initial barriers. Furthermore, long-term use of smart glasses facilitates hands-free, high-quality home care, where an expert advises in a first-person perspective, the nurse learns new skills and a vulnerable patient can remain in the comfort of their environment.

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Zooming in on the Impact of Collaborative Robot Arms in Manufacturing Workplaces:

A Comparative Case Study

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Abstract

Collaborative robot arms (cobots) are gaining a strong foothold in contemporary manufacturing workplaces. While more information about the cobot's impact becomes available, crucial design, work perception, performance, and strategic implications are systematically overlooked. Following a modern sociotechnical systems design theory (MSTS) perspective, which lies at the heart of workplace innovation literature, we studied if, how, and why the cobot made production units more resilient and strategically relevant. We ran a comparative case study involving 15 Dutch small- and medium-sized manufacturing enterprises (SMEs) and 36 interviewees (managers and operators). The results describe how the cobots are designed as autonomous and rigid mini-robots, handling one or a few high-quantity products in ways that are not inherently more reliable and efficient. Operators interacting with the cobots experience stronger motivational work characteristics, but the cobot's autonomous and stable operation also provokes classic out-of-the-loop problems. Consequently, cobot-equipped production units do not always perform better. Nonetheless, SMEs deem their units strategically relevant since they (indirectly) improve financial flexibility, increase production capacity, streamline future automation projects, and accommodate the resolution of labor scarcity issues. This research creates a pathway for more MSTS and workplace innovation research at the crossroads of human-robot interaction, organisational design, production management, applied psychology, and entrepreneurship. Practical implications are provided and discussed elaborately.

Keywords: Modern sociotechnical systems, workplace innovation, collaborative robots, future of work, comparative case study, small- and medium-sized enterprises, industry 5.0

Introduction

Rising labor shortages (European Labour Authority, 2022), high and diversifying customer demands (Pech et al., 2022), an ageing workforce (European Commission, 2023), and the Industry 5.0 policy agenda (European Commission, 2021) are just four of many external developments requiring manufacturers in Western Europe to produce more and more diverse products with fewer operators. Consequently, manufacturers must continuously increase the resilience of their production units to ensure sufficient output is generated to meet customers' demands (Romero et al., 2021). Increasing production unit resilience is a strategic issue since it affects the manufacturer's maximum production capacity. The ability to satisfy customer demands quickly and effectively is a crucial source of competitive advantage in manufacturing (Daugherty et al., 1992; Sullivan et al., 1999; Alqershi et al., 2020).

Adaptive production technologies that directly interact with and support the operator bear great potential to improve the resilience of labor-intensive production units sustainably. These technologies include pick-to-light systems that guide assembly tasks (Hercog et al., 2022), augmented reality smart glasses that project work instructions (Danielsson et al., 2020), and smart apps connected to the Industrial Internet of Things that enhance more informed decision-making (Muriathinam, 2020). However, the technical complexity of these technologies makes applying and changing them complex, lengthy, and costly activities (Bajic et al., 2020; Stentoft et al., 2021; Sony et al., 2021). This is particularly problematic for small- and medium-sized manufacturing enterprises (SMEs) that, in contrast to large manufacturers, have fewer financial and (specialised) human resources to invest in automation initiatives (Prajogo et al., 2014; Indrawati, 2020; Estensoro et al., 2022). Fortunately, adaptive production technologies are available and highly accessible to SMEs. The collaborative robot arm (cobot) is one of them.

Like a traditional industrial robot, the cobot can be equipped with a broad range of tools and used for many tasks, such as welding, packing, assembling, drilling, inspecting, and machine (un)loading (Bauer et al., 2016; Kadir et al., 2018; El Makrini et al., 2018; Salunkhe et al., 2019; Wolffgramm et al., 2021). However, the cobot is considered easier to use, faster to (re)deploy, safe for direct interaction with operators, and more affordable (Hentout et al., 2019; Sherwani et al., 2020; Javaid et al., 2022). These features are relevant for SMEs since they could increase production unit resilience while demanding limited resources. More specifically, the cobot's reach, payload, and speed require, depending on the application and human-robot interaction, fewer safety-related investments, such as cages and external sensors (Bi et al., 2021). Lower safety-related investment saves on purchasing costs, but also on floor space. Moreover, given the user-friendliness of the cobot's hardware and software (El Zaatari et al., 2019), there is a higher chance that SMEs can swiftly (re)program the cobot without the help of expensive consultants. In other words, the cobot appears to be a promising investment object for SMEs to increase production unit resilience radically. Unfortunately, in line with Cohen et al. (2021), "the

cobot literature has been quite blurred when it comes to the justification for the acquisition, installation, and deployment of cobots" (p. 15).

As attested by many literature reviews, considerable scholarly attention has indeed been paid to cobot's interaction with the operator and its impact (e.g., Wang et al., 2019; Cardoso et al., 2021; Gualtierl et al., 2021; Javaid et al., 2022; Liu et al., 2022; Faccio et al., 2023). These impacts could be roughly divided into two categories. The first category concerns the impacts of cobots on human factor outcomes, including physical ergonomics, mental workload, trust, acceptance, and usability (Rücker et al., 2018; Gervasi et al., 2020). The second category encompasses cobot-related impacts on performance outcomes at the production unit level (e.g., productivity, task completion time, error rates, and quality [Matheson et al., 2019]) or at the production system level (e.g., flexibility, reconfigurability, and agility [Faccio et al., 2023]). While the available empirical evidence provides an impression of the cobot's deployment and impact, we note that the current knowledge base fails to describe how the cobot affects production unit resilience and what organisational significance this impact holds. Arguing from a modern sociotechnical systems design theory (MSTS) viewpoint (de Sitter et al., 1997; Kuipers et al., 2020), centrally positioned in workplace innovation literature (Oeij et al., 2023) and concerned with aligning technical and social subsystems for sustainable and robust production, a cobot is a *workplace innovation* that requires more scholarly attention. We provide three reasons.

Firstly, information about the task allocation between the operator and the cobot and their mutual reliance, or interdependence, is limited to a functional approach (i.e., who does what? [Sheridan et al., 1978; Onnasch et al., 2014]). The classification by Bauer et al. (2016) or a familiar buildup is often used to classify the human-cobot interdependence based on whether they share the same workplace and how simultaneously they work on the product (e.g., Segura et al., 2021; Dornelles et al., 2023). Such a classification gives an impression of how the human-cobot production unit is designed, but it leaves out important details about the alignment of the operator's and cobot's capacities (i.e., are the operator and the cobot mutually strengthening each other? [Johnson, 2014; Wolffgramm et al., 2024]). Moreover, there is uncertainty about the product quantities and variations that the operator and the cobot, as a production unit, are supposed to handle (i.e., their functional requirements). It is particularly unclear whether these requirements differ from those of the production unit's 'previous version' (e.g., when the operator still had to execute all tasks manually). The lack of empirical evidence about the human-cobot interdependencies' functional requirements and capacity alignment is problematic since it leads to incomplete descriptions and suboptimal explanations about their impact on human factors and performance outcomes.

Secondly, important aspects of the operator's work perception are systematically understudied. Baltrusch et al. (2022) and Shaba et al. (2024) are the only ones we are aware of who conducted a literature review to clarify the link between cobot deployment and the operator's job quality

(i.e., the quality of the working environment related to the operator's well-being). Even though some or neighbouring elements were mentioned, such as autonomy, trust, and awareness, they clearly illustrated that there is no research available that extensively reports the cobot's impact on how the operator perceives its job design (i.e., the contents, methods, and relationships of jobs [Armstrong, 2001]). Moreover, cobot literature overlooks whether the operator shows out-of-the-loop symptoms when working with the cobot (i.e., implications related to the operator's removal from the control loop [Kaber et al., 1997]). These work perception insights are crucial since they both indicate whether the operator can sustain the human-cobot interdependence over time. The quality and continuity of the operator's input have considerable consequences for the performance of the human-cobot production unit and, thus, its resilience.

Thirdly, we noticed a blind spot for the cobot's strategic impact. While some scholars have highlighted the cobot's macroeconomic relevance, none of them have studied it directly (Kadir et al., 2019; Knudsen et al., 2020). Moreover, a recent literature review by Liu et al. (2022) identified 59 future research opportunities in cobot-related studies. None of these studies suggested investigating the cobot's strategic contributions. We find the same in other literature reviews (Matheson et al., 2019; Hentout et al., 2019; Sordan et al., 2021; Baltrusch et al., 2022). Vido et al. (2020) seemed an exception to this as they actively studied the impact of cobots on competitive priorities. Nonetheless, their work was limited to the operational phenomena after all. Thus, as far as we know, no academic effort has yet been directed towards clarifying the cobot's strategic impact. One concept that is likely to be influenced by the resilience of the human-cobot production unit is the SME's strategic flexibility. In line with Brozovic (2018), strategic flexibility is commonly defined as "the degree to which a firm is willing to change its strategy in response to opportunities, threats, and changes in the external environment" (Zahra et al., 2008, pp. 1043-1044).

These three shortcomings concerning the cobot's operational and strategic impact have profound implications for SMEs considering investment in cobot technology, as well as those that have already made such an investment. For SMEs that want to invest in cobot technology, it is unclear whether the design of documented human-cobot interdependencies comes with an acceptable and sustainable alignment between operator and cobot capacities. Moreover, they are uninformed about the outcomes generated by these human-cobot production units, how these outcomes differ from previous production units, and what they contribute to the SME's strategic flexibility. Consequently, SMEs might invest their scarce resources in an asset that cannot meet their operational and/or strategic expectations. For SMEs that have already invested in the cobot technology, there is no exemplary work that allows them to benchmark their cobots' impact extensively. These SMEs might unknowingly accommodate a human-cobot production unit that comes with a much lower impact than expected. To guide their (re)design efforts, both SME types benefit from rich examples of human-cobot production units that, ideally, come with more resilience and a convincing contribution to strategic flexibility. The rising cobot sales

(International Federation of Robotics, 2023) indicates a high market interest in the cobot technology, stressing the societal importance of studying the cobot's operational and strategic impact more extensively.

This research aims to *describe the cobot's (in)direct impact on four areas: the human-cobot interdependencies' functional requirements and task execution, the operator's work perceptions, the production unit's performance, and the SME's strategic flexibility*. To achieve this aim, the following research question has been formulated: *What is the cobot's impact on the design, sustainability, and performance of the production unit, and what do these impacts mean for SME's strategic flexibility?*

Given its broad thematic scope, this research benefits from a multidisciplinary research approach that uniquely combines literature from MSTS, operations management, human-robot interaction, applied psychology, and entrepreneurship. This research has three other remarkable characteristics. Firstly, it occurs at both the operational and strategic levels. Secondly, it simultaneously studies four potential cobot impacts that are systematically overlooked in cobot literature. Thirdly, human-cobot interdependencies are studied from both a task allocation and capacity alignment viewpoint. In addition to the empirical contributions to the existing literature streams, this research directly responds to calls for more MSTS-related research in contemporary work contexts (Parker et al., 2022; Govers et al., 2023; Guest et al., 2022; Oeij et al., 2023). This response is important since it will strengthen the empirical underpinnings of the workplace innovation design theory, making it more observable, convincing, and ready to become the dominant design method.

Theoretical Background

We will theoretically illustrate the four impact areas in consecutive order (i.e., human-cobot interdependence, work perceptions, performance, and strategic flexibility).

Human-Cobot Interdependence

Human-cobot interdependence originates from human-machine interaction literature (Fitts et al., 1951) and later adaptations made by human-robot interaction scholars such as Johnson (2014). We follow Clark's definition (1996), which states that (task) independence occurs when two parties mutually rely upon each other to complete several actions. The production unit's functional requirements strongly dictate the design of the human-cobot interdependence.

Every production unit must meet certain functional requirements (Yasuhara et al., 1980) or, in MSTS terms, requisite variety (Ashby, 1956). These requirements prescribe what products the unit must produce, at what quantity, and against which specifications (e.g., quality standards, just-

in-time, and first-time-right). *We expect a human-cobot production unit to face higher functional requirements than the previous version of this production unit* because the cobot can accommodate the fulfilment of increasingly complex functional requirements. As illustrated in the hierarchical task analysis literature (Annett, 2003), specific tasks must be executed to meet these requirements. How these tasks are divided between the operator and the cobot is essential for designing the human-cobot interdependence. Not only do these task allocations direct what the operator and the cobot will do, but they also determine how they will interact with each other and whether their joint efforts will result in superior task execution compared to that of the previous production unit. The latter is, thus, dependent on the *alignment* of operator and cobot capacities.

In line with the classical theory of function allocation by Fitts et al. (1951) and later reconfirmation by De Winter et al. (2014), the operator and the cobot have unique capacities and opposite shortcomings. Norman (2015) found that the operator is generally good at recognising patterns, coping with unexpected situations, and defining high-level goals. However, the operator cannot execute highly repetitive and high-precision tasks or stay alert for long. The latter are the core capacities of the cobot (Djuric et al., 2016; Taesi et al., 2023). The cobot can reliably handle highly repetitive and precise tasks. In line with the irony or fallacy of automation, the cobot's application is as robust as the variation it is programmed for (Bainbridge, 1983; Johnson, 2014; Hancke, 2020). This means that cobot will not function if it must do something unfamiliar (e.g., handling a new product type or resolving an unknown error). In such situations, the cobot requires human flexibility and intelligence to adapt to new variations and remain functional (e.g., by modifying the cobot application, writing a new application, or performing the task manually). The alignment of operator and cobot capacities characterizes the human-cobot interdependence and illustrates the unity between the technical and social subsystems in MSTS (de Sitter et al., 1997).

According to Johnson (2014), two types of task interdependencies illustrate the complementarity between the most capable actor (i.e., the performer) and the assisting actor (i.e., the supporter). The first type concerns hard task interdependencies. These are interdependencies where the performer cannot execute the task without the supporter's assistance (e.g., due to mental and/or physical limitations). The second type captures soft task interdependencies. These interdependencies enable the performer to execute tasks more reliably or efficiently (e.g., by reducing errors or handling time). Recent work by Wolffgramm et al. (2024) built further on Johnson's (2014) taxonomy. They claimed that one task interdependence could be both reliability- and efficiency-enhancing, and they introduced the negative task interdependence (Tjosvold, 1986). This interdependence occurs if the performer receives assistance that does not result in more, better, or faster task execution. Thus, whether the human-cobot interdependence captures mostly hard, soft, or negative task interdependencies depends on how the tasks between the operator and cobot are divided and who is considered the performer and the supporter. Since the operator's capacities are likely higher than those of the cobot, this research

considers the operator the performer and the cobot the supporter. Given the optimistic field results (Liu et al., 2022), *we expect that human-cobot interdependencies in manufacturing practice are primarily based on hard and soft task interdependencies*.

Work Perceptions

Quality of working life plays a crucial role in MSTS (de Sitter et al., 1997; Kuipers et al., 2020). Based on the design of the human-cobot interdependence, the operator will obtain new tasks, share some tasks with the cobot, or lose some tasks to the cobot. Two applied psychology literature streams stress that these changes could drastically impact the operator's "subjective experience and perception of work" (i.e., work perceptions [Kobasa et al., 1982, p. 25]).

Work Design Perceptions

The first stream focuses on the operator's work design and captures the "content and organisation of one's work tasks, activities, relationships and responsibilities" (Parker, 2014, p. 662). Earlier work design research has shown that individuals can only sustain their work design if certain quality criteria are met (Hackman et al., 1976). These criteria, also referred to as work design characteristics (Morgeson et al., 2006), relate to the job content (i.e., motivational characteristics), human interaction with internal or external others (i.e., social characteristics), and the environment (i.e., work context characteristics) – since this research focusses on the interdependence between individual operators and a mechanical actor in a specific work setting, we will focus exclusively on the motivational characteristics.

Morgeson et al. (2006) provide the most comprehensive overview of motivational characteristics. They listed 12 characteristics and their definitions. Humphrey et al. (2007) used these motivational characteristics in an effect study and showed how these characteristics contribute to more individual performance and help the operator stay satisfied, healthy, and committed. Two studies have shown that the use of cobots affects motivational characteristics. Berkers et al. (2023) studied cobot applications in logistic warehouses and reported positive and negative developments in the operators' task variety and autonomy. Similar findings were reported by Wolffgramm et al. (2021) for operators in the manufacturing industry. The latter also found that operators' job complexity changed.

We expect human-cobot interdependencies with mostly hard and soft task interdependencies will result in a stronger perception of the motivational characteristics by the operator. In such instances, the cobot provides relevant support to the operator, making it easier for them to cope with work-related demands and creating opportunities to focus on tasks that align with personal working preferences. Opposite outcomes are expected for human-cobot production units with mostly negative task interdependencies.

Operator-Out-of-the-Loop

The second applied psychology literature stream focuses on how technology deployment affects the operator's cognitive alertness or the extent to which the operator is placed out of the control loop (Gouraud et al., 2018). Decades of research on operator-out-of-the-loop situations have been devoted to understanding what happens when the operator shares their task with reliable technological equipment, such as an autopilot (Endsley et al., 1995). Their results showed that if the technology takes over too many or too essential tasks, it will cause alertness problems for the operator (Kaber et al., 1997). On the one hand, the operator's situation awareness will decrease. This means that the operator has problems collecting relevant info about the work system's status, interpreting these data, and predicting the system's future state (Endsley et al., 2000). On the other hand, the operator might rely too much on the cobot's reliability and become complacent towards potential system failures (i.e., automation-induced complacency [Parasuraman et al., 1993]). In either case, if the system fails, it will take the operator longer to notice the malfunction, identify the issue, and resolve it (Onnasch et al., 2014; Agnisarman et al., 2019).

Relying on operator-out-of-the-loop theory, *we expect that human-cobot interdependencies comprising hard and soft task interdependencies come with at least a similar situation awareness compared to the previous production unit and a critical stance* towards the cobot's functioning. We expect this because a human-cobot interdependence with mostly hard and soft task interdependencies does not unnecessarily take over (important) tasks from the operator. The limited takeover will likely minimise situation awareness and automation-induced complacency risks since the operator still plays a considerable role in the task execution process. Ideally, such human-cobot interdependence generates sufficient information about the situation, giving the operator enough time to perceive the cobot's risks and nuance its flawlessness (Simon et al., 2023).

Performance

As mentioned in the Human-Cobot Interdependence subsection, task interdependencies could be hard, soft, or negative. Each type of task interdependence has different consequences for the production unit's task execution. Hard interdependencies will result in more task completion, soft interdependencies in more task reliability and/or efficiency, and negative interdependencies will result in less reliable and/or efficient task execution. Given the link between task reliability and production reliability (He et al., 2018) and between task efficiency and productivity (Vatne et al., 2016), we select production reliability and productivity as the unit performance measures under study. Production reliability is "the probability that a system, component, or part will operate satisfactorily for a specified period of time under specified operating conditions" (Eaton, 2004, p. 1), expressed in the number of rejects. Productivity is defined as the ratio of output to

input for a specific production situation" (Rogers, 1998, p. 5), relating to the time needed to handle a series of products.

The design of the human-cobot interdependence and its sustainability likely influence the production unit's performance. Therefore, *we expect that the human-cobot production unit exceeds the production reliability and/or productivity outcomes of the previous production unit if two conditions are met*: 1) the human-cobot interdependence captures *primarily hard and soft interdependencies* and 2) the operator's *work perceptions are acceptable* (i.e., at least similar work design and situation awareness perceptions, and a nuanced automation-induced complacency). Inspired by Alexopoulos et al. (2022) and MSTS notion of designing sociotechnical systems that sustainably meet the requisite variety (Ashby, 1956; de Sitter et al., 1997), we consider a human-cobot production unit increasingly resilient if it 1) processes more functional requirements, 2) has acceptable work perceptions, and 3) achieves higher performance than the previous unit.

Strategic Flexibility

The strategic flexibility concept is deeply rooted in strategic management and entrepreneurship literature. In line with the dynamic capabilities approach, based on the notion that there are organisational "processes that use resources … to match and even create market challenges" (Eisenhardt et al., 2000, p. 1107), strategic flexibility is a process related to the organisation's absorption capacity (Sanchez, 1995; Volberda, 1997; Tu et al., 2006). It is based on the premise that organisations with high strategic flexibility can better and more proactively respond to developments in the external environment, as they have more alternative internal or external courses of action or strategic options to choose from (Sanchez, 1995; Herhausen et al., 2014).

Barringer et al. (1999) specified nine types of such external developments: the emergence of new technology, a shift in economic conditions, the market entry of new competition, a change in government regulation, a shift in customer needs and preferences, a modification in supplier strategies, an unexpected opportunity, an unexpected threat, and a relevant political development. Accurately responding to external developments is an important source of competitive advantage (Hitt et al., 1998; Harrigan, 2017). It improves financial performance (Combe, 2012; Verdú-Jover et al., 2014) and increases organisational adaptability in ways difficult to mimic by others (Zhang, 2005; Nandakumar et al., 2014).

Strategic flexibility holds a close resemblance to the resource-based view (Mahoney et al., 1992), claiming that competitive advantage can be created by acquiring, developing, and deploying unique (combinations) of elements (Connor, 2002). An organisation's strategic flexibility, or the set of strategic options, is determined by the flexibility of available resources and the coordination of these resources. Resources are increasingly flexible when they can be used in

alternative ways, at lower costs with less effort, and in a shorter time (Combs et al., 2011). Possessing or having access to flexible resources is necessary, but they must be actively coordinated to become a strategic option (Li et al., 2017). To illustrate, if an SME has a highly flexible cobot but only uses it for one product and cannot redeploy it, then the flexible cobot, as a resource, is not a flexible resource after all. According to Sanchez (1997), such 'coordination flexibility' redefines what the resource will be used for in the new situation, mobilises all prerequisites to make the resource usable for its new purpose, and assures that the organisational structure can absorb the repurposed resource. Higher coordination flexibility allows for a more cost-effective mobilisation of the resource, thus improving strategic flexibility if that the resource is flexible (Yuan et al., 2010; Han et al., 2021).

We expect more resilient human-cobot production units to increase the SME's strategic flexibility more extensively. As mentioned before, such units handle more functional requirements at acceptable work perceptions and similar or even better unit performance. SMEs with resilient human-cobot production units will likely benefit strategically from their operational contribution. Our link between production unit resilience and strategic flexibility is based on the premise that the human-cobot production unit has all the features of a flexible resource (i.e., multifunctional, adjustable and cost-efficient). If the unit is resilient, it is likely to meet the coordination flexibility criteria, resulting in one or more strategic options that increase the SME's strategic flexibility.

Summary

To summarise this theoretical background, our research focuses on investigating whether using a cobot in SME manufacturing: 1) results in the design of human-cobot interdependencies with primarily hard and soft task interdependencies that handle more functional requirements; 2) accommodates acceptable work perceptions; 3) enables higher performance; and 4) provides a substantial contribution to the SME's strategic flexibility.

Method

We adopt a comparative case study approach to richly and more extensively study the cobot's impact in the areas of interest. As defined by Kaarbo et al. (1999), "a comparative case study is the systematic comparison of two or more data points ('cases') obtained through use of the case study method" (p.372) … "with the purpose of examing hypotheses as critically and systematically as possible" (p. 377). As for multiple case studies, comparative case studies produce strong and reliable evidence since they richly illustrate how the phenomena under study behave in different situations (Baxter et al., 2008). According to Gustafsson (2017), such evidence stimulates the creation of a more substantial, and thus convincing, theory. This section specifies the sample, the data collection techniques, and the data analysis procedure.

Sample

The manufacturing sector suits this research. Many cobot applications have been reported in this sector (see Segura et al. [2021] for a comprehensive overview). To enhance the comparability between cases and harmonise the demographic, economic, political, and legal context in which these cases are embedded, we study manufacturing SMEs located in the same country (Stake, 2013). Previous work has shown that Dutch manufacturing SMEs use cobots in their production system (Wolffgramm et al., 2021). Therefore, this method also focuses on these SMEs.

A convenience sampling strategy was applied (Etikan et al., 2016). We started with an internet search to list down manufacturing SMEs with likely a cobot in their production system. In total, 29 manufacturing SMEs were listed. Each SME had to meet three criteria to participate in this study. These criteria were formulated to ensure that the data collection would be based on functional applications, involve informants with sufficient cobot-related experience, and allow a comparison with the previous version of the human-cobot production unit. The first criterion was that the cobot was implemented in the production system – lab and demo applications resulted in immediate exclusion. The second criterion was that the cobot had to be operational for at least six months. The third criterion was that the informants could recall the state of the production unit before the cobot's implementation (i.e., the previous production unit). After verifying the criteria with the SMEs' spokespersons and based on their availability, 15 SMEs participated in this research. Information about the SMEs is embedded in Table 1. The participating SMEs produce a wide variety of (mostly metal) products, employ roughly 7 to 140 employees, and have a functional cobot in their production system for half a year up to six years – most of the studied cobots were Universal Robots type 10.

Since this research spans both operational and strategic levels, we included two types of workers per SME. The first type captures operational workers directly interacting with the cobot, such as machine operators, work organisers, and inspectors (i.e., operators). The second type comprises managerial workers responsible for the SME's operations management and functioning strategically, such as operational directors, manager-owners, and production leaders (i.e., managers).

Table 1: Characteristics of the SME Sample Under Study (Number of Cases = 15)

SME	Core Business	Estimated Number of Employees	Cobot Type	Approximate Cobot Use in Production
A	Producing gears	65	Universal Robot 10	1.5 years
B	Producing ship doors and windows	105	Universal Robot (n/a)	.5 years
C	Producing hinges	22	Universal Robot 10	3.5 years
D	Producing wooden objects	85	Universal Robot 10	2 years
E	Producing electricity cables	130	Universal Robot 10	.5 years
F	Producing metal projects	70	Universal Robot 10	3 years
G	Producing aluminium products	140	Universal Robot 3	4 years

H	Producing plastic products	8	Universal Robot 10	6 years
I	Turning and milling bike axles	7	Techman 12	3 years
J	Assembling electrical components	130	Universal Robot 5	4 years
K	Producing sheet metal products	90	Universal Robot (n/a)	1 year
L	Producing bent pipes	75	Techman (n/a)	1 year
M	Producing metal products	10	Universal Robot 10	1.5 years
N	Producing sheet metal products	25	Universal Robot 10	1 year
O	Producing sheet metal products	100	Universal Robot 10	.5 year

To obtain valid data, both worker types had to be able to reproduce the state of the previous production unit. Operators had to recall how they behaved and perceived their work and needed sufficient working experience with the cobot. Managers had to be capable of reproducing how the previous unit performed and how strategic decisions were taken back then. They also had to be familiar with the human-cobot production unit's current performance and the SME's current strategizing process. The managers from SME B and SME G and one operator from SME B and SME H were not employed in their current function before the cobot was used. These respondents relied on internal information to illustrate the previous production unit and the strategizing process.

Spokespersons were often the managers who were later included in the sample or introduced via a human resource practitioner. The managers introduced us to their operators, who met our sampling criteria. In total, 16 strategic and 20 operational workers participated in this study – two foremen were placed in the manager or operator group depending on their involvement in the SME's strategising process. Most interviewees were male (±91 %), had obtained their highest degree at a community college (±70 %), and had worked between 4 months and 32 years in their current job. The following subsection describes how these individuals participated in the data collection. An overview of the sample characteristics is available upon request.

Data Collection

Since the impact areas and underlying concepts of interest were clear, we conducted semi-structured interviews (Kallio et al., 2016) with managers and their operators. The main advantages of such interviews are that they enable the interviewer to ask specific yet open-ended questions, obtain rich responses, and provide an opportunity to ask follow-up questions (Adams, 2015). The latter is a welcome feature, as it enriches the interviewee's response and allows the researcher to gain a deeper understanding of their thoughts, feelings, and motivations (Lambert et al., 2008). Such richness contributes to understanding the 'why' behind the cobot's impact.

Based on our theoretical framework, we developed two interview protocols. We had to develop two protocols because some of the concepts under study are tied to the experiences of a specific respondent type. To illustrate, it makes no sense to ask strategic workers how their operators' work perceptions have changed, as these are highly personal. Moreover, operational workers are

not the ideal informants to answer questions about the cobot's strategic relevance , as they are barely involved in the SME's strategising process. The full protocols, in Dutch and English, are available upon request. Managers were asked about the human-cobot production unit's location, operational use, functional requirements, performance, and strategic relevance. Operators were asked about the production unit's task execution, their perceived change in motivational characteristics and monitoring behaviors, the cobot's shortcomings and their trust in the cobot. A simple conversation tool has been developed to help the operator indicate eventual changes in its motivational characteristics. These characteristics and their definition were printed on separate cards, and a three-column table was laid out. The operator had to position each card in one of three columns (i.e., increased, decreased, or did not change) and explain its placement. This tool is included in the protocol.

The interviews were conducted in Dutch. Interviewees were informed that their data would be processed anonymously. Permission to be recorded was requested prior to the interview. Most interviews were conducted individually (i.e., 18 with operators and 16 with managers). Unfortunately, due to the limited availability of some interviewees, two out of 36 interviews were conducted in pairs. One of them was conducted with two operators in SME K and one with an operator and a manager in SME L. During the interviews, attempts were made to include both interviewees by directing specific questions to both and, especially during the duo interview with both the operator and the manager, critical follow-up questions were asked to minimise socially desirable responding (Frey et al., 1991).

Data Analysis

All interviews were transcribed verbatim and imported into ATLAS.ti (version 22). Given the predetermined concepts, a deductive coding approach was used. Following the six stages of data coding by Fereday et al. (2006), we first developed a code manual with theory-driven (sub)labels, definitions, and descriptions (i.e., coding rules). This manual is available upon request. Secondly, we tested the reliability of the codes by having four graduating bachelor students knowledgeable about the concepts under study apply the code manual to the interview data from multiple SMEs. Thirdly, the students summarised their findings per SME and were able to report specific similarities and differences between the cases. Based on the students' feedback and findings, the first author concluded that the manual was ready to use and that no modifications were necessary. Fourthly, the first author manually applied the pre-tested labels from the code manual to all interview data. A label was attached to a quotation if it met the description. For instance, "Now you also program a little instead of welding all the time" (SME N, Operator 2) was labelled as 'operator tasks' since the text mentioned an operator-related activity. In total, 1508 quotations were coded. The second and third authors have reviewed the quotations. In line with Fereday et al. (2006) and Boyatzis (1998), six labels, different from those in the code manual, surfaced during the data analysis process (i.e., facilitating conditions [62 quotations], external developments [56

quotations], operator capabilities [26 quotations], cobot capacities [17 quotations], job decision latitudes [5 quotations], and ergonomics [5 quotations]). These data-driven labels were added to the code manual. Fifthly, a case description was made for each case. In these descriptions, the concepts under study were expressed using the coded data, making similarities and differences between cases obvious. Sixthly, we created a schematic overview capturing the cases and concepts under study to confirm these patterns and convincingly visualise them. We declared for each concept whether it applied to the case or how it developed. The overview is part of the Results section. The contents of the overview and descriptions were used to verify our expectations. A ranking rule was applied to segment SMEs based on the resilience of their human-cobot production unit. We also illustrate this rule in the Results section.

Results

In this section, six results are presented. Firstly, we describe the design of the human-cobot interdependencies with explicit attention to the production unit's functional requirement and the type of task interdependencies. Secondly, we illustrate the cobot's impact on the operator's work perceptions. Thirdly, we focus on developments in the performance of the production units. Fourthly, we rank the SMEs' human-cobot production units based on their resilient attributes. Fifthly, we reveal the human-cobot production unit's presumed impact on strategic flexibility and how this impact differs per rank. Sixthly, we show an integrated overview of the core insights per case.

Human-Cobot Interdependence Design

Seven cobot applications were encountered. The first, found in SMEs B, F, K, and M-O, concerned welding cobots. These cobots would apply one or more weld seams to a clamped item. The second, found in SMEs A, D, I, and L, were cobots used for loading and unloading industrial machinery by picking and placing items in and out of the machine and communicating with the machine. The third was a cobot used at SME C for picking products, spraying them with a greasy substance, and placing them in a bin. The fourth was a cobot used at SME E for inspecting items by placing them in a testing station and then putting them in a bin corresponding to the test results. The fifth was a cobot used at SME G for drilling (screw) holes in items. The sixth was a cobot used at SME H for packing items in boxes. The seventh and final was a cobot used at SME J for assembly tasks, where a piece of glass was picked and placed with high precision.

We found that the functional requirements of the human-cobot production units barely differed from those of the previous production units. To illustrate, no data indicated that the batch sizes of production units changed. The batch size we encountered ranged from 10 to 4000. In seven SMEs, managers explicitly stated that the cobot was used for handling large batches to earn back

the cobot's installation costs and establish a return on investment. One manager stressed it as follows:

> *"It all has to do with the cost price. I can produce unmanned [with the cobot] if batch sizes are higher"*
> *(Manager 1, SME D, manages a production unit equipped with an [un]loading cobot).*

Product variety increased in two cases (i.e., SMEs I and K). Two managers mentioned that the cobot allowed them to accept more client orders, which increased the production unit's product variety. Other cases illustrated that product variation was generally low. In SMEs C, E, G, H, L, and O, the cobot was used for one to three different product types. SME J used the cobot for 40 to 50 nearly identical products. SME M used the cobot for 15 different products. The uniqueness of these products remained unclear. Managers from SMEs C, J, and M explicitly mentioned they used their cobots for repeat products (i.e., products that would be ordered again in the foreseeable future). The reason for SMEs to use the cobot for a limited number of (repeat) products seems to be related to the long time they need to reprogram the cobot and the costs of changing the cobot's physical work environment (e.g., new moulds). To illustrate this, one manager mentioned:

> *"Then I have to fully pre-program the cobot again and different types of drawers are needed. You must constantly ask yourself 'is it worth it, is it worth the investment?'. Particularly in terms of time and the investment to modify the drawers. ... Often, the answer is no"*
>
> *(Manager 1, SME B, manages a production unit equipped with a welding cobot).*

From a task allocation viewpoint, all human-cobot interdependencies under study showed a generic sequence. The operator prepared the workstation by positioning the products to be handled by the cobot in fixed spots and created or selected a pre-programmed cobot application – 15 out of 20 operators mentioned they programmed the cobot. Once programmed, the operator configured the cobot's parameters and started the program. After that, the cobot would execute the same highly repetitive and short-cycled tasks with, depending on the application and the available stock, an uptime ranging from five minutes up to ten hours. In the meantime, the operator was responsible for maintaining the cobot. This included monitoring the cobot and, depending on the application, restocking the cobot, removing handled products, troubleshooting the cobot, cleaning the workstation, and replenishing depleted resources (e.g., welding wire). Next to these cobot maintenance tasks, the operator also checked and finished handled products, prepared new tasks (e.g., moulds), processed (small) batches that the cobot could not handle, or assisted colleagues.

One (direct) hard, 13 soft, and nine negative (set of) task interdependencies were found. The hard interdependence was embedded in SME F and relates to a welding task requiring good eyesight. By executing this task, the cobot enabled welders with reduced eyesight to complete

the task and handle the remainder of the product. Most soft interdependencies concentrated on SMEs B, F, J, K, M, and N. According to these operators, the cobot handled products with higher task reliability *and* task efficiency than they could. An operator said:

> *"You cannot keep up with the speed and tightness with the cobot for the whole day. Maybe you will manage for the first two products but you will fall behind. You simply cannot keep up with him [the cobot]"*
> *(Operator 1, SME M, operates a welding cobot).*

The other soft interdependencies were reliability-enhancing. The cobot eliminated mistakes operators made due to reduced attention spans in three cases (i.e., SMEs A, G, and H), handled products in a more constant or less wasteful manner in three other cases (i.e., D, E, O), and proactively signalled mistakes made by the operator in one case (i.e., SME L). Zooming in on the negative interdependencies, we found that all machine (un)loadings had a considerable negative interdependence (i.e., SMEs A, D, I, and L). In these cases, the operators estimated their task efficiency higher than that of the cobot – the cobot was deliberately operated at reduced speed in SME D to increase the application's stability. The human-cobot interdependence in SME C also came with a negative interdependence. There, the cobot did grease products, a high-precision task, at a lower task efficiency than the operator. In SMEs E, G, H, and O, the cobot was not faster than the operator in inspecting, packing, or welding products.

In addition to the aforementioned task interdependencies, we identified a spillover effect. In all SMEs, the cobot took over many tasks from the operator. While these takeovers did not always result in more reliable and/or efficient task executions, they did allow the operator to focus on different tasks and even leave the production unit (e.g., going to another unit, getting coffee, taking a lunch break, or going home). The cobot's assistance enables these opportunities and, thus, could be considered a(n indirect) hard task interdependence. An operator formulated the cobot's assistance as follows:

> *"You must imagine that I am constantly at the machine if the batch size is large. … That time is wasted, so we let the cobot do it. It is not that we cannot do anything without the cobot, but it is like a tool"*
> *(Operator 1, SME H, operates a packing cobot).*

Work Perceptions

Motivational Characteristics

In total, 17 out of 20 operators declared if and how the cobot changed their motivational characteristics. An overview per case can be found in Table 2. We figured that 13 out of 17 operators reported an overall increase in their motivational characteristics. For them, none of the motivational characteristics deteriorated, while some were perceived as stronger. Three

other operators, from SMEs D, E, and J, reported that one of their motivational characteristics decreased since using the cobot – because the remainder of their motivational characteristics stayed the same or even increased, we consider their work perception to be both increased and decreased. One operator from SME O considered ten of its motivational characteristics unchanged, while two had decreased. We marked this operator's work perception as decreased.

This overview also gives a good impression of the presumed developments per case and the motivational characteristics. With nine increased motivational characteristics and zero decreases, operators from SMEs D and N (Operator 2) reported the most extensive increase in their motivational characteristics. In line with the previous paragraph, Operator 2 from SME O reported the poorest development in its motivational characteristics. Specialisation, problem-solving, and job complexity were perceived as stronger by 12 or more operators. Feedback from the job remained largely unchanged.

We uncovered and clustered the operators' reasoning behind each development in their motivational characteristics and placed these in Table 3. The overview shows that some operators perceived greater *autonomy* due to the cobot-related decisions they could make regarding when, if, and how to use the cobot. Other operators reported that working with the cobot did not contribute to their already high level of job autonomy. Operators who were new to cobot programming perceived a higher *skill variety*. Perceptions concerning *task variety* strongly depended on whether the operator received extra, different, or fewer tasks to complete. *Significance* intensified if the operator considered itself capable of making a more internal and/or external impact by using the cobot (e.g., increased customer or employee satisfaction). Operators related *task identity* to the overview created by the cobot. On the one hand, the cobot could contribute to streamlining the production unit and make work processes more transparent. On the other hand, the origins of malfunctions became increasingly difficult to trace, making work less transparent.

Feedback from the job increased *on* the rare occasion when the cobot contributed to the operator's support system and resulted in new insights. *Information processing* increased for some operators who had to process the data streams coming with cobot programming, document the cobot's applications, and manage their cobot-related and parallel tasks. Other operators did not experience this or even perceived less information processing due to the digitalisation and incorporation of information in the cobot software. *Job complexity* increased for operators because of the difficulties coming with (re)programming the cobot, developing a functional application, and managing different work demands. Others considered their work already highly complex. One operator reported lower job complexity since the cobot was used to handle the same product, reducing the job complexity it initially had.

Table 2: Overview of Developments in Motivational Characteristics

	SME																		Total		
Characteristic	A	B	C	D	E	F	G	H	I	J	K[1]	L[1]	M[2]		N[2]		O[2]		Incr.	Unch.	Decr,
Work scheduling autonomy							n/a												7	10	0
Work methods autonomy							n/a												9	8	0
Decision-making autonomy							n/a												8	9	0
Skills variety							n/a												11	6	0
Task variety							n/a												9	7	1
Significance							n/a												9	8	0
Task identity							n/a												7	9	1
Feedback from job							n/a												2	15	0
Information processing							n/a												7	8	2
Job complexity							n/a												12	4	1
Specialisation							n/a												15	2	0
Problem-Solving							n/a												14	3	0

Abbreviations: Incr. (increased perceptions); Unch. (unchanged perceptions); Decr. (decreased perceptions); n/a (data not available)
Legend: Green (perception increased); Blue (perception remained unchanged); Red (perception decreased)
1: Only one out of two operators declared its motivational characteristics
2: Column is split since multiple operators declared their motivational characteristics.

Table 3: Arguments for Developments in Motivational Characteristics

Motivation Characteristic	Increased Because:	Unchanged Because:	Decreased Because:
Work scheduling autonomy	Operator can make choices about working on cobot or parallel tasks	Perceived autonomy was already high	-
Work methods autonomy	Operator can choose between manual execution or cobot use		-
Decision-making autonomy	Operator can make more work-related choices due to the cobot		-
Skills variety	Operator needs more skills to program the cobot	The cobot's ease of use requires no extra skills, or operator is experienced	-
Task variety	Operator considers its job to be subjected to task extension	Operator considers its job to be subjected to task exchange	Operator considers its job to be subjected to task erosion
Significance	The operator's work output increased	The operator's work output caused a limited impact	-
Task identity	Job is more transparent	Job is equally transparent	Job is less transparent
Feedback from job	Cobot becomes an integrated part of the operator's support system	Cobot does not provide feedback	-
Information processing	More data circulates in the production unit	The same amount of data circulates in the production unit	Less data circulates in the production unit
Job complexity	Job becomes more demanding	Job becomes equally demanding	Job becomes more repetitive
Specialisation	Unique capacities are required to program and operate the cobot	Job is already specialised and the cobot is very easy to use	-
Problem-solving	Cobot malfunctions are considered common and complex	Operator is unauthorised to troubleshoot or has experiences	-

Operators perceived more *specialisation* since working with a cobot required advanced and specific skills, especially in programming. Others were already specialised or felt the cobot's ease of use did not require a higher specialisation. *Problem-solving* has increased since the cobot caused considerably more (technical) issues than manual labor. These issues had to be understood and resolved accurately, which gave many operators a greater sense of problem-solving. The operators who did not experience this were either not allowed to solve issues or could rely on their previous work experiences.

Situation Awareness

The results showed that operators' situation awareness either remained unchanged or decreased. These results seem to be related to how the cobot was deployed. In all cases, the

cobot was programmed to function autonomously for a longer period. Since the operators' interference would not be required constantly, their physical presence and mental attention shifted from the human-cobot production unit to where their parallel tasks were embedded (e.g., a different production unit). Operators told how they stayed with the cobot when it executed its first tasks and how they would leave the production unit if the cobot executed a sequence of tasks accurately. From that moment, the operator's situation awareness about the human-cobot production unit is based on two occasions. The first is based on visually inspecting the human-cobot production unit to see if it is still functional. The second is an inspection of the unit's output to determine if the unit functioned as intended during the operator's absence. Depending on how operators handled these occasions, their situation awareness either decreased or remained relatively similar to that of the previous production unit.

The operators' situation awareness decreased in nine out of 15 cases (i.e., SMEs A, C-E, and J-N). These operators monitored the cobot less frequently over time. They checked less often if the cobot was still operational and/or inspected its output less extensively over time (e.g., from inspecting all products to inspecting only a selection of production). These monitoring behaviours are caused by the cobot's constant and accurate functioning. One operator mentioned:

> *"I measure one in the morning at 11:00 hours, one at 15:00 hours, and one at 16:30 hours before going home. If everything checks out, then I have full trust … I will absolutely not spend too much time on it [checking the cobot's output]"*
> *(Operator 1, SME L, operates an [un]loading cobot).*

While operators in six other cases (SMEs B, F-I, and O) also frequently left their human-cobot production unit, they regularly checked the cobot's functioning and inspected the same number of products over time. We found three reasons for these behaviours. Firstly, they inspected all the cobot's output as they had to finalize it or follow a company policy on output monitoring. Secondly, the operator stayed nearby or directly saw the cobot to sense cobot-related movements or sounds. Thirdly, operators who could not see the cobot at a distance frequently walked by to monitor its status, especially if the cobot's application was considered unstable (i.e., prone to error).

Automation-Induced Complacency

To determine the operators' automation-induced complacency, we studied their cobot-related assumptions and the nuances that accompanied them. Automation-induced complacency was considered prevalent if the operator did not nuance its cobot-related assumptions (e.g., by stressing the cobot's technical limitations). If such a nuance was provided, then automation-induced complacency was considered 'neutralised' and, therefore, absent.

We encountered two types of complacency-prone assumptions. The first type of assumption is related to the cobot's accuracy, repeatability, and safety. All operators expressed such an assumption at least once. Operators seemed to have these assumptions since they were physically separated from the cobot and needed to rely somewhat on the cobot's functioning. In all cases, the operator assumed that if the cobot executed the first few tasks as intended, its remaining tasks would be handled just as well. The following quotations illustrate two assumptions about the cobot's functioning:

> *"If I let him* [the cobot] *run and I know for sure it runs well, then I can leave him and walk away. I got that trust"*
> (Operator 1, SME B, operates a welding cobot).
>
> *"I must say that the cobot's safety also lowers some consciousness because you rely on the fact that the cobot is safer. It is not a dangerous machine to work with"*
> (Operator 1, SME M, operates a welding cobot).

The second type of assumption relates to the buildup of the cobot's programs. Operators from SMEs B, D, F, I, J, and M mentioned that they relied heavily on the cobot programs they had developed or those developed by others. They assumed that the programs were successfully configured and would control the cobot as intended. One operator expressed this assumption as follows:

> *"I just know from myself, if I configured him [the cobot] right, nothing can go wrong. Simple as that"*
> (Operator 2, SME J, operates an assembling cobot).

Operators from SMEs D, H, I, and L-O nuanced their cobot assumptions. Most of these nuances are based on previous (technical) experiences with robotics or the cobot itself. Based on these experiences, operators understood which cobot applications were prone to error and what risks the cobot came with, enabling a more critical approach towards the cobot. One of these experienced operators mentioned:

> *"I have seen robots do weird things over time. Very weird things. I always assume that a cobot is the same as a robot, but a mini-sized version"* (Operator 2, SME O, operates a welding cobot).

Performance

Production Reliability

Production reliability developed in multiple directions. All SMEs, except for SMEs C, D, and I, reported increased production reliability. This increase ranged from up to 2% fewer defects and less finetuning to lower energy consumption and less oil waste. Managers attribute these increases to the fact that the cobot has taken over monotonous tasks that the operator could not execute for a prolonged period without wasting resources or causing errors (e.g., identifying mistakes or ensuring all weld seams were applied). SMEs B, G, J, L, and O also mentioned that using the cobot led to increased automation and, thus, standardization of their production system. This resulted in more stable and outlined production processes that are less dependent on the operator.

In contrast to the increase in production reliability, we also encountered various decreases in production reliability. The most visible decrease relates to the operators' situation awareness and automation-induced complacency. In SMEs A, D, E, J, and L-N, operators have, on a structural basis, conducted fewer product inspections since the arrival of the cobot. Consequently, there is a higher chance that mistakes made by the cobot are detected too late or not detected at all by the operator. Having a weaker grip on product quality decreases production reliability. Due to the physical distance between the operator and the cobot, the number of defects increased in SMEs C and G. In the contrary, production reliability remained unchanged for SME I.

Productivity

We found that production unit productivity increased at five SMEs since the introduction of the cobot (i.e., SMEs B, J, K, M, and N). Managers from these SMEs reported that the human-cobot production unit handled products considerably faster than the unit's previous version. To illustrate, the welding cobot in SME B handled products three times faster than the manual production unit did and handling time was reduced by 50% in SME M. Before proceeding, it is important to nuance the productivity increase in SME J. Since their cobot became part of a larger automation solution, the productivity increase cannot be ascribed entirely to the cobot.

Productivity decreased in SMEs A, D, G, I, and L. In these SMEs, the handling time of the human-cobot production unit was longer than that of the previous version of the production unit. Not surprisingly, each of these units' human-cobot interdependencies came with a negative task interdependence. The cobot was also used outside regular working times (e.g., during overtime, evenings, or even nights) to compensate for its slower handling time. Operators would fully prepare the cobot before going home and generate one or more hours' worth of output depending on the cobot's autonomous uptime and the presence of technical issues. These extra machine hours do not increase the human-cobot production unit's productivity. Still, they do harmonize the output of the human-cobot production unit with that of the previous production unit – in the case of SME A, it even led to an increase in output.

Moreover, we did find that the cobots in SMEs A, C, D-G, J, L, and M faced a structural standstill, (further) lowering the human-cobot production units' productivity. In SMEs D, E, J, L, and M, these standstills are caused by the operator noticing the cobot's standstill too late (e.g., due to the physical distance between the cobot and the operator or distraction by the parallel tasks). Moreover, in SMEs F, G, and M, the cobot's structural standstill is caused by the limited number of products it is programmed for. Consequently, the cobot is out of commission until these products are being (re)ordered. The reason(s) behind the structural standstill in SMEs A and C remained unclear. Due to insufficient information, productivity developments could not be established for SMEs H and O.

Resilience Ranking

We ranked the resilience of the human-cobot production units under study based on their design, the operator's change in work perceptions, and the unit's ability to meet or exceed the performance generated by the previous version of this unit. Seven ranks are mentioned in Table 4. Most of the SMEs have a human-cobot production unit with a resilience rank of 3 or 4. This implies that the unit 1) faces similar functional requirements, 2) comes with or without a considerable negative interdependence, 3) was run by operators with a similar, better, or nuanced stance towards at least two out of the three work perceptions under study (i.e., motivational characteristics, situation awareness, and complacency), and 4) achieved similar or higher production reliability and/or productivity. The two SMEs that successfully managed to process more functional requirements achieved the highest ranks. The lower ranks are associated with units that, alongside considerable negative task interdependence, exhibit fewer acceptable work perceptions and/or performance. This ranking will be used in the following subsection to determine whether more resilient units are associated with a greater impact on the SME's strategic flexibility.

Table 4: Resilience Ranking

Rank	Increase in Functional Requirements	Interdependence has no considerable negative task interdependence	Number of Acceptable Work Perceptions	Number of improved Performance Measures	Applies to SME(s)
1	Yes	True	2	0	I
2	Yes	False	1	1	K
3	No	True	2	1 or 2	B, F, M, N
4	No	False	2	1	E, H, L, O
5	No	False	1	1 or 2	A, G, J
6	No	False	2	0	D
7	No	False	1	0	C

Strategic Flexibility

Developments in SMEs' External Context

Except for SME L, all managers gave an impression of the developments taking place in their external context that affected the SME's production system. Five developments were deducted. Most of these developments are related to *increasing customer demands*. Managers from SMEs A, B, E-K, and M reported that customers are becoming more demanding. Customers still require products manufactured in large quantities, and they demand higher product quality and swift delivery. The second external development concerns the *increasing staff shortage*. Managers from SMEs A-E, G-I, and O emphasized that production labor is becoming increasingly scarce and, therefore, difficult to acquire and retain. The third development focuses on *intensifying price competition*. The managers from SMEs D, E, G, H, J, K, and M-O also brought up this development. Those from SMEs D, G, M, and N explicitly referred to increasing price competition with foreign manufacturers in low-wage countries (e.g., Eastern Europe). Three managers from SMEs E, G, and H stressed increased local competition due to the rising reshoring activities (i.e., Dutch manufacturers relocating their foreign production activities to the Netherlands). The fourth development relates to *technical innovation*. Three managers from SMEs F, H, and N stressed the availability of new technological opportunities to replace outdated machinery and further automate their production systems. The fifth development, mentioned by one manager from SME N, captures an *increase in supply chain problems* caused by resource scarcity and geopolitical conflict.

Developments in SMEs' Strategic Flexibility

We could distillate the cobot's presumed contribution to strategic flexibility for all SMEs, but SME L. AI managers presumed that their cobot positively contributed to their SME's strategic flexibility. This contribution enabled the SME to respond more effectively to two or more external developments. Four contributions were deduced from the data.

The first contribution concerned the SME's *response to customer needs*. This contribution was mentioned by managers, except for SME C. The absolute majority stressed that the cobot contributed to their production capacity for one or more of the following three reasons. Firstly, the cobot produces both during and after regular working hours, resulting in increased machine hours and a higher volume of handled products. Secondly, the cobot achieves higher task reliability, resulting in fewer defects. Thirdly, by functioning unmanned, the cobot allowed the operator to focus on other tasks, accommodating additional production capacity. The increased production capacity allowed SMEs to accept more customer orders and meet higher quality standards. In exceptional cases, using the cobot enabled SME J to estimate production capacity more accurately and helped SME M engage in product redesign activities with the client to ensure the cobot could handle the product optimally. One manager explained how the cobot increased their SME's strategic response to client demands as follows:

> "*The core business of this enterprise did not change because of the cobot. … Only the possibilities within this enterprise changed. Those that allow us to increase the production capacity in particular*"
> (Manager 1, SME H, manages a production unit equipped with a packing cobot)

The second contribution relates to responses to changes in market opportunities. These market opportunities solely concern the availability, attraction, and retention of scarce production labor. Managers from SMEs A-E, G, H, N, and O brought up these responses. In these SMEs, the cobot changed the operators' job demands. We found that SMEs A, C, and D used the cobot to increase their operators' job demands by allocating repetitive tasks to the cobot and occupying the operator with more complex tasks. This would allow the SMEs to leverage their human resources more effectively. SMEs B, E, and N took a different approach. They used the cobot to create a highly automated job with low job demands. A broader group of (very) practically educated workers could do such a job, increasing hiring chances. SMEs C, D, H, and N stated that the cobot contributed to the quality of production labor by reducing the number of repetitive tasks and preventing current and future operators from having to work in shifts and during the night. Finally, SMEs D, F, G, and O mentioned that, by taking over human labor, the cobot decreases their strategic dependability on human resources. One manager illustrated this as follows:

> "*Because you can use it [the cobot], we can keep running the process. Later, if all labor potential dried up here in the Netherlands and in our own enterprise, we would be strategically unable to run the process. In such a case, because of cobot, due to automation, you can continue to operate here in the Netherlands*"
> (Manager 1, SME G, manages a production unit equipped with a drilling cobot).

The third contribution is directed towards the response to new technology. This contribution was expressed by managers from SMEs A-C, E-G, I, J, and O. In these SMEs, the cobot primarily helped to kickstart new automation projects. Managers explained how the SME's implementation and working experience with the cobot resulted in specific insights into the cobot's strengths, weaknesses, and necessities. Moreover, operators encountered the cobot and developed programming and/or gained end-user experiences. These advancements lead to more enthusiasm for automation and new ideas for future automation projects. It also allows the SME to develop more specific (technical) requirements that a future automation project should meet. The cobot-related experiences are presumed to enhance the quality and implementation speed of these projects. Moreover, SMEs A, C, F, G, and N emphasized that the cobot enabled them to expand and innovate their machinery, as well as solve deep-rooted technical problems cost-effectively. These enhancements create better technical conditions for future technology implementations. One manager illustrates how the cobot contributes to the SME's strategic flexibility towards new technology as follows:

> *"You mostly know what you do not want. … Because of that, you can quickly make a wish list with the things you definitely want and do not want. … Reach, the angle, the door opening, the products I would like to make … Based on your wish list, a very select number of solutions [for future automation] remain*" (Manager 1, SME I, manages a production unit equipped with a [un]loading cobot).

The fourth and final contribution relates to how the cobot enabled SMEs to respond better to *changes in economic conditions*. SMEs E, G, J, K, and M-O presumed that the cobot's contribution to their production capacity indirectly increased their financial degrees of freedom. Managers from these SMEs explained that products handled by the cobot had a higher profit margin than those handled entirely by an operator. This difference is caused by the cobot's lower deployment and handling costs. Due to the higher profit margin, SMEs could choose to offer their customers at a lower price or use it to increase their negotiating space. SME N used the higher profit margin to generate additional revenue.

> *"It* [the cobot] *is some sort of a cost reduction. You will either end up with a better price or a better margin"* (Manager 1, SME J, manages a production unit equipped with an assembling cobot).

Resilience Ranking and Strategic Flexibility

Table 5 provides an overview of the strategic flexibility increases per SME. The table is sorted sorts the table ranks and visualizes whether SMEs with a more resilient human-cobot production unit comes with a more extensive increase in strategic flexibility. The overview shows that SMEs N, E, and G reported the most extensive increase (i.e., their strategic response to four out of four developments was presumably enhanced by the human-cobot production unit). SME's B, A, and J reported this for three out of four developments. Consequently, over half of the SMEs only reported improvements in two areas. Moreover, the most extensive increases in strategic flexibility were not reported by ranks 1 and 2 but were all embedded in ranks 3 to 5.

Table 5: Strategic Flexibility Increases per SME, Specified per Resilience Rank

SME		More Strategic Flexibility to Respond to:			
Reference	Resilience Rank (High = 1; low = 6)	Customer Needs	Market Opportunities	New Technology	Economic Conditions
I	1	✓	-	✓	-
K	2	✓	-	-	✓
B	3	✓	✓	✓	-
F	3	✓	-	✓	-
M	3	✓	-	-	✓
N	3	✓	✓	✓	✓
E	4	✓	✓	✓	✓
H	4	✓	✓	-	-

L	4	n/a[1]	n/a	n/a	n/a
O	4	✓	✓	-	✓
A	5	✓	✓	✓	-
G	5	✓	✓	✓	✓
J	5	✓	-	✓	✓
C	6	-	✓	✓	-
D	6	✓	✓	-	-

1 (n/a) data not available

Overview

Table 6 schematically summarizes the results section. We presented the core results per case and specified these for each of the (sub)concepts under study (e.g., motivational characteristics). To simplify and harmonise the overview, we note per concept how it occurred, whether it was present or absent, or whether it has changed since the use of the cobot. Resilience rankings are also incorporated in the table.

The overview showcases a range of cobot applications that primarily handle the same product quantities and varieties as those managed by the previous version of the production unit. The designs of human-cobot interdependencies encompass a wide range of (indirect) hard and soft task interdependencies, but most of them also exhibit considerable negative task interdependence. The operators' motivational characteristics show few signs of decay. More concerning are the operators' decreases in situation awareness and signs of automation-induced complacency – one and/or the other were present in almost all cases. Regarding performance, the human-cobot production units often had similar or higher production reliability than productivity. Most units had a resilience rank of 3 or 4. Finally, each human-cobot production unit provided at least two distinctive contributions to the SMEs' strategic flexibility. Many of these contributions enabled the SME to better cope with changes in customer demands from a strategic viewpoint.

Discussion

Being the class example of a modern workplace innovation, cobots can potentially contribute to operational and strategic outcomes. This research aimed to describe the cobot's (in)direct impact on four areas: the human-cobot interdependencies' functional requirements and task execution, the operator's work perceptions, the production unit's performance, and the SME's strategic flexibility. A multidisciplinary framework was constructed to guide a comparative case study involving 36 operators and managers from 15 Dutch SMEs. Per case, interview data was gathered at the operational and strategic levels. The rigorous data analysis and systematic comparison of the results allow us to answer the central question of this research: *What is the cobot's impact on*

the design, sustainability, and performance of the production unit, and what do these impacts mean for the SME's strategic flexibility? In this section, we will answer the research question in light of our expectations, present practical implications, and elaborate on research limitations and opportunities for future research.

General Discussion

Our *first expectation* was that production units equipped with a cobot face higher functional requirements than their previous version (i.e., smaller batch sizes and/or higher product varieties). *This expectation was not met*. We have only encountered two production units handling a higher product variety since the introduction of the cobot. This is the first indication that the human-cobot production units were limitedly resilient and that an important cobot feature (i.e., its reconfigurability [Matheson et al., 2019]) was ignored systematically. This indication was confirmed, as most cobots run on one or a few (similar) cobot programs, stressing that the cobot is primarily used for a limited number of large-quantity and repeat products. Using the cobot in a highly autonomous manner, combined with its limited intuitiveness, comes with high (re)programming efforts that can only be earned back if the batch size is large enough.

Our *second expectation* is that human-cobot interdependencies primarily comprise hard and/or soft task interdependencies. *This expectation was partially met*. We encountered six of these human-cobot interdependencies. Most of them were used for welding purposes. Other human-cobot interdependencies came with a considerable negative task interdependence, which, at first glance, would be a sign of suboptimal design. SMEs seem to take the negative task interdependencies for granted. On the one hand, the soft interdependencies would generate enough task improvement to compensate for the task decay associated with the negative interdependence. On the other hand, these negative interdependencies are tolerated due to the indirect hard interdependencies they come with. The human-cobot interdependence was designed to be both sequential (Thompson, 1967) and autonomous, allowing the operator to execute other tasks outside the production unit. The first signs of such operator decoupling were reported by Wolffgramm et al. (2021). We hoped that manufacturers would have discovered ways to generate value by having operators and cobots interact more interdependently in the meantime. But to no avail. Depending on the number of products that can be stocked, the duration of the cobot's task execution, and the cobot's reliability, its autonomous operation ranges from minutes to hours. This decoupling of operators leads to the ignorance of another important cobot feature (i.e., its capacity to directly interact with the operator [Djuric et al., 2016]).

Table 6: Overview of Core Results per Case and Concept Under Study

SME	Cobot Application	Change in Unit's Functional Requirements		Task Interdependencies in Human-Cobot Interdependence			Change in Work Perceptions			Change in Unit Performance		Resilience Rank	More Strategic Flexibility in Terms of:			
Reference	Core Deployment	Batch Size	Product Variation	Hard	Soft	Negative	Motivational Characteristics	Situation Awareness	Automation Complacency	Production Reliability	Productivity	(High = 1 - low = 6)	CN[1]	MO[2]	NT[3]	EC[4]
A	(Un)loading	=	=	✓	✓	✓	↑	↓	✓	↑↓	↓	5	✓	✓	✓	-
B	Welding	=	=	✓	✓	-	↑	=	✓	↑	↑	3	✓	✓	✓	-
C	Greasing	=	=	✓	-	✓	↑	↓	✓	↓	↓	6	-	✓	✓	-
D	(Un)loading	=	n/a	✓	✓	✓	↑↓	↓	-	↓	↓	6	✓	✓	-	-
E	Inspecting	=	=	✓	✓	✓	↑↓	↓	✓	↑↓	↓	4	✓	✓	✓	✓
F	Welding	=	n/a	✓	✓	-	↑	=	✓	↑	↓	3	✓	-	✓	-
G	Drilling	=	=	✓	✓	✓	n/a	=	✓	↑↓	↓	5	✓	✓	✓	✓
H	Packing	=	=	✓	✓	✓	↑	=	-	↑	n/a	4	✓	✓	-	-
I	(Un)loading	=	↑	✓	-	✓	↑	=	-	=	↓	1	✓	-	✓	-
J	Assembling	=	=	✓	✓	-	↑↓	↓	✓	↑↓	↑↓	5	✓	-	✓	✓
K	Welding	=	↑	✓	✓	-	↑	↓	✓	↑	↑	2	✓	-	-	✓
L	(Un)loading	=	=	✓	✓	✓	↑	↓	-	↑↓	↓	4	n/a			
M	Welding	=	=	✓	✓	-	↑	↓	-	↑↓	↑↓	3	✓	-	-	✓
N	Welding	n/a	n/a	✓	✓	-	↑	↓	-	↑↓	↑	3	✓	✓	✓	✓
O	Welding	=	=	✓	✓	✓	↑↓	=	-	↑	n/a	4	✓	✓	-	✓

Legend: (↑) increase; (↓) decrease; (↑↓) both increase and decrease; (=) no development; (✓) applicable; (-) not applicable; (n/a) data not available
1: customer needs; 2: market opportunities; 3: new technology; 4: economic conditions

Our *third expectation* was that operators who run human-cobot interdependencies comprising mostly hard and/or soft interdependencies perceive their motivational characteristics as strong as or stronger than they did before working with the cobot. *This expectation was largely met*. Most of the human-cobot interdependencies without negative task interdependence came with increased motivational characteristics. It is essential to emphasize that such perceptions were also frequently found in human-cobot interdependencies with a negative task interdependence. In contrast to the various warnings for quality of working life decay (Baltrusch et al., 2022; Shaba et al., 2024), most operators perceive their motivational characteristics as strong or stronger since the introduction of the cobot. This was caused by increased work demands, resulting in more perceived specialisation, problem-solving, job complexity, and skill variety. These findings differ from those of Berkers et al. (2023), who reported considerable developments in the operators' task variety and autonomy, and less physically and cognitively demanding working conditions. The developments in job complexity align with those of Kadir et al. (2018) and Wolffgramm et al. (2021). Bragança et al. (2019) and El Zaatari et al. (2019), who rightfully anticipated the developments in perceived skill improvements. While our findings are positive, it is important to remain cautious about too-much-of-a-good-thing effects (Zhou, 2020).

Our *fourth expectation* was that human-cobot interdependencies comprising hard and soft task interdependencies come with at least a similar situation awareness compared to the previous production unit and a critical stance towards the cobot's functioning. *This expectation is not met*. The operators running human-cobot interdependencies with both hard and soft interdependencies consistently reported a decreased situation awareness and/or a complacent tendency towards the cobot. They were not the only ones. In fact, classic operator-out-of-the-loop symptoms were broadly encountered. Operators were removed, or decoupled, from the workstation and, in addition to monitoring the cobot, were provided with new job demands. This led to a physical distance between the operator and the cobot, as well as distraction for the operator. Consequently, according to operator-out-of-the-loop theory, the operator's situation awareness decreased due to poor monitoring behavior (Endsley, 2017). Moreover, the various unnuanced assumptions about the cobot's flawlessness indicate a deep-rooted overreliance on the cobot (Wickens et al., 2015). While we often encounter these thoughts and behaviours amongst operators controlling multiple autonomous (CNC) machines, it is essential to take these signals seriously. Unlike such machines, the unattended cobot is uncaged and has fewer safety measures, increasing the risk of injury to the operator and passersby. Moreover, it evidently results in more defects and downtime.

Our *fifth expectation* was that production units with a human-cobot interdependence comprising mostly hard and soft interdependencies and acceptable work perceptions would establish better production reliability and/or productivity outcomes than the previous version of the production unit. *This expectation was not met.* None of the units met these requirements. This is primarily caused by the operator's poor situation awareness and apparent automation-induced

complacency. Moreover, the cobot's lower task efficiency frequently resulted in poor productivity that could only be compensated by running the cobot during and after regular working hours, contrasting productivity increases reported by Realyvásquez-Vargas et al. (2019) and Galin et al., (2020). The performance outcomes also suffered from the operator's out-of-the-loop behaviour. Poor monitoring behaviour increased the chance of cobot-related flaws not being noticed by the operator in time or at all, resulting in more defects in some cases. Productivity outcomes were hindered by structural downtime caused by the operator notifying too late that the cobot had come to a standstill. Similar findings were reported by Kaber et al. (1997). Other examples of structural downtime were related to the cobot's narrow deployment. Due to the limited product variety, the cobot has a high chance of standing still if these products are not in demand.

Our *sixth and final expectation* was that more resilient human-cobot production units to increase the SME's strategic flexibility more extensively. *This expectation is not met*. Based on the resilience ranking we applied, we found that production units with higher rankings came with less extensive increases than units with moderate rankings. On a positive note, the SMEs under study believed that their human-cobot production unit improved their strategic response to external developments, such as high customer demands (Pech et al., 2022) and staff shortages (European Labour Authority, 2022).

The production unit's most prominent contribution relates to how SMEs respond strategically towards customer needs. The cobot's autonomous operation and the decoupled operator increased production capacity, generating strategic opportunities to accept new and/or more advanced customer orders (i.e., its absorption capacity increased [Tu et al., 2006]). Another contribution relates to the SME's strategic dependability on human resources. The human-cobot production unit facilitates job enrichment and job simplification, making the SME a more attractive employer for a specialised or more practical operator population. Moreover, the implementation and working experience with the cobot resulted in collective knowledge about and positive attitudes towards robotisation. These dynamic capabilities (Eisenhardt et al., 2000), combined with the enhanced modernisation of the SME's technical infrastructure, increased its capacity to absorb new (robot) technologies. Finally, in line with the common notion that strategic flexibility results in more financial resources (Combe et al., 2012; Verdú-Jover et al., 2014), the cobot generates more financial degrees of freedom. The SME can use these to offer a more competitive price or reinvest them into their resources and coordination.

From an MSTS viewpoint (de Sitter et al., 1997; Kuipers et al., 2020), the often rigid and misaligned human-cobot interdependencies under study show a minimal increase in requisite variety and unity of technical and social subsystems. Moreover, the operator's quality of working life is demonstrated in order regarding its motivational characteristics, but raises a cause for concern regarding out-of-the-loop behaviour. Finally, the production system's robustness increased clearly, but it was due to the decoupling of the operator instead of a resilient interplay between

(wo)man and robot. In summary, most of our expectations were not met or were only met partially. Nonetheless, this research uniquely specified the cobot's impact and placed MSTS, and thus the workplace innovation design theory, in a contemporary and advanced work context, delivering its theoretical contribution to the fullest (Parker et al., 2022; Govers et al., 2023; Guest et al., 2022; Oeij et al., 2023).

Practical Implications

We formulated three practical implications. The first implication relates to the design of human-cobot interdependencies. Rather than prioritizing decoupled human-cobot interdependencies over highly collaborative ones, we argue that both are necessary and recommend a dual strategy. The decoupled human-cobot interdependencies enable the automation of oversimplified and tedious operator tasks, thereby improving the motivational characteristics of the 'mainstream' operator. To prevent operator-out-of-the-loop problems, the human-cobot production unit must be closely monitored. Due to its operational simplicity, this could be done by a highly practical operator or even sheltered workers. In an ideal scenario, such an operator will oversee multiple highly autonomous cobots. This is a good solution for individuals with a physical or mental challenge to participate more prominently in the labor process and a promising avenue to minimize operator-out-of-the-loop waste. Moreover, this approach targets vulnerable worker groups that have been systematically overlooked (Rom et al., 2023).

In addition to more autonomous cobots, developing more interactive forms of human-cobot interdependencies for and with mainstream operators is essential – Alasoini et al. (2023) show that broad employee participation is the backbone of innovative businesses. These applications are highly complex because they must exceed the operator's high mental and physical capacities. Nonetheless, we encourage SMEs to collaborate with researchers in this area and look for lucrative and sustainable solutions. It is essential not to reason from an automation perspective but to follow a capacity-enhancing perspective instead. This way, the operator and its flexibility remain part of the production unit, allowing more task interdependencies across a wider product range (i.e., high-mix, low-volume production).

The second implication concerns the operator's quality of working life. To ensure that the human-cobot production unit remains sustainable, it is crucial to pay close attention to the operator's development in motivational characteristics and its showcasing of operator-out-of-the-loop symptoms. As part of this work, we provide a conversation tool that makes discussing motivational characteristics more convenient. Moreover, we illustrated what a deteriorated situation awareness and an unnuanced overreliance on a cobot entail. Managers can regularly converse with their operators to discuss the latter's work perceptions. Given their work and organisational psychology background, this is also an ideal way for Human resources professionals to immerse themselves in using and optimizing cobot applications. They can advise

managers or directly support them when discussing quality of working life matters with the operator.

The third implication concerns the evaluation of the human-cobot production unit. To better understand the cobot's impact, assessing the human-cobot production unit in light of relevant external developments and strategic ambitions is recommended. This research gives an impression of the dimensions that can be used to analyze the human-cobot production unit, how to rank the unit's resilience, and what external developments and strategic impacts to consider. These evaluations can be done both before and after the deployment of the cobot. In both cases, redesign initiatives must be seriously considered if the strategic impact does not meet expectations.

Limitations and Future Research

This research comes with three noteworthy shortcomings. The first and foremost limitation is that this research lacks the quantitative data to estimate the magnitude of the cobot's impact (e.g., uptime, downtime, time to complete, and rejects data). The available data is limited to whether an impact is presumed. Ideally, conducting observations and studying historical performance data leads to more quantified reports about the cobot's impact and a more specific resilience ranking. Since the operator is likely to be decoupled, studying spillover effects outside of the human-cobot production unit is also essential. In addition to its operational impact, the cobot's strategic impact also warrants further attention. We were unable to express these impacts in economic values (e.g., market share and revenue growth). Researching the SME's strategy and strategic decision-making process more explicitly could place the cobot's strategic impact into a better perspective. It is also recommended to study whether the cobot hinders strategic flexibility. These impacts did not surface in this research but were also not studied explicitly.

Secondly, the analysis of the human-cobot interdependencies under study was somewhat simplistic, as the method lacked an in-depth task analysis. We recommend using the interdependence scoring method (Wolffgramm et al., 2024) to better interpret the relevance and ratio of the hard, soft, and negative interdependencies encountered. Thirdly, this research is based on cases involving autonomous cobots. Highly interdependent human-cobot production units might generate very different results, such as out-of-the-loop behaviour. Scholars are encouraged to search for such exceptional cases in, for instance, the social domain (e.g., sheltered workshops). In addition, we strongly endorse more (applied) research into the direction of building, testing, and applying highly interdependent human-cobot production units. An example can be found in Wolffgramm et al. (2025). The cobot technology offers a prosperous avenue for long and impactful collaborations between scholars and manufacturers. Finally, scholars are invited to continue applying MSTS concepts and principles in contemporary

manufacturing. These applications contribute to the embeddedness of the workplace innovation design theory and help to identify a wide variety of important antecedents (e.g., learning and development requirements that enable workers to use job decision latitudes constructively [Hammouch, 2025]).

Conclusion

In this comparative case study, we deduced the cobot's impact on the design, sustainability, and performance of production units and described the implications of these impacts for SMEs' strategic flexibility. Being a prime example of a workplace innovation, the cobot's impact is considerable but not necessarily positive by default. The units' design became more rigid due to the substantial removal of the operator. Their sustainability and performance often improved, but these benefits were often suppressed by operator-out-of-the-loop problems and the cobot's technical limitations. The human-cobot production units are presumed to enhance the strategic flexibility of SMEs. The extent of this enhancement seems unrelated to the unit's resilience. Theoretical and practical recommendations at the crossroads of MSTS, workplace innovation and modern manufacturing are provided to quantify and expand the cobot's impact.

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A design framework for ecosystems that facilitate continuous employee skill development

A theoretical integration of interorganisational skills learning communities, modern sociotechnical systems, and network theory.

Koen Nijland
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Abstract

In today's dynamic business landscape, the continuous development of employee skills is an important driver for innovation and performance in the workplace. However, employee skillsets are often inadequate, posing a challenge for organisational innovativeness and performance. Although concepts and instruments at the organisational level are helpful, organisations need additional methods to facilitate continuous skill development. Interorganisational skills learning communities (ISLCs) have recently emerged in Europe to address this need, presenting a promising approach to enhance employee skill development. Nevertheless, designers and employees face significant challenges in ensuring long-term skill development through ISLCs. Treating ISLCs as dynamic interorganisational ecosystems that must adapt to changing contexts is essential, but learning community literature currently lacks specification on how adaptive and effective ISLCs can be designed.

In the present paper, we present a novel and comprehensive ISLC design framework underpinned by modern-sociotechnical systems theory (MSTS), network theory, and state-of-the-art literature on skills learning communities. Accordingly, an adaptable and effective ISLC can be achieved through (1) distinction of different design levels, (2) distinction between design of a learning structure and governance structure, (3) pursuit of a specific design sequence, (4) clusters of micro learning communities (LCs), and (5) an iterative, interactive and multi-level design of feedback loops. The resulting design framework breaks new ground for interorganisational learning community theory-building and offers a novel direction for researchers, HRD practitioners and policy makers to address

HRD problems in today's changing business environment. More research should be conducted on the validation of this conceptual design framework.

Keywords: interorganisational skills learning communities (ISLC), ecosystems, modern-sociotechnical systems (MSTS), network theory, workplace innovation, continuous skill development, Industry 5.0.

Introduction

In today's complex and changing world, there is an increasing need for continuous development of employee skills. Developments in information technology such as virtual reality, cloud computing and AI have led to changing demands in terms of employees' skills (e.g., Verma et al., 2023; Wilson et al., 2017). Increasingly, smart skills are needed to leverage information technology (Nair et al., 2024). Here, smart skills are defined as the abilities needed to use and appropriate technologies (Trotta et al., 2024). The rise of the Industry 5.0 (I5.0) concept sets new requirements to both the technology and the skills needed to utilise them (Oeij et al., 2024). The nature of the I5.0 context in which organisations operate implies that technology adoption is not static. Instead, technology and manufacturing processes are continuously modified and customized to meet user requirements and needs (Carroll et. al., 2003; Dix, 2007). Vice versa, skill requirements also change continuously as the use changes. Thus, employees are not only faced with a shift to smart skills but also need to continuously develop smart skills as they appropriate smart technologies.

Organisations have an important role in facilitating and enhancing the continuous development of employees' smart skills as it can drive innovation and performance in the workplace (Oeij et al., 2021). Organisations do so through adopting concepts such as workplace innovation (WPI) and human-centered design (ISO 9241-210; Oeij et al., 2017). In addition, organisations use related (HR) practices such as formal training, supervision, feedback from peers, and on-the-job training. These concepts and practices are often not effective for the continuous and multidisciplinary development of employees' skills (Torraco & Lundgren, 2020). Hence, organisations seem to lack a manner with which continuous and multidisciplinary updating of these skills can be facilitated and enhanced (e.g., Ardichvili, 2022). Additionally, organisations seem to have an internal focus when it comes to employee development, whilst an external focus has proven to be effective learning practices (Hardy et al., 2003; Koster, 2024) Thus, organisations need a novel approach to skills development that goes beyond collaboration within their own organisation and fosters continuous development of employees' smart skills.

Recently, learning communities have emerged in Europe to address the much-needed development of modern employee skills, such as smart skills (e.g., Corporaal et al., 2021; Gelten et al., 2023; van Rees et al., 2022). Especially interorganisational skills learning communities (ISLCs) seem promising as these provide employees to work in dedicated learning focused communities with different people and organisations in different but innovation-oriented contexts. Also, they can provide organisations with support and knowledge about the required smart skills that they are missing (Dingyloudi & Strijbos, 2020; Gebauer et al., 2020). We define an ISLC as an interorganisational public-private partnership in which learning, researching, working and innovating are brought together in a hybrid learning environment that offer learning to all parties involved (Dingyloudi & Strijbos, 2019; Topsectoren, 2019). We further specify learning as the extent to which all parties have achieved continuous development of their employee smart skills (from now on ISLC

effectiveness). The manner of which to achieve ISLC effectiveness can be different in every ISLC as the context changes. This context is determined by external demands and characteristics of the whole ISLC (i.e., contextual dimensions) (Daft, 2020). Examples of external demands include the specific skills that should be learned or a need for additional funding. Contextual dimensions relate to the number of participants in the ISLC, level of agreement over ISLC-goals, level of trust between participants and the difference between participants in terms of learning needs and background (Provan & Kenis, 2008; Schipper et al., 2023).

Principles for designing effective ISLCs in specific contexts and fields such as engineering (Gelten et al., 2023), the installation sector (Corporaal et al., 2021; van Rees et al., 2022), and logistics (Hofstra et al., 2021; Preenen et al., 2021) have been defined and studied. There are also first initiatives that set out to summarise these design principles for ISLCs (Kerngroep Netwerk Learning Communities, 2023). We understand design principles as general guidelines based on current knowledge that informs the specific design of the ISLC. Furthermore, recent publications have contributed by specifying design elements that are relevant to designing an ISLC (Schipper et al., 2023). Design elements, or structural dimensions, are the choices that design professionals make regarding internal characteristics of the ISLC (Daft, 2020). Overall, the growing body of literature and initiatives for ISLCs show promise regarding facilitation of employee smart skill development.

Despite the promising impact of skills LCs, current design principles do not facilitate ISLCs that aim to continuously develop employee skills. More specifically, current design principles inform the design of an ISLC given a specific set of skills that need to be developed in a given context. However, the required skills of employees continuously change, participants may change and the levels of trust amongst participants may fluctuate over time. This may result in the need to change the design of an ISLC to cater to ISLC effectiveness (Provan & Kenis, 2008). In addition, as changes in the context occur at an increasing rate the design of an ISLC would benefit from being less prone to changes in skill requirements and enhanced adaptation to continuously changing contextual dimensions as well. Therefore, ISLCs should be designed for adaptability to the context such that the ISLC remains effective over time.

In order to facilitate the design of adaptive and effective ISLCs, solitary insights of learning community literature, network theory (Provan & Kenis, 2008) and Modern Sociotechnical System (MSTS) theory (de Sitter et al., 1997) are integrated. The theoretical integration in the present study is valuable and unique for several reasons. Firstly, MSTS theory provides design elements and strategies that help an ISLC to become more adaptable and less prone to changes in the context. Secondly, MSTS theory and Network further enhance our understanding of how design elements and contextual dimensions interact with each other to attain an effective ISLC. Thirdly, MSTS theory and Network theory allow for a fine grained categorisation of terms that have been used in ISLC design literature. The proliferation of a broad array of design terms such as building blocks (Mariotti, 2012; Schipper et al., 2023; Preenen et al., 2021), principles (Corporaal et al., 2021), structural properties (Provan & Kenis,

2008), prerequisites (Van Rees et al., 2022), guidelines (Gelten et al., 2023) and success factors (Hofstra et al., 2021) underscores the fragmentation of existing literature and a need for one comprehensive overview for designing ISLCs that integrate all the aforementioned terms. Fourth, Network theory adds insights about the role that governance plays in the adaptability and effectiveness of an ISLC. This theory is particularly valuable as it further specifies which governance structures fit particular contextual dimensions of the ISLC to remain effective (Provan & Kenis, 2008).

Approach of the paper

Below, we present a novel design framework for effective and adaptable ISLCs. This framework provides clarity on how to design on micro LC-, cluster-, and ecosystem level.
We do so through (1) a literature scan of research on skills learning communities, and (2) a theoretical integration of MSTS and network theory. First, we describe the design fundamentals of learning and governance structures that contribute to adaptable and effective ISLCs. Second, we apply these insights to the design of a learning structure at ecosystem-, cluster- and micro level. Third, our understanding of design fundamentals are applied to the design of a governance structure at micro-, cluster- and ecosystem level. These findings are summarised into a comprehensive design framework for adaptable and effective ISLCs. We end with conclusions and theoretical contributions, practical implications and suggestions for future research.

1. Design fundamentals for adaptable and effective ISLCs

In this chapter, we integrate ISLC design literature with insights of MSTS and network theory to provide design principles, strategies and sequences to follow for adaptable and effective ISLCs. More specifically, we first specify the general goals we try to achieve with an ISLC design. Different levels in an ISLC design are then explained. We subsequently elaborate on the design principles that should be followed. Then the strategies that can be used to achieve this are described. Finally, we lay out the design sequence that should be followed when applying the aforementioned design strategies and principles.

1.1 General goals of an ISLC

In our study we have defined ISLC effectiveness as "the extent to which learning is stimulated and activated in employees to continuously develop their skills". Corporaal et al. (2021) describe three general ISLC goals that, if achieved, contribute to ISLC effectiveness: (1) all participants learn, (2) the collaboration is purposeful, and (3) both formal and informal learning activities are integrated. We add a fourth goal which is the ability to adapt the ISLC over time such that the former three goals are still met. An ISLC should have interactive relationships which support and reinforce each other with respect to achieving all four general ISLC goals (de Sitter et al., 1997). See table 1 for a more thorough description.

Table 1. Description of general ISLC goals based on Corporaal et al. (2021) and de Sitter et al. (1997)

ISLC goal	Description
All participants learn	A starting point is that everyone can determine what should be learned and engages in reciprocal learning in which participants alternate between the role of student and teacher. To ensure all participants learn it is important to determine what knowledge is missing in the ISLC and which learning activities fit. Based on this a shared vision and goals is created to foster commitment, mutual understanding and cooperative activities.
The collaboration is purposeful	In a purposeful collaboration the information is shared, activities are altered, resources are shared, and participants are willing to help others. Through these collaborative activities the participants learn. Collaborative learning can be further enhanced through the use of facilitators, interaction with knowledge-experts, peer guidance, group brainstorming, peer reviews or debates. Finally, collaboration is multi-disciplinary by nature given that the learnings of employees should lead to new behaviour in practice.
Formal and informal learning activities are integrated	A prerequisite for integration of formal and informal learning activities is to understand the implicit (i.e., know-how) and explicit (i.e., know-that) knowledge present in the ISLC participants. The relevant workplace goal determines what kind of learning activity the participant will participate in. Reflection is subsequently used to find out which learning activity should be chosen. This approach leads to integration of informal learning activities (e.g., observation, experimenting with new products and brainstorming) and formal learning activities (e.g., online learning modules, presentations and trainings).
General goals are met when circumstances change	Learning vision and goal, learning activities and collaboration should be organised in such a way that they can be adapted when needed. Governance activities such as reflection and expert sessions are fundamental for monitoring internally and externally a need to change.

1.2 Learning and governance structure at different ISLC levels

An ISLC is a collaboration between multiple organisations that require design on both micro-, cluster- and ecosystem level. All three levels the design should encompass a structure for shaping and execution of learning activities, and a structure for governance of learning activities. Learning structures are understood as the organisational structure and responsibilities, the learning climate, the nature of the learning activities, where these activities take place, and whether they are more learner-directed or facilitator-directed (Poell et al., 2000). Learning actors are the employees who "co-organise their learning on the basis of their ideas and interests, instead of reducing their participation to being at the receiving end of a training course" (Poell et al., 2000, p. 32). Moreover, a governance structure entails a feedback loop consisting of monitoring, evaluating, and adapting activities (de Sitter et al., 1997; Provan & Kenis, 2008). Evaluation processes have proven to be useful for knowledge

creation and learning and can differ in frequency, form and on which level is evaluated (Katz & Earl, 2010). Finally, a follow-up process warrants that suggested improvements in the evaluation a adopted (Schipper et al., 2023).

The micro-level entails the design of a single learning community that focuses on a specific skill at a specific level that an employee should learn (from now on micro LC) (van Rees et al., 2022). However, employees need a broad array of skills to work and appropriate technologies. Therefore, within an ISLC there will be several micro LCs to cover all the necessary skills that should be developed for technology usage and appropriation. The cluster-level is the design of groups of micro LCs that cover similar skills. The ecosystem level is the overarching ISLC that contains all clusters of micro LCs that cover similar skills as well as contain all participating organisation that want their employees to continuously learn skills to work with and appropriate technologies. For instance, smart skills for AI literacy can be a focus of an overarching ISLC. The ISLC would then contain several clusters that focus on specific skills that employees should obtain such as the ability to recognise AI, understand intelligence, and interdisciplinarity of AI (Long & Magerko, 2020). Overall, most literature on ISLCs have focused on the design of the micro-level (e.g., Corporaal et al., 2021; van Rees et al., 2022) whilst some have also paid attention to shaping learning activities on ecosystem level (e.g., Schipper et al., 2023). We integrated MSTS and network theory to also specify how the governance structure on cluster and ecosystem-level should be designed. See figure 1 for a visualisation of the ISLC design levels.

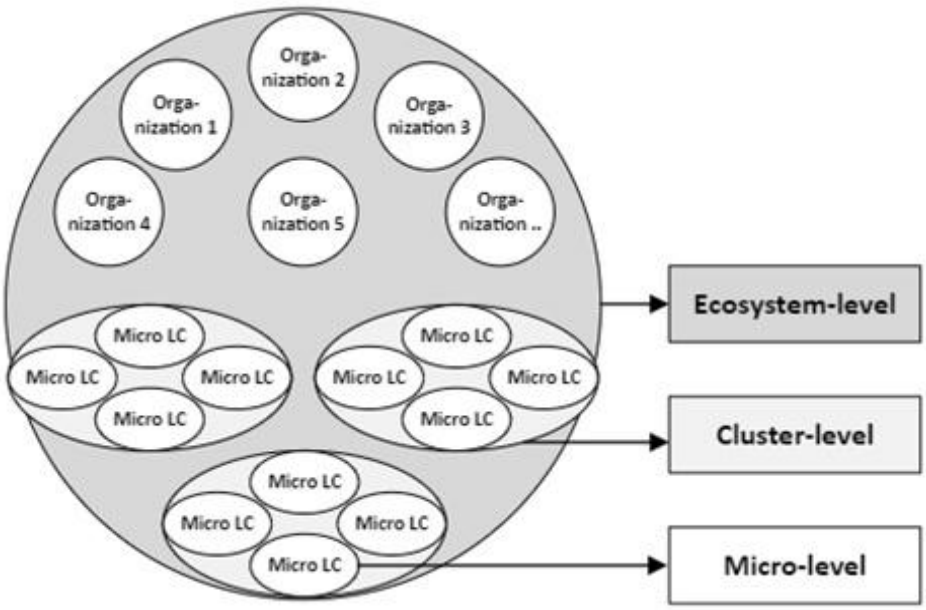


Figure 1. Overview of different design levels of an ISLC

1.3 Principles for designing ISLCs

ISLCs are complex collaborations between multiple organisations and stakeholders, with varying goals, and a structure that changes over time. Following MSTS, an ISLC structure

should jointly optimise a multitude of goals of both participating organisations and participants of micro LCs. To achieve this, interactive relationships between social and technical elements of the ISLC should be identified and designed (de Sitter et al., 1997). For instance, hosting a learning community meeting consists a set of relations between social (e.g. behaviours) and technical (e.g., facilities for the meeting) elements. These sets of relationships can differ as learning goals can vary. Depending on the learning goal of that meeting, the learning activities can differ, the role of the facilitator can be different, and a suitable physical or digital location can be chosen (Corporaal et al., 2021). However, designing interactive relationships between all social and technical elements of an ISLC would lead to an inability to deal quickly and adequately with changing demands in learning or from external stakeholders. To mitigate this, designers should follow these two principles (de Sitter et al., 1997):

1. Reduce disturbance probabilities by a reduction of impending variety;
2. Reduce disturbance sensitivity by an increase in governance capacity.

The reduction of the impending variety is addressed in the design of the learning structure. The learning structure can be split, coupled or differentiated into different learning tasks, activities and roles to limit the variation within these functions. The differentiation, split and coupling of these learning functions enhance the options for process variation (de Sitter et al., 1997). An ISLC can consequently offer flexible learning pathways, customized learning resources, differentiated instruction, or collaborative learning opportunities. De Sitter et al. (1997) indicate that the design of the governance structure should ensure that these options for process variation are utilised if required. This requires the governance structure to have sufficient governance information to effectively manage and coordinate the learning processes. This can be done by monitoring, evaluating and adapting the learning activities.

1.4 Design strategies

De Sitter et al. (1997) have formulated various design strategies in relation to the aforementioned design principles. These design strategies address the specific design of an ISLC following that particular strategy (see table 2).

Table 2. Design strategies derived from de Sitter et al. (1997)

Focus	Strategy	Description
Learning structure	Parallelization	Reduction of the impact of variation of what should be learned on the required number of relations between participants through the introduction of independent parallel learning pathways. These pathways correspond to the different external requirements of what should be learned. For example, learners with different skill levels or learning objectives may be grouped into separate cohorts or tracks, allowing for tailored instruction and support.

	Segmentation	Reduction of required number of relations, communication, and information sharing between participants through clustering of smaller learning tasks, activities and roles that have minimum interaction points with other clusters. This requires clustering of learning functions that have a maximum mutual interdependence.
Governance structure	Unity of time, location and action of governance activities	Governance activities are closely aligned with the specific time and place where learning processes occur and are selected based on close monitoring and evaluation of the learning processes (i.e., a governance cycle). Related goals are that timely feedback can be given, real-time interaction can be achieved if needed, both off-site and on-site learning can be integrated, learning events can be coordinated and the technological infrastructure can be used in a supportive manner.
	Bottom-up allocation of governance cycles	The allocation of governance cycles on workstation level or on whole-task group level. This is possible if preparatory, supporting and execution of learning tasks, activities and roles are deconcentrated independent flows of whole task segments. These are typically created through parallelization and segmentation.
	Building governance capacity in every task	Every individual for every task they execute receives sufficient governance information to steer their own learning activities such that they can achieve the individual and collective learning goals that are associated with the task.

1.5 Design sequences

The design process encompasses which design questions come first and who should be involved. To facilitate in the design process, we have adopted the design sequence rules from de Sitter et al. (1997) and applied this to the context of an ISLC. This design sequence provide clarity that designers should first set-up the learning activities in an ISLC following a top-down approach. They should subsequently design the governance structure bottom-up including appropriate governance cycles. See table 3 for more details.

Table 3. Rules for the design process of an ISLC based on de Sitter et al. (1997)

Sequence rule	Description for an ISLC
Design the learning structure first and then proceed with the design of the governance structure	The work processes in which participants learn to continuously develop employees' skills should be set-up before processes for information flow are set up form and to participants.
Design the learning structure top-down	Establish a work process by first identifying potential parallel flows. After this, learning activities can be segmented. Finally, the structure of the parallel and segmented smaller learning community learning activities that foster collaboration and engagement should be designed.

The design of the learning structure precedes the design of process technology	After establishing the work processes it can be defined who needs which process technology to assist their work processes.
Design the governance structure bottom-up	Starting with the identification and design of individual support elements, such as mentoring programs and resources, and then gradually scaling up to interlocal support systems such as intervision between micro LCs, and global support systems such as an external support network.
Design governance cycles according to the sequence: allocation, selection and coupling	Support elements should be allocated based on the specific needs and requirements of the skills learning activities, tasks and roles. The selection of support elements should consider the primary dimensions of support required in each context. Couplings between different support elements should be determined to ensure timely and effective support deliver

2. Structure for learning in an ISLC

This chapter describes the first step of designing adaptable and effective ISLCs. Here, we delve into designing the structure of learning activities for participating employees from a top-down approach. A top-down approach means that we first set up the ecosystem-level structure that enables the shaping of learning activities, then we design the clusters of learning activities and finally we design the micro LCs.

2.1 Ecosystem-level foundations for shaping learning activities

As a first step, participating organisations establish the focus of the ISLC. Then, they decide on a strategy for achieving this. Participating organisations are typically represented by professionals that are responsible for skill development at their respective organisations. At the end of this design step, participating organisations should have agreed upon the subject and strategy of the ISLC (Schipper et al., 2023). For instance, in the production sector organisations continuously digitise their organisation to the point that they start to integrate AI into their systems (Zhang et al., 2021). This pushes the need for production workers to be able to work with, and appropriate, AI. Therefore, production organisations could decide to focus on the topic of "AI literacy" for the ISLC (Long & Magerko, 2020). After this, participating organisations discuss the strategy for continuously developing AI literacy for their production workers.

We use the definition of Oeij et al. (2021) who described a strategy as "the determination of the long-term goals and objectives of an enterprise, the adoption of courses of action and the allocation of resources necessary to carry out these goals" (p. 201). In the context of an ISLC the challenge is to formulate a collective strategy that brings together different strategies of participating organisations as well as their own learning needs (Schipper et al., 2023). In the process of doing so, it is important to consider the following factors for building

a collective strategy: "create and align common goals between organisations, secure equal commitment from all parties involved, overcome cultural differences, establish forms of communication as well as roles, and work across organisational boundaries" (Smith & Thomasson, 2018, p. 194).

As collective long-term goals and objectives are created the next step is to build a course of action to achieve this. The learning activities of an ISLC should be shaped such that they are less prone to changes. MSTS provides valuable input for this through a parallelization strategy. This can be achieved through grouping independent learning pathways for developing employee skills (de Sitter et al., 1997). These pathways correspond to different skills that should be learned to work with a given technology. Employees with different skills or learning objectives may be grouped into separate cohorts or tracks, allowing for tailored instruction and support. For example, a micro LC about learning skills for working with AI can be grouped into learning pathways that are fitting. In addition, these learning pathways could focus on different cohorts of learning objectives of the production workers such as computer vision, Natural Language Processing (NLP) and reinforcement learning in production settings. We view the creation of a collective strategy as an ongoing and iterative design process. Commitment, individual goals, roles and forms of communication can all change over time as participants in the ISLC change, skill demands change due to technological developments, or strategies of participating organisations change. Therefore, the collective strategy is continuously monitored, evaluated and adapted to these changes. This process will be part of the ecosystem-level governance structure in chapter 3.

2.2 Clusters of learning activities

When parallel learning pathways are shaped, they can be clustered into smaller segments of learning activities which have minimum interaction points with learning activities of other clusters. If a skill requirement then changes due to technological developments then it only affects a smaller portion of the micro LCs. The whole ISLC is therefore less prone to these changes.

Segmentation requires clustering of learning functions that have a maximum mutual interdependence. For instance, in a micro LC focused on interaction skills for working with artificial intelligence the employees first learn beginner level things (e.g., fundamentals of AI), they learn moderate level things in segment 2 (e.g., AI algorithms and techniques), moderate to high level things in segment 3 (e.g., AI interaction in production), and finally advanced level skills in segment 4 (e.g., ethical and responsible use of AI in a production setting). Figure 2 shows a visualisation of clusters of micro LCs in an ISLC.

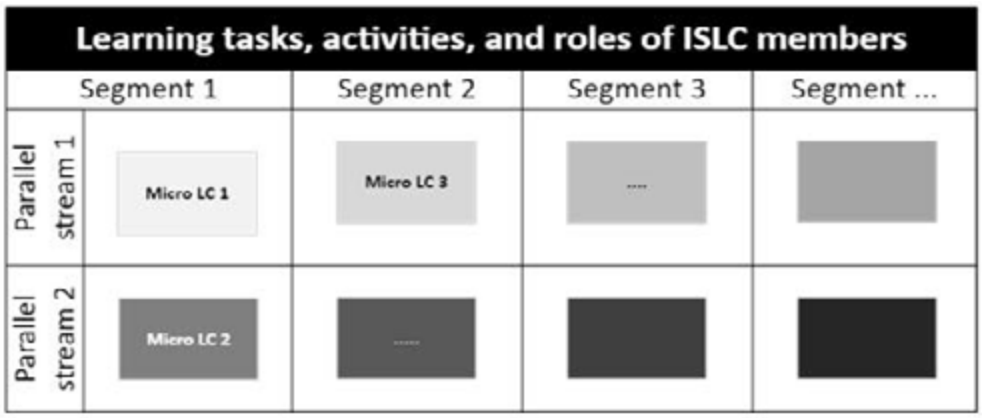


Figure 2. Overview of the clusters micro LCs

2.3 Design of micro LCs

Within every cluster there are several micro LCs that should subsequently be shaped. Micro LCs entail the actual learning tasks, activities, and roles that are executed in this ISLC. When shaping these micro LCs, designers should decide upon (1) the timespan, (2) form of meetings between participants of the micro LC, (3) the role of the facilitator, (4) the number of participants, and (5) the degree of heterogeneity of the participants in the micro LC, (Corporaal et al., 2021; Schipper et al., 2023).

The time span of an ISLC is an important consideration as it influences the time that a micro LC focuses on learning a specific skill at a given level. In the context of continuously updating skills and need for adaptability of the ISLC, it is advisable to adopt a structure that facilitates a shorter time span. The adoption of a Scrum format with cycles of ten weeks is an example of such a structure. For example, in the installation sector the participating organisations worked on achieving collective objectives during a time span of ten week (Corporaal et al., 2021). It is advised that during these ten weeks physical meetings are held between participants of the micro LC such that could foster knowledge sharing and learning. Physical meetings are preferred in contrast to digital meetings as they enhance higher levels of trust, reciprocity and identification of the group which, in turn, contribute to knowledge sharing and learning (Schipper et al., 2023).

The role of the facilitator can vary depending on the chosen collective strategy, the needs of micro LC participants, and the available (human) resources. A facilitator is tasked with the guidance of participants of a micro LC through their day-to-day activities (Li et al., 2009) and the providence of possibilities and resources without interfering in the process (Nyström et al., 2014). There are, however, several types of roles in which a facilitator can do this. They could do this in a fixed or rotating role among ISLC actors (Vangrieken et al., 2017), the facilitators could be an external or internal person (Van Rees et al., 2022), or they could have the role of a 'knowledgeable other' (Takahasi & McDougal, 2016). In sum, depending on the context, the role of the facilitator could be more content based (e.g., knowledgeable other) or process-based (e.g., scheduling and time-tracking).

The ideal number of participants within a micro LC is scarcely discussed in literature. However, there is evidence that more participants increase the likelihood of disagreement and conflict within a micro LC (Davis, 2016). In an example from the installation sector there seemed to be an indication that a lower number of participants also helps with the agility of the micro LC (Van Rees et al., 2022). In turn, Corporaal et al. (2021) indicated that a micro LC ideally includes six to ten participants. Therefore, although there is limited academic literature available there seems to be evidence that a low number of participants is ideal for adaptable micro LCs.

The degree of network heterogeneity is understood as the difference in knowledge, technology, ability, professions and number of participants in the micro LC (Xie et al., 2016). Heterogeneity of participants seems to be a double-edged sword as it can positively influence knowledge sharing (Rock et al., 2016), but seemingly also negatively influences the agility of the micro LC (Van Rees et al., 2022). Thus, it seems that heterogeneity of participants does not need to be a goal in itself but can be a means depending on the collective goals and strategy of the ISLC.

Example of a micro LC structure

The aforementioned design considerations are incorporated in an example of the design process of a micro LC for production workers (see figure 3 for a summary).

Figure 3. The design process of a micro LC (based upon Corporaal et al., 2021)

First, participating organisations should identify employees who want to and need to develop skills in relation to the chosen subject. Participating organisations should hold orientation talks to identify which micro LCs fit the learning needs of their employees (Corporaal et al., 2021). Consequently, the employees are placed in the micro LCs that fit their learning needs. The learning needs of participants of a specific micro LC should subsequently be the central topic when shaping the learning tasks, activities and roles within this micro LC. Based on the accumulation of learning needs of all participants, the micro LC is shaped in week 1 (Corporaal et al., 2021).

After this, the micro LCs are assembled, including six to ten participants. In the first session, participants discuss their personal learning goals and revisit the shared goal of the micro LC, so that they are clear to all participants. The participants in the learning micro LC remain the same over the ten-week duration and the members can differ in knowledge, abilities, and professions (Corporaal et al., 2021). If the group of participants is relatively homogeneous

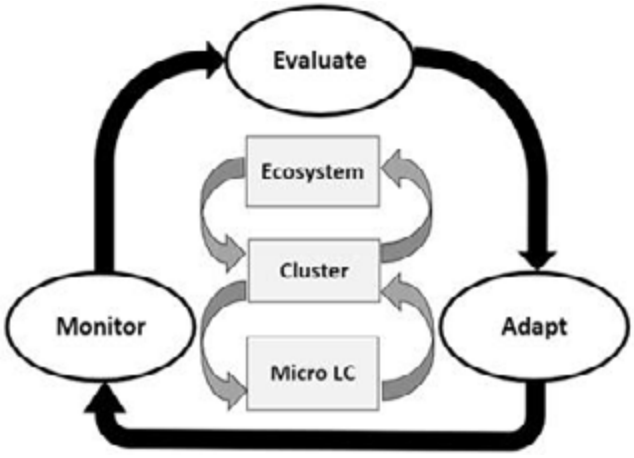
then a facilitator can more likely focus on a role of knowledgeable other. In a heterogeneous group the facilitator should focus more on process guidance (Schipper et al., 2023).

After the assembly of the micro LC, there will be weekly physical work sessions alternating fitting learning activities (< 45') under the guidance of a facilitator. The facilitator guides the participants through the process and adds content knowledge if needed. These weekly work sessions will continue for eight weeks. In the tenth week, a final session will summarise the learnings from the previous nine weeks and preview potential next steps. After completing the learning micro LC, participants will apply the learnings in their daily work (Corporaal et al., 2021). Adaptability is achieved through reflection on the learning process and outcomes after each cycle. Following the reflection, they will then decide whether to initiate a new cycle and what the learning topic will be. This aligns with the viewpoint of Schipper et al. (2023), who emphasised the importance of evaluating and following up on learning activities and outcomes. Chapter 3 further elaborates on the design of these governance mechanisms.

3. Governance structure of an ISLC

This chapter outlines the second step in designing adaptable and effective ISLCs. We examine a multi-level, iterative governance structure using a bottom-up approach, starting with micro LC governance, moving to cluster-level governance, and finally ecosystem-level governance. All governance levels should include iterative monitoring, evaluation, and adaptation of learning activities. Furthermore, governance loops at different levels should interact with one another to provide governance information to all levels (de Sitter et al., 1997; Provan & Kenis, 2008). For instance, facilitators might receive feedback on the specific needs of micro LC participants, such as additional knowledge from extra participants or additional funding for more learning activities. This governance information can be shared by facilitators of a micro LC with cluster-level governance professionals, enabling them to identify broader needs within the cluster. Subsequently, this need can then be shared by cluster-level governance professionals to the ecosystem level, allowing them to determine how to address it through, for example, the acquisition of additional funding, external information, or new learning pathways. See figure 4 for an overview.

Figure 4. Overview of an iterative and multi-level governance structure of ISLCs



In this chapter, we first describe the set-up of the micro LC governance structure. Second, we elaborate on the design the governance structure of the various clusters of micro LCs in the ISLC. Finally, we detail the ecosystem-level governance structure options.

3.1 Governance structure of micro LCs

On the micro LC-level, the governance structure should contribute to the timely delivery of feedback, real-time interaction when needed, integration of both off-site and on-site learning, coordination of learning events, and the use of technological infrastructure in a supportive manner (Corporaal et al., 2021; de Sitter et al., 1997). The participants of a micro LC (1) have their role(s) and responsibilities to support these goals, and (2) they are supported by a facilitator of the micro LC (Corporaal et al., 2021; Schipper et al., 2023).

Firstly, participants of a micro LC can contribute to ISLC governance through their roles in the broader ISLC at both the cluster and ISLC levels. They can undertake twelve role-related tasks, such as initiating network connections, making decisions, influencing others, and balancing actions and relationships within the network to prevent conflicts (Schipper et al., 2023). Additionally, participants may also take on formal or informal leadership roles, which is a crucial determinant of the collaboration process (Nyström et al., 2014). Typically, leaders do not hold formal leadership position within the ISLC structure (Schruijer, 2021). They often facilitate and support members, with roles being either permanent or rotating. However, the literature is unclear on how these leadership styles impact processes and outcomes (Schipper et al., 2023). Nonetheless, MSTS theory indicates governance roles should be allocated from the bottom up, with the governance structure at both cluster and ecosystem levels emerging from this (de Sitter et al., 1997).

Secondly, every participant of a micro LC should receive sufficient information, autonomy, and stimulus to monitor, evaluate, and adapt their learning tasks and activities. To achieve this, employees should first evaluate if they possess the resources to execute their learning activities to achieve their personal and micro LC goals. This can be done through a task and interdependence analysis. First, they analyse all the tasks and required resources related to the learning activities. Then, they establish which interdependencies they might have to supporting tools and technologies for executing the learning activities (Johnson et al., 2019). A facilitator is vital for guiding participants of the micro LC through this feedback loop. A facilitator is tasked with guiding micro LC participants through their day-to-day activities (Li et al., 2009) and providing possibilities and resources without interfering in the process (Nyström et al., 2014). For instance, a facilitator can monitor and evaluate during weekly work sessions of a micro LC. A facilitator has the following tasks that empower participants and contribute to meaningful work (Corporaal et al., 2021; de Sitter et al, 1997):

- Guidance of participants with personal goal-setting.

- Facilitation of mutual shaping of a broad and meaningful set of learning activities of participants that relate to both personal and organisational-level goals.
- Guidance for learning activities that engage both thinking and doing, catering to various participant preferences.
- Support indirect learning activities that enhance participants' work meaning. For instance, a production worker operating a welding machine can also learn quality control or equipment maintenance tasks.
- Guidance of participants in sharing ideas and knowledge related to these activities with other participants of the micro LC.

3.2 Governance structure of micro LC clusters

The governance structure of micro LC clusters entails the monitoring, evaluation and adaptation of learning activities within the cluster. The governance structure has two main functions: (1) governance of the fit between micro LCs in the cluster, and (2) enhancement of governance interactions between micro LC and ecosystem level (de Sitter et al., 1997; Provan & Kenis, 2008). There is limited literature regarding how the cluster governance should be shaped. However, based on design guidelines of de Sitter et al. (1997) and Provan and Kenis (2008) we can establish that the role of a cluster-level governance professional can be either a participant, the lead organisation, or an external party. In that sense, we have taken the role description of a governance manager by Provan and Kenis (2008) and applied the principles of de Sitter et al. (1997) regarding putting responsibilities low in the ISLC hierarchy to enhance governance capacity.

The governance of the fit of the micro LCs with the cluster can be enhanced through the interaction between a micro LC's facilitators and the cluster's responsible governance professional. Governance interactions between micro LCs and ecosystem level can be enhanced through a ‘pass-through’ role of the cluster-level governance professional. It is important to establish interactions between processes on different levels to align governance activities (de Sitter et al., 1997). In addition, frequent interactions between members of the ISLC on different levels can stimulate active participation and facilitate a cohesive network with high trust, learning intention, and explicit and tacit knowledge sharing (Filieri et al., 2014). Cluster-level governance professionals can gather information from facilitators of the respective micro LCs and share a broader need from micro LCs in their cluster with the ecosystem-level governance professionals.

3.3 Governance structure of ISLC ecosystems

After establishing the micro LCs' governance structure, we can design the overarching ISLC ecosystem governance. This includes (1) an appropriate governance form and (2) a structure to govern the ISLC ecosystem during runtime.

The selection of an appropriate governance form

An ISLC ecosystem can be participant-governed or externally governed. Participant-governed networks are, at one extreme, governed either collectively by the members themselves (i.e., shared) or, at the other extreme, by a single ISLC participant that takes on the role of a lead organisation. Externally governed networks are governed by a unique network administrative organisation (NAO) which may be either voluntarily established by network members or mandated as part of the network formation process (Provan & Kenis, 2008) (see Table 4).

Table 4. Governance Forms of an ISLC Adopted From Provan and Kenis (2008)

Governance form	Governing party	Description
Shared governance	Multiple to all participants	Smaller, multi-firm strategic alliances and partnerships in which multiple or al participating organisations collaborate intensively and share ecosystem-level governance activities.
Lead organisation	One lead Participant	There is a core provider organisation that assumes the role of network leader because of its central position in the flow of clients and key resources. For instance a common supplier for all participants. In this form, lead organisations take most strategic and operational governance decisions.
Network administrative organisation (NAO)	External party	An external party executes all ecosystem-level governance activities. It requires greater involvement by at least a subset of participating organisations (often, NAO governing board members for monitoring governance actions of the NAO) that are committed to ISLC-level goals and have a strategic involvement with the network as a whole. Other participating organisations are less involved. This typically enhances network legitimacy, helps with dealing with unique and complex network-level problems and issues, and reduces the complexity comparted to governance. Additionally, government run NAOs stimulate growth through targeted funding and/or network facilitation to achieve goals.

The chosen governance form of the ISLC should accommodate the characteristics of the whole ISLC. More specifically, (1) trust, (2) number of participants, (3) goals consensus, and (4) need for network level competencies should be considered when choosing an appropriate governance form for the ISLC (Provan & Kenis, 2008).

Trust is "the willingness to accept vulnerability based on positive expectations about another's intentions or behaviours" (McEvily et al., 2003, p.92). For understanding network-level interactions, however, the distribution of trust is critical and whether or not it is reciprocated among network members. High density of trust is when trust across members is widely distributed across members, and low density of trust is when trust is only narrowly distributed such that it is occurring differentially within individual dyads or cliques (Provan &

Kenis, 2008). As it takes time to establish these relationships and trust, this is a vulnerable process when members join or leave the ISLC (Vangrieken et al., 2017). This is the case as the power of members in the ISLC shapes both group dynamics and team learning (Yorks et al., 2003). In addition, there can be knowledge boundaries between and across organisations depending on the elements such as differences in beliefs, content expertise, industry expertise, language, interests and other team diversity elements (Schipper et al., 2023). As mentioned before, A way to tackle these challenges could be to design for frequent interactions between members of the organisation such that active participation is stimulated and a network with high trust, learning intention, and explicit and tacit knowledge sharing is developed (Filieri et al., 2014). Overall, high-density trust seems more crucial for participant-governed ISLCs, which require a lot of collaboration and decrease in importance as collaboration decreases.

The number of participants in an ISLC can be defined as the number of organisations participating in the ISLC (Provan & Kenis, 2008). There is evidence that more partners increase the likelihood of disagreement and conflict and therefore increases the complexity of governing the ISLCs (Davis, 2016; Provan & Kenis, 2008). Disagreement and conflict can have several negative consequences such as a disturbance in the professional and reflective dialogue in the ISLC or a reduced identification with the community which, in turn, could lead to reduced learning outcomes. A suitable network form can mitigate risks of a high number of participants through reduced number of interactions required for ecosystem-level governance (Provan & Kenis, 2008). For instance, the lead organisation form is highly centralised and requires less interactions between participating organisations about governance activities which reduced the chances of conflict and, in turn, increases the number of participants that this governance form can effectively operate with.

Goal consensus is the extent to which participating organisations agree on ISLC-level goals. Provan and Kenis (2008) describe examples such as reducing conflict among participants, attracting funding for the ISLC, addressing community needs, or improved service to participating individuals. However, goal consensus does not mean that the goals of participating organisations should be similar. Goal consensus allows participants to perform better when there is conflict whilst conflict can also be a stimulant for innovation. High goal consensus can lead to more commitment of network members and collaboration amongst network members. However, high goal consensus is not always required as networks can still be effective when they have a suitable governance form (Provan & Kenis, 2008). A highly centralised governance structure requires lower goal consensus as interactions between participating organisations are less frequent. In this sense a shared governance structure would require high goal consensus, and a lead organisation form requires low goal consensus.

Network-level competencies are competencies required to achieve network-level goals and different network governance forms require the members of the network to provide different competencies and different levels of these competencies. Network-level competencies can

be divided into internal and external competencies. Internal competencies refer to the nature of the tasks that are performed by network members and external competencies refer to the competencies to deal with external demands and needs the network is faced with. Internally, if the network's task is one that requires significant interdependence among members, then the need for network-level coordinating skills and task-specific competencies will be great, meaning that governance needs to facilitate interdependent action. Externally, demands may also range from high to low, requiring varying degrees of competencies at the network level. External tasks may include the roles of buffering, or protecting the network from environmental shocks such as shifts in funding or new regulations, and bridging, which might include the roles of lobbying, seeking out new members, acquiring funding, building external legitimacy, and so on (Provan & Kenis, 2008). In the context of an ISLC external network-level competencies may include the competencies to deal with changing requirements in terms of the skills that participants of micro LCs should learn. As we reason under the assumption that ISLCs should deal with constantly evolving smart skills requirements, an ISLC should have a high level of external network-level competencies. In this case, an NAO seems best equipped to deal with high need for network-level competencies as an NAO deploys network-level staff to develop the skills that are needed for network-level actions. This means that members are better equipped to deal with high competency demands such as interdependent tasks and external demands.

Overall, trust, number of participants, goal consensus, and the need for network-level competencies affect which governance form of the ISLC is effective. For instance, as trust becomes less densely distributed throughout the network, as the number of participants gets larger, as network goal consensus declines, and as the need for network-level competencies increases, brokered forms of network governance, like lead organisation and NAO, are likely to become more effective than shared-governance networks (Provan & Kenis, 2008). Table 5 shows the possible combinations contextual dimensions and governance forms leading to effective ecosystem-level governance.

Table 5. Configurations that lead to effective ecosystem-level governance (Adopted From Provan & Kenis, 2008)

Governance forms	Trust	Number of participants	Goal consensus	Need for network-level competencies
Shared governance	High density	Few	High	Low
Lead organisation	Low density, highly centralised	Moderate	Moderately low	Moderate
NAO	Moderate density, NAO monitored by members	Moderate to many	Moderately high	High

Governance of the ISLC-ecosystem during runtime

The characteristics of the ISLC develop over time. Therefore, a fit between governance forms and ISLC characteristics is crucial, not only during design phase but also during runtime.

Practitioners should distribute governance tasks among ISLC members if a shared governance form is chosen, or assign a governance manager if a lead organisation or NAO form is adopted (Provan & Kenis, 2008). In both cases, these professionals should follow the principles listed below (adopted from Provan & Kenis, 2008):

- *Principle 1:* ensure consistency between characteristics of the whole ISLC and the governance form.
- *Principle 2:* adopt shared network governance if trust is widely shared among network participants, when there are relatively few network participants, when the network-level goal consensus is high, and when the need for network-level competencies is high;
- *Principle 3:* adopt lead organisation governance if trust is narrowly shared among network participants, when there are a relatively moderate number of network participants, when network-level goal consensus is moderately low, and when the need for network-level competencies is moderate
- *Principle 4:* adopt NAO network governance if trust is moderately to widely shared among network participants, when there are a moderate number to many network participants, when network-level goal consensus is moderately high, and when need for network-level competencies is high.
- *Principle 5:* as a network manager, recognise and respond to the following three basic tensions, or contractor logics, that are inherent in network governance; (1) efficiency versus inclusiveness, (2) internal versus external legitimacy, and (3) flexibility versus stability
- *Principle 6:* periodically evaluate the contingencies of the network to change the network governance accordingly.

4. A design framework for adaptable and effective ISLCs

In this chapter, we summarise the application of design fundamentals from chapter 1 to the design of the learning structure and governance structure of an ISLC into one comprehensive design framework. With this framework we adopt both design strategies, principles and sequences from MSTS theory for shaping learning structures. In addition, we integrated design principles, strategies and sequences from both MSTS theory and network theory for designing a governance structure. These insights have been integrated with learning community literature to create a comprehensive design framework (see figure 5).

The design framework starts at the left of the model with designing the ISLC-level foundations. In this step the participating organisations of the ISLC, the subject, and the strategy are established (see chapter 2.1). In the next design step the clusters of micro LCs are formed through segmentation and parallelisation, and the design of the micro LCs themselves is shaped (see chapters 2.2 and 2.3). Finally, an iterative and multi-level governance structure is set up following a bottom-up approach (see chapter 3). This, together, creates the design of an adaptable and effective ISLC.

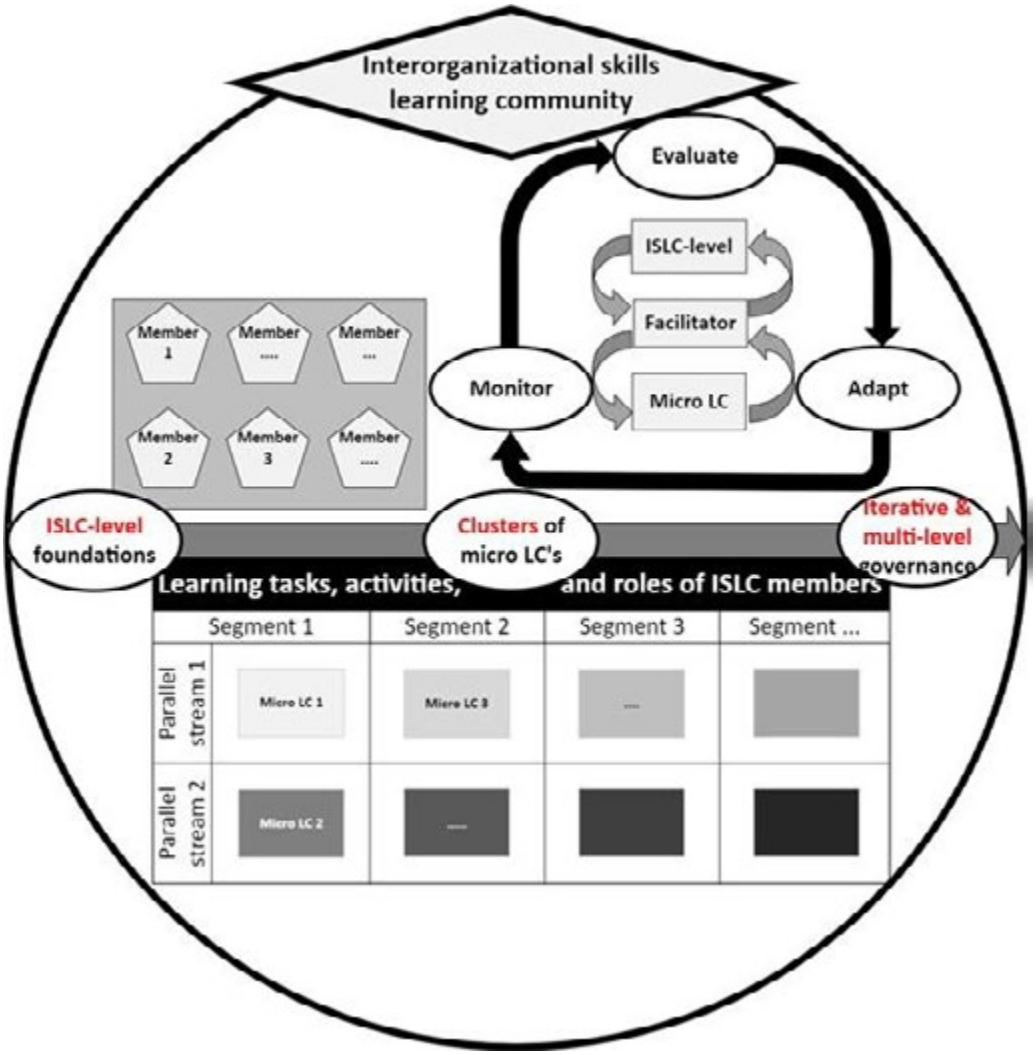


Figure 5. A conceptual design framework for adaptable and effective ISLCs

5. Conclusions and discussion

In this chapter, we discuss which conclusions can be drawn from our theoretical integration study, along with its theoretical and practical implications. Lastly, we identify limitations and outline future research opportunities.

5.1 Main conclusions and theoretical contributions

Our main goal was to establish a first comprehensive design framework that facilitates the design of adaptable and effective ISLCs. We found that it is crucial to reduce disturbance probabilities of the ISLC and improve governance capacity to be able to adapt to changes more effectively. In our study, we have developed a design framework that specifies how these design principles can be achieved. In sum, we found that it is pivotal to (1) distinguish

different design levels, (2) distinguish between design of a learning structure and governance structure, (3) follow a specific design sequence, (4) cluster micro LCs, and (5) design iterative, interactive and multi-level feedback loops.

We found that ISLCs are designed at the ecosystem, cluster, and micro LC levels. These design levels apply to both the learning and governance structures of an ISLC. One should first design the learning structure from the top down and then the governance structure from the bottom up. The learning structure should contain clustering of micro LCs through parallelisation and segmentation design strategies. Finally, the governance structure must include feedback loops for monitoring, evaluation, and adaptation via a bottom-up approach, interacting with loops at other levels. These findings contribute to a novel design framework for developing adaptable and effective ISLCs.

Implications for workplace innovation and learning community research in I5.0

Workplace innovation (WPI) emphasizes a skilled workforce with decent jobs as a driver for innovation and performance (Oeij et al., 2021). WPI incorporates MSTS theory and other sociological research into four aligned bundles of practices: (1) Jobs, Teams & Technology, (2) Employee-Driven Innovation & Improvement, (3) Organisational Structures, Management and Procedures, and (4) Co-Created Leadership & Employee Voice (Oeij et al., 2017; Oeij et al., 2021). This study aims to enhance workplace innovation by developing an interorganisational solution to the skills challenge organisations in the I5.0 context face. Our approach uniquely integrates principles similar to WPI, such as MSTS design, into this solution for a skilled workforce. This supports Prus et al.'s (2017) assertion that "in order to face the conceptual fuzziness and instability of workplace innovation, future research privileges a context-aware view of innovation. Scholars may learn more about possible ways to identify and justify relevant boundaries for analysis of WPI" (P. 1264). Prus et al. (2017) noted that exploring these boundaries at the ecosystem level, as in this study, adds value to concepts addressing boundaryless, ubiquitous, and digital workplaces. Thus, our contributions to workplace innovation include developing a design framework that offers an interorganisational solution to skill development in I5.0.

In this paper, we contribute to existing theory of interorganisational learning and learning community design through the integration of MSTS theory (de Sitter et al., 1997) and network theory (Provan & Kenis, 2008). This integration is particularly valuable as it can facilitate continuous skill development in I5.0 by designing adaptable ISLCs, which are currently lacking in the literature. More specifically, we add to existing ISLC literature (Corporaal et al., 2021; Schipper et al., 2023) by identifying three levels of an ISLC, distinguishing between the design of a learning structure and a governance structure, specifying the design principles, explaining the design sequence, and describing design strategies. These new insights are subsequently applied to the context of designing an ISLC that does not exist in the current literature. This approach can be particularly valuable for the dynamic and fast-changing I5.0 as the governance structure is designed to adapt to continuous changes. Therefore, this

paper not only adds to the current state of the literature but also has practical implications for design professionals.

5.2 Practical use of the design framework

Although design and governance professionals should merely use the design framework as a basis and then apply it to their context, it holds unique value for both ISLC design and governance professionals. The framework offers a step-by-step guide for design professionals for setting up adaptable and effective ISLCs. However, the design framework also provides guidance for governance professionals. ISLCs develop over time, meaning that the governance structure should be managed such that the ISLC remains effective. The responsible professional is dependent on the chosen governance form. If an NAO is adopted, then an external professional is responsible for managing the governance structure. If a shared or lead organisation governance structure is adopted, then a professional is chosen who participates in the ISLC (Provan & Kenis, 2008). According to Provan and Kenis (2008), a governance professional should have the following tasks:

- Recognise and respond to the following three basic tensions that are inherent in ISLC governance; (1) efficiency versus inclusiveness, (2) internal versus external legitimacy, and (3) flexibility versus stability;
- Continuously monitor, evaluate and adapt current governance practices on ecosystem-level;
- Continuously monitor and evaluate the characteristics of the ISLC and adapt the governance form accordingly.

We suggest that such a governance professional also be in close contact with professionals who execute governance tasks on cluster and micro LC-levels. This interaction is vital not only for executing the aforementioned tasks but also for providing information and resources to other participants in the LC who are tasked with governance activities on their respective levels.

Finally, our design framework could hold practical value for governmental and regional policymakers that are in charge of skilling issues. Examples could be enhancing continuous development of production workers' skills in eastern Netherlands (e.g., Saxion, n.d.), or the national initiative in the Netherlands to upskill and reskill workers to address the tight labour market (*Smart skills at scale*, n.d.). These policymakers could benefit from our design framework as it facilitates effective regional and national interorganisational collaborations that could strengthen the economy (Cascio, 2019).

5.3 Future research

Although our paper has significantly contributed to ISLC design literature, several issues must be addressed. First, we have done a theoretical integration that conceptually studies the subjects of adaptable and effective ISLCs. While this enriches understanding of designing ISLCs, it is not comprehensive (Elsbach & Knippenberg, 2020). This means that our design framework requires empirical research to assess its reliability and validity. Empirical research in the I5.0 context is especially necessary, as this context demands continuous skill development. More specifically, it should be evaluated which configurations should be selected for ongoing skill development for a particular set of individual and ISLC goals, and how this is governed over time.

Second, the design framework dictates what designers should do in which sequence, and under what circumstances. However, this study has not delved into the role of the designer. Future research could address this gap by specifying the ISLC-designer role, their tasks and contextual factors to consider that could influence these roles and tasks.

Third, more research should be done regarding the design elements and contextual dimensions of an ISLC, such that additions can be made to the design configurations proposed by Provan and Kenis (2008). We have partly addressed this by creating a design framework that integrates design elements and contextual dimensions that are currently known. However, this does not provide an overview of how the related design elements in the framework should look like in specific contexts. Future studies could study these various contexts such that our understanding of configurations of design elements that lead to effective ISLCs in a particular context can be broadened. The I5.0 context is especially interesting as the interconnectivity of all sociotechnical subsystems can challenge segmenting and parallelising learning activities in micro LCs. Although it takes a lot of time and resources, ideally, longitudinal field experiments following different ISLCs are needed to further enhance our understanding of effective ISLC designs in various contexts and their adaptation over time. Longitudinal research is valuable as it can be used to establish the mechanisms with which ISLCs adapt to various contexts.

Ultimately, for policy makers and practitioners, it is not about the perfectly conclusive scientific model or an all-encompassing framework for ISLC design. Above all, having a solid basis with knowledge, principles and steps to build on is important. Collaboration in ISLCs is also a matter of starting and learning by doing, and today's challenges also do not wait and need everyone's attention and collaboration now. Our paper and framework can inspire, help, and guide practice in decision making, focusing, developing and starting ISLCs that can be maintained over time.

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