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TOPICAL REVIEW

Upskilling for Advanced Digitization: A Scoping Review

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ABSTRACT In a rapidly transforming technological landscape, higher education institutions struggle to meet the demands of industry in providing timely and appropriate upskilling and reskilling opportunities for the workforce. Under the umbrella of ''advanced digitization'', a term prominent in European discourse, covering a wide range of new digital technologies within the Industry 4.0 and Industry 5.0 paradigms in manufacturing, ICT and engineering, we use scoping review methods to explore the unique challenges and interventions in this area, highlighting potentials for further research. Our scoping review examines 81 peer reviewed Scopus-indexed papers, outlining the current global research on the challenges and interventions in upskilling the workforce for advanced digitization. Our results show that research in this area is most prevalent in Europe, North America, and Asia and is most frequently done within the manufacturing and ICT sectors. Due to the fast pace of advanced digitization, close collaboration between education providers and industry is required to develop relevant and appropriate upskilling opportunities. We underline the importance of developing strategic management and change management knowledge alongside technology skills. We also highlight the importance of inter- and trans-disciplinary knowledge development. While determining skill needs has attracted substantial research focus, businesses may struggle with developing strategic upskilling plans despite being aware of their skills needs. We conclude that interventions that foster situated engagement and hands-on experience are vital for the future of upskilling.

INDEX TERMS Industry 4.0, upskilling, reskilling, digitization, HR strategy, workforce development, engineering education, digital transformation.

I. INTRODUCTION

As the pace of technological change speeds up, businesses need to adopt advanced digital technologies rapidly to remain competitive. Advanced digital technologies, beyond basic digitization, represent the cutting edge of new market-ready technologies. At the forefront of Industry 4.0, skills in advanced digital technologies are in high demand. However, despite the demand to keep up with the latest technology, upskilling and reskilling employees remains challenging.

Previous research on upskilling for digital technologies has focused on identifying and predicting future skills needs [1], [2]. Other research has focused on skills and competencies required for Industry 4.0 and Industry 5.0 [3], [4], [5].

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However, despite the growing urgency for workforce upskilling in response to the rapid changes in the technology, there remains a limited understanding of how universities, businesses, individuals, and governments implement effective upskilling strategies for advanced digitization. Additionally, there is limited analysis of how different pedagogical and policy interventions can help meet current skills needs. To address this gap, this scoping review maps the current landscape of research on upskilling for advanced digitization, with a focus on identifying key challenges, learning and policy intervention types, and areas for future inquiry.

In this article, we consider the full range of advanced digital technologies, including but not limited to: AI, robotics, cybersecurity, and advanced ICT applications. We aim to understand how businesses and sector leaders are grappling with upskilling and reskilling in a rapidly changing environment, and to map the work presently being done in this area. The following two research questions guide our approach:

1) How does the existing literature conceptualize the main challenges to workforce upskilling for advanced digitization for businesses, education providers, and workers?
2) How are learning and policy interventions aligned with these challenges?

A. BACKGROUND

1) INDUSTRY 4.0 AND ADVANCED DIGITIZATION

At the core of Industry 4.0 is digitization, which is the process of bringing together the physical world and the digital world in a way that may lead to transformation and innovation across a plethora of sectors [6]. For business, Industry 4.0 brings access to more advanced digital technologies, and the opportunity to gain deeper insights using emerging tools like digital twins, advanced data analytics, and interconnected systems.

Currently under debate is the paradigm shift from Industry 4.0 to Industry 5.0. Industry 5.0 is not a technological movement per se, but a value-driven movement enabled by technologies. The values behind this movement are human-centricity, sustainability, and resilience [7]. Technologies considered to be enabling the Industry 5.0 paradigm might include things that encourage human-technology collaboration, automation, and immersion, such as simulations, cyber-physical systems, and decentralized computing [8].

Both Industry 4.0 and Industry 5.0 require leveraging and adopting new digital technologies. In the wider literature on new digital technologies, there are two main ways in which advanced digital technologies are framed: emerging or disruptive. Emerging technologies are novel and steadily expanding technologies whose most prominent impact rests in the future [9]. It may be uncertain whether they will open a new market niche or displace an existing technology. In contrast, disruptive technologies are those that are actively displacing existing technologies and creating new markets. With this displacement, disruptive technologies bring new ways of measuring performance that are distinctly different from the technology being displaced [10]. Disruptive technologies also have the potential to introduce disruption on a social level [11]. Importantly, Industry 4.0 shares characteristics with disruptive technology, such as a strong entwining of technology with social life [12].

In our study, we use the framing of advanced digitization. Sitting at the nexus of Industry 4.0 and Industry 5.0, advanced digitization covers those digital tools that are enablers for Industry 5.0, such as the internet of things (IoT) and autonomous systems, visualized in Figure 1. Unlike emerging technologies, whose use is not yet stabilized, advanced digital technologies are those that are at the forefront of current technology but are in the early stages of deployment.

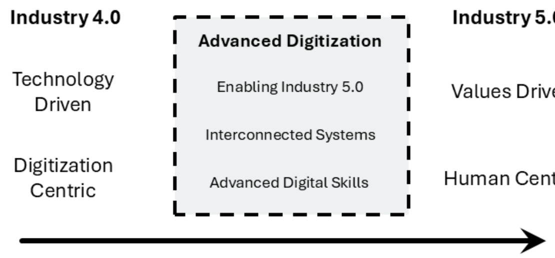

FIGURE 1. Relationship between Industry 5.0, Industry 4.0 and advanced digitization.

2) UPSKILLING AND RESKILLING WORKERS FOR ADVANCED DIGITIZATION

There are three important challenges facing workforce planning in Industry 4.0. Firstly, the format of work in Industry 4.0 is no longer based around people performing the same standardized tasks each day [7]; repetitive tasks are ideally automated, and people are placed in the position of decision-makers in their environments. Secondly, there is a workforce shortage that severely impacts some of the most important domains in industry 4.0, in particular there is a large shortfall of people with cybersecurity skills, due to the increasing complexity and ubiquity of internet-connected technology systems [5], [13]. Thirdly, people are living longer and therefore working longer [7]; this means that working adults need to actively engage in upskilling to remain relevant and productive in the workforce, as new technologies come to fore during their working lives.

Workforce shortages in advanced digital technology areas are a strong driver for upskilling and reskilling the current workforce. Increasing the potential pool of skilled workers in advanced digital domains also requires reaching out to a more diverse pool of people than currently work in these sectors [14]. Therefore, there is a need for reskilling efforts to be accessible to a broad range of workers.

One way in which educational offerings are made accessible has typically been to offer Massive Online Open Courses (MOOCs) and micro-credentials, which are bite-sized learning opportunities that award higher education credits. While MOOCs are historically run as courses with low interaction and interactivity, over the last ten years there has been a movement towards designing MOOCs with community in mind [15], [16], which we will return to in the discussion.

Research on learning transfer has also highlighted the importance of ecological validity [17], which refers to the idea that learning environments should reflect real-world conditions to enable transfer of learning to workplace settings. This is particularly relevant in Industry 4.0 settings, where skills requirements are complex and specific to given contexts.

The skills and competencies required for workers to adapt to Industry 4.0 are diverse [18]. Hecklau et al. [19] suggest that workers need a mixture of technical competencies, personal competencies, methodological competencies, and social competencies; as a result, successful upskilling needs to take a holistic approach. Building on Hecklau et al.'s research, Flores et al. [20] put forward a model of "Human capital 4.0", which posits that there are five core competencies needed for workers in Industry 4.0: Soft skills, hard skills, digital skills, cognitive skills, and emotional intelligence. These two models give a clear direction about the types of skills and competence that workers need. However, there exists no research mapping how educational interventions can help develop these interconnected skills, and how proposed interventions can relieve the challenges for different actors in workforce upskilling. To meet this challenge, we undertook a scoping review of the existing literature.

II. METHOD

Scoping review methods [21] were selected to map the breadth of the existing research in upskilling and reskilling for advanced digitization. To ensure that the review could capture patterns and gaps in this under-defined and rapidly evolving area, the scope of the review was kept wide.

A search was performed using the Scopus database, for articles published before 2025. The search was restricted to one database in order to give a depth of analysis. Scopus was selected due to having the best coverage for science and technology articles [22], [23]. The search term used for the review was:

(TITLE-ABS-KEY ("advanced digitisation" OR "advanced digitalisation") OR TITLE-ABS-KEY ("industry 4.0" OR "industry 5.0" OR "secure digital platforms" OR "cyber security" OR "edge" OR "cloud" OR "5G" OR "6G" OR "autonomous systems" OR "data-driven" OR "model-driven" OR "simulation" OR "software development" OR "system-of-systems" OR "AI" OR "Artificial intelligence" OR "Internet of Things" OR "IoT" OR "blockchain" OR "machine learning") AND TITLE-ABS-KEY ("Upskilling" OR "Reskilling"))

The chosen terms reflect the types of technologies frequently mentioned in relation to advanced digitization by the European Commission [24] and by the Swedish funder Vinnova [25].

Criteria for inclusion in this review were (a) that the paper explored learning interventions, policy interventions, or challenges in upskilling or reskilling and (b) that the upskilling or reskilling was directed to a topic considered to be advanced digitization and (c) that the paper was peer reviewed. Book chapters, conference articles, and journal articles were included, but full books and opinion pieces were not included.

Papers were categorized and tagged manually using RAYYAN, an online system for managing literature reviews collaboratively. Reviewers included papers in the review if at least one reviewer decided the paper met the three criteria listed above.

Once included, we applied a structured coding framework informed by engineering education pedagogy and workforce development literature. Codes were organized into three main categories: (1) actor: business, education provider, or individual (2) challenge type, and (3) intervention type. Interventions were further grouped according to which pedagogical strategies in engineering education [26] they aligned closest with: behaviorist strategies, cognitivist strategies, or situative strategies. The papers were then analyzed using ATLAS.ti, a cloud-based qualitative analysis platform. Themes were derived in a top-down fashion based on the challenge and intervention type described in the paper and are presented in the results section.

In total, 550 records were screened, 219 were assessed for eligibility and 81 were included in the review. The results of the screening are presented in a Prisma chart in Figure 2.

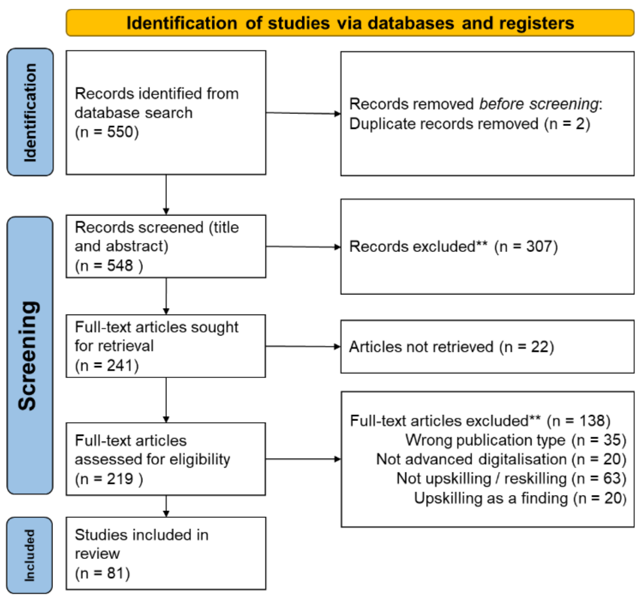

FIGURE 2. PRISMA chart.

Excluded papers were grouped into three categories. The first category, **not upskilling / reskilling**, primarily represents papers that are focused on identifying skills needs or on describing the future of work generally, but that do not have a specific goal of investigating upskilling. The second category, **not advanced digitization**, were papers that primarily described using technologies for upskilling purposes rather than upskilling people to use that technology, for example, studies that explore the use of virtual reality (VR) to train medical students on routine procedures, but that are not training the students in the use of VR. The third category, **upskilling as a finding**, are papers that discuss other challenges in the workforce and conclude the solution to these challenges would be to upskill the workforce, but do not engage with the topic of upskilling. Further papers were excluded for being the **wrong publication type**, these mostly included magazine articles, books, general descriptions of projects, corrections, or low-quality publications as deemed by the authors. Low quality publications typically were those that did not contribute new empirical material.

III. RESULTS

In this section, we first present some of the statistical characteristics of the data set and then go on to discuss the main challenges and interventions found in the data.

The most represented economic sectors in the dataset are ICT and manufacturing, see Figure 3. The dominance of these sectors reflects their central role in Industry 4.0. However, as automation becomes more commonplace, particularly as a result of advanced AI capabilities, more research is likely to be required for upskilling in other industries, such as the business and services sector. This highlights a crucial gap in the current literature base.

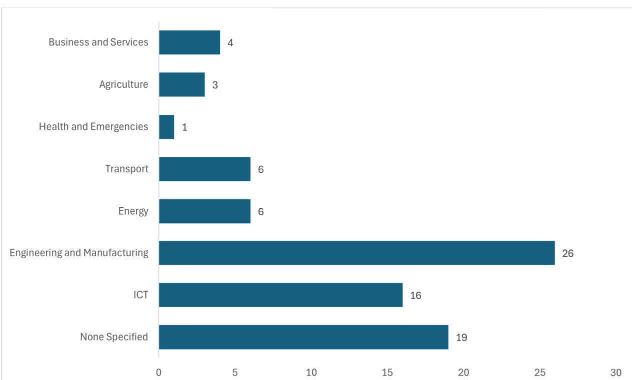

FIGURE 3. Sectors represented in the dataset.

The majority of the papers in this set were published after 2019, with two outlying papers published in 2001 and 2013. These papers were on aviation digitization and mobile application development, respectively. The clear upward trend in papers published in this area indicates the rapid growth of research in this area. This is visualized in Figure 4.

The majority of the papers in this set were based on research conducted in Europe, showing the issue as being prominent in Europe. North America and Asia are well represented in this set, while Africa, South America, and Oceania are less represented. Nine of the studies reported on research conducted in multiple regions. This is visualized in Figure 5.

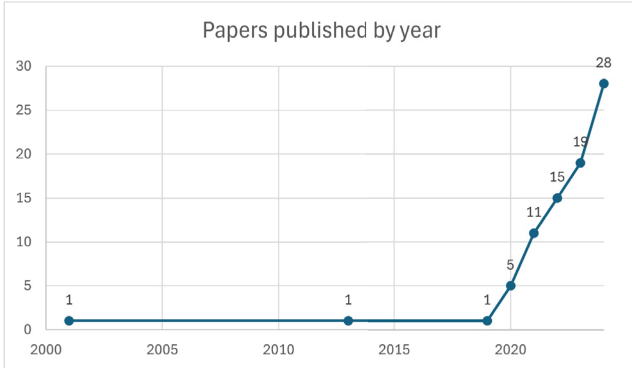

FIGURE 4. Papers published by year.

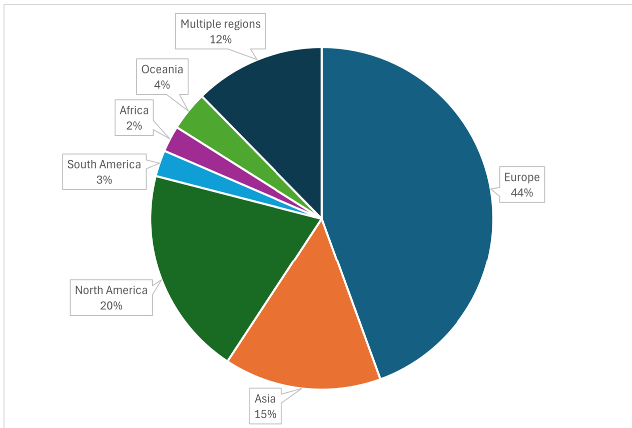

FIGURE 5. Papers published by region under study.

IV. CHALLENGES FOR UPSKILLING AND RESKILLING

In this section, we explore the major themes in the challenges to upskilling and reskilling reported in the dataset, grouped by whether the challenge affects education providers, industries, individuals, or the relationships between actors.

A. EDUCATION PROVIDERS

In this data set, the main group of education providers covered are universities and other higher education institutions (HEIs). In this section, we explore the major challenges identified in this literature review to education providers for providing upskilling for advanced digitization, exploring the administrative issues, the challenge of designing curricula, and the challenges of multidisciplinarity in this space.

1) ADMINISTRATION

In relation to admissions and credit transfer, HEIs ability to recognize and accredit prior formal learning can be an issue for offering effective upskilling for individuals in the workforce. When admitting mature students, the HEI must have a procedure in place to recognize equivalences in previous qualifications and courses, even if those qualifications have been taken in other universities or in other countries [27]. These intricacies cause delays and slowdowns for students looking to upskill, for example, a potential student may have learned programming skills through a nonstandard route like a hackathon, but because the certificate doesn't attract formal credits the student cannot be admitted to a higher-level course.

The kinds of cohorts who enroll on upskilling courses also present logistical challenges for HEIs. Being able to provide upskilling opportunities for adult workers requires integrating a diverse student cohort with a variety of backgrounds, skills, and expectations [28]. Timing and physical location, as well as whether the course can be studied from distance, are an important factor in offering courses for these mixed cohorts, especially if learning experiences can be provided after working hours [29], [30].

2) DESIGN

We identify many new factors to be considered in designing upskilling and reskilling curricula for Industry 4.0 and for advanced digital skills.

One challenge presented by the literature is the lengthy delivery and design cycles for new courses and programs. This has been coined as a need for a new ''educational supply chain'' [31]. While businesses have very fast operational cycles and are able to adapt rapidly to changes, those who supply teaching and upskilling for the technology, particularly HEIs, are often a step behind in the process [28]. This causes a 'lag', where there can be demand for upskilling in a particular new technology area, but no appropriate higher education courses or interventions have been developed to fill this need. This is part of a repeating pattern.

This 'lag' is compounded by information flows between education providers and industry. To design and develop appropriate courses or interventions, educators require clear and concrete case studies that demonstrate how new technologies are being used [32], [33] and need to develop good communication links with industries to continuously obtain information that can improve the relevancy of academic courses [34]. The challenge to an education provider is developing those communications and nurturing connections with business and industry leaders.

3) MULTIDISCIPLINARITY

Upskilling for advanced digitization requires more than just technical upskilling. Jaiswal et al. [35], in their exploration of upskilling multinational companies for AI, identify three major areas of upskilling that workers require: data and digital skills; cognitive and decision-making skills; and leadership and communication skills. Theben et al. [36] produced a literature review on competencies in accelerated digitization that confirms that a blend of skills are required. In their analysis, Theben et al. [36] also group skills into three categories: soft skills, complex cognitive skills, and technical skills. These taxonomies demonstrate the need to facilitate multidisciplinary approaches to a range of skills. It is important not to neglect the social and cognitive aspects of skills development.

In this data set, there is a particular emphasis on the importance of workers having the appropriate management and leadership skills to adapt to rapidly changing environments. This dataset suggest that a modern curriculum should balance technology, management, problem-based learning, and self-directed learning [37]. Practical experiences need to be integrated alongside the acquisition of deep knowledge [38], [39], [40]. There is a challenge in designing educational interventions that can meet all of these requirements.

The demands of Industry 4.0 require multidisciplinary knowledge, which may travel between and across academic disciplinary boundaries [41]. Over and above finding a way to integrate management skills and social skills with technology skills, learning interventions need to be designed across academic disciplinary boundaries [42], as often many different technical domains are at work in new digital technologies. This is often difficult to achieve within the setup of a university of HEI, where researchers may be encouraged to have focused knowledge in just one topic [28]. Equally, the research interests of staff can be out of step with the topic knowledge demanded for designing upskilling interventions [43].

B. BUSINESSES

In this section we explore the main challenges found in the dataset for businesses in upskilling and reskilling for advanced digitization. We note that there is some variance in the types of challenges encountered by small and medium enterprises (SMEs) and large enterprises, which are often linked to strategy and resources.

1) STRATEGY

Lack of a coherent digital strategy or road-map is a big hurdle for many businesses, particularly a lack of clearly defined projects in digitization [44]. This typically means that upskilling for advanced digitization is left by the wayside. Ideally, upskilling strategies should be well communicated to workers and should be clearly available to workers at all levels of employment [45]. The rapid rate of technological change suggests that a continuous learning strategy will be a desirable option [35], [45], [46], [47], meaning that businesses may want to consider incorporating routine upskilling as part of their normal operations.

Despite often knowing what kinds of skills their workers need, few companies prioritise creating or locating formal upskilling opportunities [44]. Generic external training may often be insufficient, as workers increasingly need to understand the specific skills, concepts and technologies used within an organization [48].

In addition to technological skills, some researchers also point out the importance of cultivating English language skills in the workforce as having a strategic benefit [37], [49]. The terms used in new technologies are often based in English, and training opportunities are often more readily available in English. We argue that this may also point to a greater need for localization of existing upskilling materials into a more diverse array of languages.

2) RESOURCES

Overall, success in adoption of industry 4.0 technologies seems to be related to the size of the company, with small companies faring the worst at technological adoption [50]. This may be affected by their ability to offer upskilling programs. Larger companies are more likely to offer developed professional development programs [51], which may contribute to their success. The small companies who do adopt new technologies are much less likely to engage in upskilling [50].

Some businesses may struggle with finding the capacity to allocate enough of workers' time for upskilling interventions [52]. While there is a clear long-term benefit to allocating time for workers to engage with in-depth learning opportunities, this is often at odds with the short-term pressures of work efficiency [53]. This may indicate a need to consider strategies for staffing resources.

C. INDIVIDUALS

In this section we explore the main challenges for individuals in selecting and completing upskilling and reskilling opportunities, focusing on choice, motivation, and individual characteristics.

1) CHOICES

Either due to lack of employer resources or business strategy, the responsibility for upskilling for advanced digitization may fall on the individual [36], [47], including finding the time to take part in upskilling and paying the upfront costs of upskilling programs.

Access to appropriate training may be difficult for individuals, who have to navigate a complex landscape of certifications, where the most effective upskilling route may be unclear [54]. Some individuals may find it difficult to decide between upskilling routes offered by HEIs and those offered by private providers. Industry certifications in specific technologies, such as Amazon Web Services certifications, can be very important for entering the job market, and are an important complement to traditional university certifications [39].

There are a lack of affordable training options and a lack of systematic support for people who want to upskill [28], [55], which varies considerably according to geographical context. For example, in the USA, the cost of upskilling certification combined with uncertainties about employment opportunities can prevent individuals from taking part in programs [28]. Some countries, for example Sweden, have localized programs for reskilling people who are unemployed [56], but such opportunities might be harder to find for people outside of targeted groups looking to change employment sector. Many affordable and time-effective online training options are only available in English, which may also be a problem particularly in India and Southeast Asia, where it is less common to have fluency in English [55].

When upskilling opportunities take place outside of normal working hours, it can be difficult for workers to balance the time demands of upskilling with the time demands of their jobs and family lives [57], [58]. Achieving work-life balance is important for the well-being of workers [59]. Similarly, for the self-employed or those in precarious job positions, taking on upskilling opportunities might mean losing income in the short term [60].

Physical distance to attend training venues may have a strong effect on choice of upskilling program [61]; convenience is very important for retention and uptake since workers may be short on time or busy with other demands [55].

2) MOTIVATION

Research suggests that workers may drop out of reskilling interventions because of their workload, the skill gap between their current work tasks and the skills they require, or because they are unsure of if they will use the skills in the future [61].

In order for upskilling initiatives to be successful, it is vital that the intervention is seen as personalized and relevant, and something that workers can 'buy in' to [53]. Not all workers are equally open to taking part in upskilling programs [62]. Additionally, if there is a misalignment between the ambition of individual workers and the corporate strategy, there will likely not be any improvement in uptake of upskilling [61].

The constant change and rate of technological change may in itself be demotivating for some workers, who feel like they are always having to catch up [55]. Media reporting on job displacement, particularly for sectors investing in AI, can be a large contributory factor to resistance to change and upskilling [52].

3) INDIVIDUAL CHARACTERISTICS

Access to reskilling and upskilling opportunities may not fall evenly across the population. The research base has some coverage of three categories of difference: age, gender, and migration status.

A survey of engineers in research and development jobs at multinational companies working with emerging digital technology suggested that older workers with more years of experience may be less likely to self-nominate for upskilling opportunities [61]. However, these individuals have valuable perspectives in the workplace and offer important organizational experience, therefore it should be a high priority to ensure they are supported in being upskilled [46].

Women are generally underrepresented in technology job roles and face specific challenges in their working environments [63]. Barriers for women who want to reskill in technology might include lack of flexibility in course scheduling, lack of support for 'returnships' or internships aimed at people returning to the workforce after career breaks, and perceptions that companies are not willing to consider atypical CVs [39], [64]. A survey of professionals working in internet of things suggests that, provided the appropriate opportunities, women are more likely than men to gain substantial learning from upskilling opportunities, though the reasons for this are not explored in this data set [58].

Migrant workers may struggle to find appropriate reskilling or upskilling opportunities due to language barriers and lack of networks in the local area [56].

D. COLLABORATION

Collaboration frameworks between the different actors involved in upskilling for advanced digitization are an area of challenge. Many papers mention the triple helix model as a framework for developing collaboration. The triple helix model is a spiral model that represents the complex links between businesses, governments and HEIs [41], [65]. While strong collaboration is seen as necessary to meet the demands of upskilling and reskilling, there remains challenges in developing appropriate collaborative structures [66], [67], [68].

The communication gap between academia and industry is a challenge, with no systematic feedback from industry to academia that explicates skills needs [34]. There are clear benefits from improving this communication gap around upskilling skills needs, such as the research opportunities can emerge when universities take up new upskilling programs. When set up strategically, upskilling programs can provide good conditions to foster collaborative innovation opportunities [69], bringing together actors across sectors.

Collaboration in providing upskilling opportunities between businesses and academia could benefit from making better use of each other's resources. Providing upskilling and training that can combine experiences in the workplace with experiences outside the workplace is important, but often difficult to achieve [38]. Newly acquired skills are best retained when they can be used and reinforced quickly [61], so interventions can benefit from being designed with a view to their immediate applicability in work situations.

Variation in levels of government involvement in setting the policy agenda around upskilling is also a potential factor in how well collaboration can be set up. For example, one paper in our dataset from 2022 discusses how at the time the Mexican government did not have a well-defined political agenda for skills development, meaning that universities have to do extra work to set up frameworks and structures for collaboration [70]. We note that government-level skills agendas are changing rapidly due to the demand for AI strategy, and the current state is therefore not fully reflected in our dataset. However, we emphasize that government coordination plays an important role in facilitating collaborations between industry and universities.

V. INTERVENTIONS IN UPSKILLING AND RESKILLING

In this section, the interventions found in the dataset are grouped into *learning interventions* and *policy interventions*. Learning interventions have been grouped within the three pedagogical paradigms commonly used in engineering education [26]. Policy interventions are much less common in this dataset and are presented according to if they relate to businesses, HEIs or government.

A. LEARNING INTERVENTIONS

The most frequent learning intervention types in the data set are summarized in Figure 6.

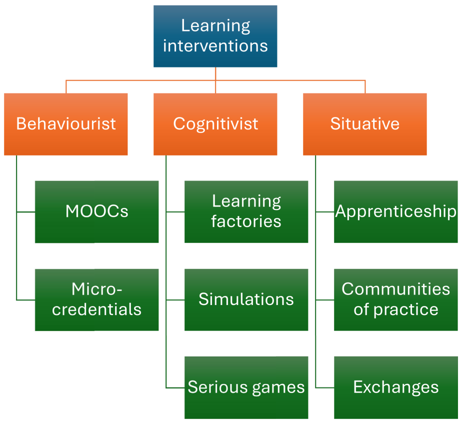

FIGURE 6. Summary of interventions.

1) CONVENIENT AND SHORT INTERVENTIONS–BEHAVIORIST APPROACHES

In this section, we discuss the short form learning interventions in the data set. These interventions could be considered inspired by modern behaviorist approaches to learning. These interventions generally focus on how learning can be reinforced through behavior and are typified by smaller learning opportunities that use gamified mechanisms, like badges, to reinforce learning. The two main interventions in this paradigm that we find in the dataset are MOOCs and micro-credentials.

MOOCs, or Massive Open Online Courses, are internet-based courses with large cohorts and low requirements for entry. These courses are very flexible, can be taken anywhere, and are usually self-paced, meaning that learners can progress at their own speed. They may involve little to no interaction with instructors or other learners. MOOCs can be a cost-effective and flexible for learners [71]. Courses can be designed as "mobile-first" [72], intended to be run on smartphones and tablets, meaning that the courses are accessible to a large range of people.

Challenges for providing effective MOOCs might arise when trying to blend 'live' lectures and teaching moments on these typically asynchronous courses [73]. Opportunities to collaborate and network with other students may also be lacking [73]. Completion rates for MOOCs tend to be low [43], [71].

Research in this dataset describes designing new platforms for hosting MOOCs that are tailored to the needs of Industry 4.0 [65], [73], [74]. These are often linked to micro-credentials.

Micro-credentials are a proof of completion, such as a digital badge or certificate, for a small, standalone learning opportunity [75]. These are commonly offered by private learning platforms such as LinkedIn Learning and Coursera but are increasingly also offered by HEIs. While many private platforms offer micro-credentials for learning delivered in the form of MOOCs or on-demand learning, HEIs may also offer micro-credentials for completion of other types of courses with campus-based delivery [30]. Micro-credentials can be designed as "stackable" [39], meaning that they can be combined over time to contribute toward a larger certificate, award, or "micro-qualification" [75].

2) LEARNING BY DOING-COGNITIVIST APPROACHES

Cognitivist approaches to upskilling interventions foreground the need to actively interact with technology, either directly or as part of a simulation. In some interventions, this can be as simple as integrating regular laboratory sessions with learning, ensuring that learners have the opportunity to apply learning to hands-on activities [29]. Examples of interventions designed in this paradigm found in the dataset include learning factories, simulations, and serious games.

Learning factories are simulated, lab-like learning environments where learners can physically interact with new technology, such as robotics and cyber-physical systems used in manufacturing. Often touted as an 'authentic' learning environment [76], [77], learning factories offer people the opportunity to develop a range of skills in realistic situations, including social skills, technical skills, and physical skills [42], [67]. Learning factories can even be extended with augmented reality and virtual reality, making it possible to simulate a variety of settings and situations [77], [78]. Some interventions describe including learning factories as part of a blended learning program, combined with traditional teaching or supporting online modules [79].

Other types of simulated learning environments are also present in the literature, though they may focus less on having the same physical equipment as in a work-based environment and more on having the same software tools. These might include cyber-training ranges [48], [63], hackathons [80], and bootcamps [69], [81]. These interventions all focus on having hands-on experiences that are representative of work or work tasks in their respective fields.

'Serious games' are another type of game-based approach to learning that may use simulation, and that can be designed with or without digital elements [82]. They might involve, for example, groups of students role-playing as different actors in a process. Not to be confused with gamification, serious games do not have a primary focus of entertainment or encouraging reward-seeking behavior. While relatively uncommon in this dataset, one example discusses designing serious games to help teach supply chain quality assurance [82].

3) LEARNING SOCIALLY-SITUATIVE APPROACHES

Situative approaches center the need for social and peer learning. In this dataset, situative approaches focus strongly on the social side of learning and workforce integration, such as mentoring, networking, and communities of practice. For underrepresented groups, these opportunities can be vital in ensuring success in the workforce [83].

Situative approaches can be very effective when they are fully embedded in a work situation. Modern apprenticeship collaborations are one way to organize a situated learning intervention, allowing learners to build networks and learn from industry mentors in situation [38], [51], [68]. While this can prove effective for developing technical skills, apprentice-type approaches require a planned structure to ensure rounded skills development [51].

Communities of practice are a social, peer-based intervention mentioned less frequently in the literature. Often used as a supplement to MOOCs and other types of distance learning, communities of practice facilitate peers forming groups where they can share their learning and discuss with their coworkers or fellow learners [51], [58], [81]. On a larger scale, this kind of intervention could be organized similarly to a conference event, bringing people together for a scheduled day of presentations and networking [64].

To support communities of practice, it is important for businesses to have robust ways to share knowledge internally, in peer-based settings [84]. Some of the resource tensions faced by businesses could be ameliorated by facilitating knowledge sharing between businesses in similar sectors, particularly SMEs [38], [84].

Other approaches in this literature set describe a fully informal peer-based approach to knowledge building in companies, through employee exchanges or through hiring new personnel. Cross-training individuals between work areas, and creating peer-based opportunities to learn can be an important part of an upskilling strategy [28]. A similar effect could be achieved by job rotation or internal secondment [38], [78], encouraging workers to get experience of different positions within the same company. Peer-based learning can also occur through a formal employee exchange, which might involve trading workers between two companies on a temporary basis [57]. However, peer-sharing should not become the entire solution to upskilling, as this potentially leads to knowledge inertia or a failure to assimilate new knowledge.

Some businesses might also find that a good supply of newly trained graduates can be an important part of refreshing the company's skill set [38]. Introducing newly hired workers who have more recent experiences of formal education or who may come from companies already using advanced digital technologies can help integrate and promote learning in an organizational context [38], [85], and may address knowledge inertia.

B. POLICY INTERVENTIONS

In this section, we briefly discuss some of the policy interventions in the data set, as they pertain to government, education providers, and businesses.

Government has an important role to play in facilitating upskilling interventions, supporting both financing and collaborative arrangements. Some governments, for example, Japan, offer subsidies to companies to provide paid leave for training [57]. When it comes to recognizing learning, the government is, in many cases, best positioned to negotiate and coordinate issues around credit recognition and credit transfer [27]. For example, the European Credit Transfer and Accumulation System (ECTS) framework is one way in which government coordination can allow qualifications from multiple regions to be recognized by employers and education providers in other countries. In this system, there is an agreed way to represent the number of study hours that each credit represents, making it clearer how credits from different countries can be equivalent.

Some of the papers in this data set suggest that governments should consider radical reform of universities and higher education institutions as a whole to adapt to the new landscape. There is a divide between suggesting a greater amount of centralization or a greater amount of decentralization. Those advocating for centralization imagine "education-as-a-service" (EaaS) [86] or "knowledge-as-a-service" (KaaS) [54]. Inspired by "software-as-a-service", formal higher education is proposed to be on-demand and available through centralized digital platforms. Other researchers take similar inspiration, coining terms like "just-in-time skills development" [75]. In contrast, others imagine that the university of the future could have smaller, geographically distributed community-based hubs that are more physically accessible [43]. The decentralized university is imagined to be more adaptable to local needs and contexts.

Other possible ways to structurally address the challenges of upskilling may involve questioning the current model of higher education. For example, Stanford University suggest an "open loop" university system, questioning if students should have access to further years of college education beyond the standard four year degree, integrated with their careers [32].

In those papers that describe how industries have worked with others to supply upskilling, one possible design is for industries to have a multi-partner approach to upskilling, using the services both of a university who supplies theoretical knowledge and consultants who supply training in practical applications [53]. This approach is referred to as "co-design".

In co-design approaches, businesses work in close collaboration with universities or education providers to design and deliver a course or intervention [56], [86]. Courses or interventions can thus be designed with specific workers and workforce needs in mind. For example, education providers can design learning activities around specific and authentic problems that exist in the workplace [68], [87], [88]. They can also integrate learning opportunities in both the workplace and outside of the workplace [38], [79].

Co-designed courses may also have the benefits of pooling resources, such as software and equipment, between both education providers and industries [89]. Many co-designed courses used some elements of blended learning [90], which generally means combining online and distance learning with on-site and physical learning.

Meanwhile, businesses are suggested to strengthen their communication with workers and support their workers with adapting to change. Businesses must pro-actively address resistance to change, through clear communication and reassurance about job security [91]. They can do this through fostering openness to change and supporting their employees in finding appropriate opportunities [45], [47].

VI. DISCUSSION

We have so far shown how the literature conceptualizes challenges for upskilling in advanced digitization, and discussed the different types of educational and policy interventions that are present in the literature. In this section we present a simplified mapping of challenges and interventions, along with our reflections on the material in the data set.

In Figure 7, we show a summary of how different interventions meet some of the main and current challenges in upskilling for advanced digitization identified in the dataset. Policy interventions are generally warranted at the strategic level, either in terms of developing national and business level strategies, or guiding course design strategies. Having a clear policy direction from an employer may also help guide individuals in making course selections. For universities, policy around admissions and enrollment may be a particular challenge.

Behaviorist interventions like MOOCs and micro-credentials are generally strong options for solving issues of course selection and scalability. Both MOOC interventions and situative interventions can provide flexibility and can be delivered with lower time and resource cost to businesses. For example, these interventions can be integrated into the working day, using already available resources, without need to specifically release employee time. Situative interventions are generally well suited to solving challenges relating to developing social skills and encouraging networking between employees. Both situative and cognitivist interventions are well suited to presenting learning situations that are reflective of real-life situations.

Cognitivist interventions are best for developing hands-on skills in new technologies and for potentially integrating and simulating complex day-to-day work tasks. They go a long way toward addressing the challenge of ensuring that curriculum is relevant and applicable to a current workplace.

While in this review we have encountered MOOCs as aligned with behaviorist approaches, often referred to as expert MOOCs or xMOOCs, there are other approaches to MOOCs that take on situative pedagogic design elements, for example, collaborative MOOCs or cMOOCs [15], [16].

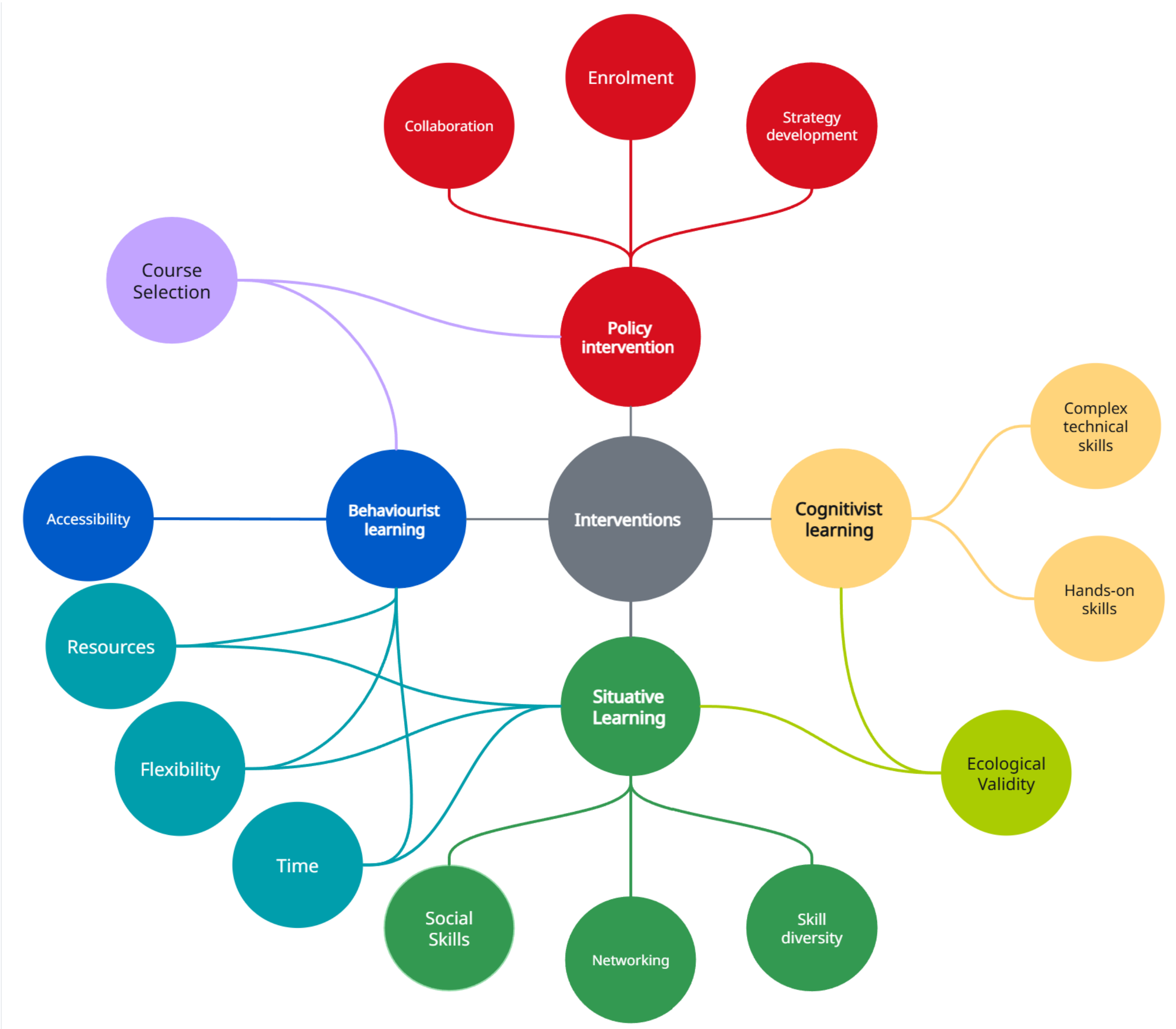

FIGURE 7. **Categories of educational interventions mapped with the main challenge for students, business, and universities that they address.**

These types of design may offset some of the weaknesses of the MOOC, but at the cost of increased resource and time requirements. Such interventions are not explicitly described in the dataset and may be worth exploring for advanced digitization upskilling.

The call for trans-disciplinary collaboration is strong in this data set, and the fresh interconnectedness of established and emerging knowledge forms is very evident. Cybersecurity stands as a concrete example of the way in which the workforce of the Industry 4.0 must be prepared and trained to cross disciplinary boundaries [54]. Simply being proficient in the core technology is no longer enough, one must also be able to understand the technical security requirements and the social psychology of risk inherent in new technologies. In this respect, while our research lends support to models of skills development such as those proposed by Hecklau et al. [19] and Flores et al. [20], we place additional emphasis on the need for trans-disciplinary knowledge.

We note in this data set that the concept of 'ecological validity' in education is relevant but not explicitly applied. Ecological validity is the extent to which a learning situation is representative of a real-life situation, and how well learning is therefore able to transfer to a real-life situation [17]. In the increasing complexity of technology in Industry 4.0, where system configurations and technologies might be quite specific to the context of one particular business, ensuring that workers know how tools will work in their own environment is paramount.

However, contained within the notion of the Industry 4.0 is the hyperbolic push and pull of speed and stasis [12]; a contradiction we find here in this data set. The looming promise of transformation of the employment landscape, with expected changes to work categories, is repeatedly stated - but its advent is always immanent, and never fully realized. While speed narratives have a role to play in motivating change, they may equally contribute to workers' resistance to upskilling.

We also find intractable delays, between new technologies being adopted and education providers being able to teach those new technologies. This is complicated by a subtle shift away from universities being the ones developing near-market technology, to private research and development companies being the ones on the forefront of new technologies, particularly in the UK [92]. Even in cases where university research is close to market, researchers involved in developing the technology may not fully anticipate the ways in which industries may adopt and use the technology. This causes a 'lag' that can produce frustration [28], but that lag is not possible to solve within the current system of upskilling approaches. It will be necessary to form closer ties between industry-based researchers and education providers.

VII. LIMITATIONS

Scoping review methodology was selected in order to give a broad coverage of the existing research. However, while this methodology is appropriate for identifying patterns in the literature, it does not enable systematic judgments about the effectiveness of interventions.

Additionally, this review was conducted using materials from only one database, the Scopus database. While there are overlaps between the major databases, there may still be relevant materials that are not covered by this review. In particular, there may be relevant social science papers not covered by the Scopus database. The choice to focus on peer reviewed literature also means that the results may exclude relevant policy documents and industry initiatives that are not formalized in academic research.

VIII. CONCLUSION

In this scoping review, we have explored the challenges for education providers, businesses, and individuals in upskilling and reskilling for advanced digitization. We have outlined the major educational and policy interventions captured in the dataset and assessed their strengths and weaknesses in addressing those challenges.

When designing and delivering interventions, we note tensions between validity and accessibility, and between depth and convenience. While it is increasingly necessary for learners to have hands-on experiences, those experiences need to be accessible and ecologically valid to properly support upskilling. The need for ecological validity means that employers must be amenable to giving their employees time within their working hours for learning and means that education providers must follow codesign principles to ensure that learning opportunities generate experiences that are applicable for employees everyday working lives. While micro-credentials, MOOCs, and small modular formats for course design may be attractive in terms of convenience and resource allocation, these interventions may not be able to offer the depth and complexity of learning required for ecological validity.

While in the analysis of challenges, we discuss that HEIs are often out of sync with industry needs, very few papers in the literature explore or compare HEI offerings against private actors and consultants in the education industry. A future direction for research might include greater attention to the other agents and actors in the upskilling space.

We note that upskilling strategy can often be the bottleneck for businesses navigating the new technological frontier. While it may be tempting to allow individuals to take responsibility for their training needs, with the sheer complexity of the current pace of change, there is a clear benefit to developing and implementing training strategies. We recommend that further research is done into effective upskilling and reskilling business strategies.

It is reasonably uncommon in this dataset to engage with policy issues, or to conceptualize some of the challenges as issues from a systematic policy perspective. For upskilling and reskilling initiatives to be resilient to future challenges, systematic approaches are warranted [93]. We suggest that more attention needs to be paid to how policies at government, business and universities affect upskilling in the context of advanced digitization. Positive examples of collaboration between actors to facilitate upskilling would add considerable value to this area of research.

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AI use statement: Microsoft Copilot was used to preprocess the article data from RAYYAN, separating the tags into separate columns for analysis. The output was manually cross-checked for accuracy.

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