AN INVESTIGATION OF INDUSTRY 4.0 SKILLS REQUIREMENTS

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ABSTRACT

The Industry 4.0 wave is built on technological advancement that is bringing about significant change. The impact of Industry 4.0 is being felt across all industries, including the education sector. During the 2019 State of the Nation address, the President of South Africa pointed out that the government was seeking to respond to the change in skills requirements. In this paper, a systematic literature review will be performed to investigate Industry 4.0 skills requirements in the engineering profession and the role of capability development in meeting Industry 4.0 requirements. An exploration of the impact of Industry 4.0 on technical institutions as opposed to academic institutions will also be discussed. This paper incorporates this exploratory investigation into detailed research on developing a skills development framework that seeks to bridge the gap between Industry 4.0 skills requirements and development in South Africa.

OPSOMMING

Die verskynsel van Industrie 4.0 word gedryf deur tegnologiese vordering wat beduidende verandering teweegbring. Die impak van Industrie 4.0 is oor alle industrieë waarneembaar, insluitend die onderwyssektor. Gedurende die 2019-staatsrede het die President van Suid-Afrika daarop gewys dat die regering poog om die verandering in vereistes vir vaardighede te hanteer. In hierdie artikel word ‘n sistematiese literatuuroorsig uitgevoer om vas te stel wat die vereistes is vir Industrie 4.0-vaardighede in die ingenieursprofessie asook die rol van vaardigheidsontwikkeling om aan Industrie 4.0-vereistes te voldoen. ’n Ondersoek na die impak van Industrie 4.0 op tegniese instellings in teenstelling met akademiese instellings word ook bespreek. Hierdie werkstuk inkorporeer hierdie verkennende ondersoek in gedetailleerde navorsing oor ’n vaardigheidsontwikkelingstruktuur wat ten doel het om die gaping tussen vereistes vir vaardighede vir Industrie 4.0 en ontwikkeling in Suid-Afrika te oorbrug.

1 INTRODUCTION

According to historians, human civilisation has, to date, undergone three industrial revolutions: the first industrial revolution (mechanisation), the second industrial revolution (mass production and electricity), and the third industrial revolution (automation) [1, 2]. These revolutions not only influenced production and business models: they also affected the skills required by future employees in various industries [3]. From one industrial revolution to the next, some jobs disappeared while others were created. More importantly, some skills became redundant while others became valuable. The upcoming fourth industrial revolution is no exception with regard to the replacement of jobs and skills. Industry 4.0, an acknowledged initiative driving the fourth industrial revolution, is characterised by significant technological advancement that requires a specialised and skilled workforce [3].

Industry 4.0 is driving the world into a global, automated, virtual, and flexible environment, which results in a global contest for jobs that demand specialised skills for the digital and sharing economy [4]. The adoption of Industry 4.0 technologies results in people working in a digitised and networked workplace that promotes interaction with algorithms and robotics, as well as operating in a virtual world [5]. These changes result in new job requirements for a unique and specialised skills set [6, 7]. Thus there is bound to be a noticeable change in the skills requirements between the fourth industrial revolution and the previous three industrial revolutions.

The availability of relevant skills and capabilities in a country's workforce will significantly influence the successful adoption of Industry 4.0 at the micro- and macro-level. Moreover, the quality of skills and qualifications of the workforce will play a noticeable role in driving the innovation and competiveness of organisations [3, 8]. Conversely, a lack of the required skills set will result in a noticeable drop in performance and reduced competiveness in organisations. Yet Schallock, Rybski, Jochem, and Kohl [9] state that Industry 4.0 is more than technological advancement; it also has to prioritise human resource development, which involves developing the skills that will be required in the future [9].

Unemployment stands to be one of the biggest outstanding challenges in developing countries, including South Africa. Listed among the factors that contribute to high unemployment are: (a) the mismatch between available skills and skills required in the industry; (b) the high level of unskilled labour; and (c) inadequate education [10-12]. Industry 4.0 offers the prospect of opportunities for quality and productive employment. The problem lies in the fact that Industry 4.0 has the potential to increase unemployment through the loss of manual and repetitive jobs that can easily be automated, unless the subject of skilling and re-skilling for the digital economy is addressed from the onset by enhancing skills development in technical and academic institutions.

Developing countries are faced with a critical shortage of professionals with the required Industry 4.0 skills set [13]. This makes it necessary to investigate closely the essential requirements for the skills in this digital economy, and to determine how these skills can be developed and incorporated into existing educational structures.

Shvetsova and Kuzmina [14] point out that there is an existing gap between the skills required and the skills developed in the Industry 4.0 era. This could be because there is no clear awareness of the skills that meet Industry 4.0 requirements.

The South African National Development Plan prioritises the creation of employment and the improvement of the quality of education and skills development in a way that will bring about inclusive development and fight poverty [15]. In the 2019 State of the Nation address, the President of South Africa pointed out that one of the challenges the nation faces is creating jobs. He further pointed out that the government is seeking to respond to changing skills needs and the skills needs of the future by enhancing training in the education system [16]. This confirms that an investigation into Industry 4.0 skills requirements and a skills development framework are vital.

This paper seeks to investigate Industry 4.0 skills requirements in the engineering profession and skills development through performing a systematic literature review (SLR). An exploration of the impact of Industry 4.0 on technical institutions, as opposed to academic institutions, will be discussed. This paper conducts an exploratory investigation into developing a skills development framework that seeks to bridge the gap between Industry 4.0 skills requirements and development in South Africa.

The paper outline is as follows: Section 2 presents an Industry 4.0 overview, and Section 3 outlines the methodology to investigate skills requirements for Industry 4.0. The SLR results and a discussion of the results are presented in Section 4 and Section 5 respectively. Section 6 outlines the conclusion and future work.

2 INDUSTRY 4.0 OVERVIEW

The rapid transformation of jobs has resulted in a wide mix of skills, attitudes, experiences, and requirements in Industry 4.0 [17-19]. The trend of job complexity has been upward through successive industrial revolutions [20]. Industry 4.0, by virtue of driving the fourth industrial revolution, could pose a significant threat to employment, given the increased complexity of workplace requirements. This effect extends to the skills requirements of jobs and skills development in educational institutes.

Performing a skills requirements study in the Industry 4.0 era is of significance because it informs employment seekers and skills development institutions about what to work towards and what to expect. Adolph, Tisch, and Metternich [21], referring to production environments, point out that technological megatrends will significantly affect the skills and competencies needed. This in turn requires organisations to develop strategies, and skills development institutions to be innovative, in creating the required skills and competencies.

Gudanowska, Alonso, and Törmänen [22] report that, although the competencies required in different fields might differ, there are similarities in the competencies required in different industries. They add that soft skills will be as important as technical skills in the engineer of the future [22]. The future engineer's interaction with intelligent machines will form a symbiotic partnership that requires a firm base of soft skills, such as emotional intelligence, critical thinking, innovation, communication, collaboration, leadership, and teamwork [23]. Intelligent machines cannot apply common-sense reasoning; neither can they show empathy, which humans need to do to increase productivity when working in smart factories [24].

2.1 Engineering professionals in South Africa

Engineering professionals in South Africa are generally categorised into four distinct levels: specified category practitioner, technician, technologist, and engineer, as presented in Table 1, which was formulated using a significant amount of information from the Engineering Council of South Africa website [25]. Identifying Industry 4.0 skills requirements for each engineering professional level is significant in determining how individuals should respond to the new work landscape.

Table 1: Engineering professional categories in South Africa [25]

Expertise layer	**Qualification**	**Institution type**	**Description**
Specified category practitioner	Higher Certificate in Engineering	Technical vocational education and training (TVET)	Vocational with strong industry-oriented focus, simulated work experience, or work-integrated learning.
Technician (NQF 6)	Advanced Certificate in Engineering Practice	Universities of Technology, TVET	The individual has a vocational-orientated qualification; demonstration of focused knowledge and skills in a particular field is essential. Knowledge and skills gained in workplace. Uses the work-integrated learning approach.
	Diploma in Engineering Technology	Universities of Technology, TVET	Vocational or industry-oriented training, prepared to enter a particular role in the industry; does not include work-integrated learning.
	Diploma in Engineering	Universities of Technology, TVET	Vocational orientation, which includes professional, vocational, or industry-specific knowledge. Demonstration of focused knowledge and skills in a particular field.
	Advanced Certificate in Engineering	Universities of Technology	Vocational-industry orientation; demonstrates sound knowledge in a particular field or discipline, and ability to apply knowledge and skills.
Technologist (NQF 7)	Advanced Diploma in Engineering	Universities of Technology and Comprehensive Universities	Industry-oriented, professional and career focus, ability to demonstrate initiative and responsibility in either academic or professional environments, may contain work-integrated learning.
Engineer (NQF 8)	Bachelor of Engineering / Bachelor of Science in Engineering	Universities	Oriented towards imparting firm base in mathematics, natural science, engineering sciences, engineering modelling, engineering design in order to solve problems in the societies in which we live.
	Bachelor of Engineering Technology Honours	Universities	Enhances the application of research and development, expertise in a particular discipline. Graduates must work independently in applying original thought and judgement to technical and risk-based decisions in complex situations.

The universities of technology referred to in Table 1 were formerly known as technikons. Although the institution type that offers a particular qualification is not fixed, Table 1 generalises according to traditional offerings. Figure 1 presents the professional skills level with the skills complexity, skills required, and task frequency at each level. It can be seen that skills complexity and skills required decrease from the level of engineer to the level of specified category practitioner, and vice versa: task frequency decreases from the bottom to the top level.

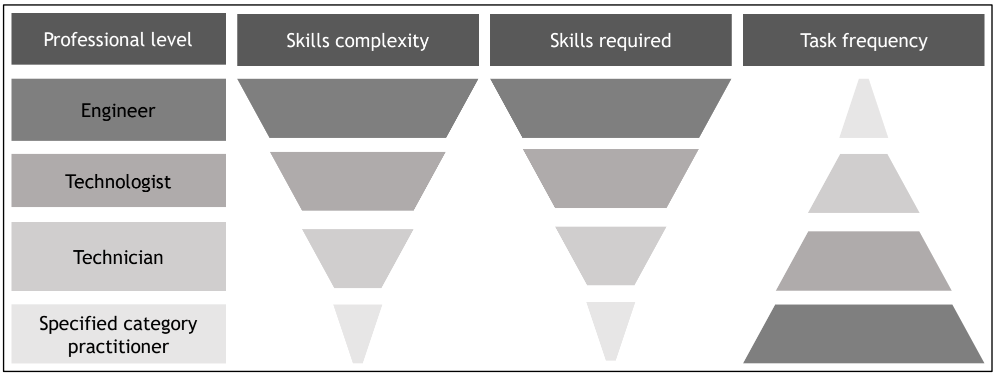

Figure 1: Skills level vs skills complexity, skills required, and task frequency [Own work]

Figure 1 shows that the current set-up of the engineering profession is that the skills required and the skills complexity differ from one engineering professional level to another. Could there be the same expectation in the Industry 4.0 era? Are specific skills expected at each engineering professional level?

2.2 Impact of Industry 4.0 on skills requirements

The best talent is not the machines but [a] combination of both humans and machines [20]

Jaschke [26] points out that successive industrial revolutions noticeably changed the nature of work processes, which resulted in the transformation of employees' roles and required skills. The disruptive nature of Industry 4.0 brings about considerable changes in work processes, which consequently requires a different approach to the way work is performed [27]. Sackey and Bester [28] further highlight that Industry 4.0 will significantly transform employees' work profiles. New skills sets will be required to perform existing and new jobs that will emerge owing to Industry 4.0 technological advances [18]. The future factory will be significantly populated with collaborative robotics that can interact with humans in the workplace. This implies that, although the degree of automation will vary with sectors and types of jobs, its impact will be universally felt [29]. Such an environment requires humans to develop logic, which will be applied by advanced robots [30]. Collaboration of humans and robots will be inevitable for improved productivity [23]. Adopting this view, the authors conclude that Industry 4.0 will result in noticeable changes in the employees' skills requirements.

The literature [17, 18, 20, 31] converges on the view that there will be a rise in automation and advanced robotics replacing routine, repetitive, and middle-income jobs. Technological advancement in Industry 4.0 is significantly diminishing the relevance of existing skills sets and encouraging the creation of new skills sets [18, 19]. Benefits associated with these developments include the elimination of unsafe routine and repetitive jobs, the exclusion of non-stimulating jobs, and the creation of opportunities to develop meaningful and transferable skills.

A significant number of authors [18, 20] state that technical skills must be complemented by strong social and collaborative skills. Big data analytics has proven to be the outstanding skill that engineers must possess to be relevant in Industry 4.0 [18]. To make a noticeable impact, data analytics skills must be coupled with technical skills, business and industry knowledge, and soft skills [17]. Technical commercialising skills will be desirable in Industry 4.0.

Because of Industry 4.0, both technical and academic institutions must strive to supplement theoretical knowledge with practical skills, social skills and responsibility, ethics and values, and entrepreneurship capability, among others [20]. Other countries are moving towards rolling out work-based learning degree programmes that are meant to achieve learning and innovation skills, information technology skills, and life and career skills [32].

Prifti, Knigge, Kienegger, and Krcmar [27] point out that skills for Industry 4.0 will require a certain level of engineering professional training. Advanced Industry 4.0 technologies in the workplace will significantly change the skills profile of engineers and information technology professionals [27]. This can be demonstrated by the use of digital twin skills by engineers in commissioning machines from remote service centres and troubleshooting equipment in remote areas.

Prifti *et al.* [27] explain that the skills requirements for Industry 4.0 differ from previous developments in the industry because, beyond domain knowledge, personal skills prove to play a vital role, and the interaction between the technologies and their virtual nature creates something conceptual. These personal skills can be learned and adopted. Engineering training must not focus only on specific discipline knowledge; behavioural skills must also receive significant consideration. Beyond balancing discipline knowledge and behavioural skills, interdisciplinary understanding must be developed [27]. Industry 4.0 technological developments are in the virtual world; thus our typical behaviours are not effective, stressing the need for interdisciplinary understanding.

Furthermore, the sudden and impactful advances of Industry 4.0 technologies require employees to possess life-long learning capabilities [27]. According to Prifti *et al.* [27], big data and data analytics, combined with other skills, are more important than the technical skills required in individuals working in Industry 4.0. However, the comprehensive work by Prifti *et al.* [27] does not include the identification of skills and competencies for each professional level.

Cotet, Balgiu, and Zaleschi [33] identify soft skills and hard skills in comparison with behavioural skills and domain skills respectively, unlike Prifti *et al.* [27]. In the work of Cotet *et al.*, soft skills are identified as contributing significantly to the success and development of the employee in the Industry 4.0 era [33].

According to Cotet *et al.* [33], the three top soft skills required in an Industry 4.0 era employee are creativity, emotional intelligence, and proactive thinking. The authors' understanding is that those three top skills assist an employee to adapt easily to the incremental changes that are characteristic of the nature of Industry 4.0 technologies.

Adolph *et al.* [21] discuss competencies that include, among others, agility in problem solving, the ability to reshape processes, flexibility, and self-learning as central in driving production environments in Industry 4.0.

2.3 Impact of Industry 4.0 on technical and academic institutions

If young people are making a tube frame chassis for a racing car, suddenly trigonometry becomes very interesting — they see the point of all the measurements and calculations [20].

Over the years, the importance and preference attached to technical institutions has been on a downward trend in academic institutions in a significant number of countries, including South Africa. Industry 4.0 skills requirements demand a reconsideration of the importance that is attached to qualifications obtained from technical and vocational institutions. Technical institutions should be modernised and informed by industry requirements. Industry 4.0 calls for the enhancement of the social status of technical institutions. Technical institutions are relevant in the digital transformation ecosystem, since they are the mainstay of developing a technically skilled workforce [11].

This requires both academic and technical institutions to provide opportunities for lifelong learning. Jaschke [26] highlights that the changing role of employees due to industrial revolutions has changed how the required skills are developed and employees are trained. Sackey and Bester [28] state that the engineering profession is directly linked to changes in technological developments. It can thus be concluded that Industry 4.0 will result in noteworthy changes in skills development and, consequently, in technical and academic institutions.

Technological advancement is happening at a fast pace resulting in new skills requirements and thus raising the need for an agile response in order to develop relevant skills that address the need. The skills development models must capacitate the urgent mitigation of skills challenges [18]. The World

Economic Forum [19] advocates that technology should be embedded in the education system to reveal its importance in Industry 4.0.

Technical institutions must be supported and strengthened, since technical and practical skills remain essential in Industry 4.0 [17]. South Africa's technical institutions must promote the education of engineering professionals at all levels in advanced information technology to ensure that they are ready to meet the demands of Industry 4.0.

To be effective in Industry 4.0, technical and academic institutions must promote novelty in methods of acquiring and using knowledge. Baker [17] puts it like this: "abstract knowledge and reasoning need to be connected with [the] real world through practical applications". Collaboration between industry and institutions of higher learning must be fostered to promote the solving of real world problems. Traditional academic subjects must be blended with technical specialisation and project-based learning. The primary object should be to ensure that students find relevance in what they are studying.

Selamat, Taspir, Puteh, and Alias [20] state that the teaching methods and organisational structures in future higher institutions will change significantly. Interdisciplinary training, massive open learning, and personalised learning will be experienced. Technological advancement is happening fast; thus institutions of learning must adapt to match innovation cycles [20].

Kumar and Gupta [34] observe that, in response to technological advancements, industry has shifted to a new paradigm of knowledge orientation, which is supported by the three pillars of skills, education, and research and development. A significant number of developing countries' tertiary education produces unskilled graduates with a vast amount of theoretical knowledge [34]. Weak research and development, a result of poor collaboration between industry and tertiary institutions, has resulted in developing countries being imitators and users of technological advancement from leading economies [34].

The Industry 4.0 era demands high cognitive abilities, which requires transformation in the higher education system. The open education system is slowly taking over, and this will have a significant impact on higher education academic institutions. Higher education institutions might need to realign their business model to accommodate the open market [35].

Sackey and Bester [28] state that Industry 4.0 could result in changing the knowledge and skills required by industrial engineers. They further suggest that there is a need to transform the curriculum of industrial engineering in South Africa and to focus on big data and human-machine interface skills [28]. Thus it can be concluded that Industry 4.0 will affect the curriculum of both technical and academic institutions. The curriculum should be suitable to address issues and prepare students to be competent in the digital economy.

To meet the demands of Industry 4.0, mobile learning applications that allow students to enter a virtual working environment and allow them to work independently have been suggested by Jaschke [26] for technical training in engineering.

Gudanowska *et al*. [22] argue that skills in the manufacturing industry can be developed in the work environment, whereas formal education cannot achieve this. Although not specifying the mode of learning, Prifti [27] points out that competencies can be taught.

Change in technical and academic institutions is inevitable to achieve alignment between skills requirements and skills development. Shvetsova and Kuzmina [14] point out that there could be a reduction in the need to train for the highest qualifications and an increase in the need for active technological expertise.

Although not specifying the actual type of institutions affected, Shvetsova and Kuzmina [14] point out the changes that are needed in higher education systems [14]: digitalisation of education, training personalisation, integration of professional and academic training, the creation of creative spaces, and the creation of university hubs.

3 METHODOLOGY

A study by Prifti *et al.* [27], which presents a systematic literature review on competencies required in the Industry 4.0 era, is acknowledged. Although the study was detailed and comprehensive, the competencies pointed out were generic, and the authors did not attempt to categorise the skills required for the different engineering professional levels.

Kitchenham [36] defines SLR as "a means of evaluating and interpreting all research relevant to a particular research question or topic area or phenomenon of interest" [36]. Using the points of view of Brereton, Kitchenham, Budgen, Turner and Khalil [37] and Siddaway [38], the researcher conclude that SLR seeks to provide an objective summary of relevant evidence by performing a meticulous and systematic process of finding, evaluating, and making a judgement on the outcome of relevant research output on a specific topic of interest.

In line with what Kitchenham [36] and Siddaway [38] point out about what a good SLR must accomplish, this study is undertaken as an SLR that aims to determine the degree to which existing research output has moved towards clarifying the discrepancy between Industry 4.0 skills requirements in the engineering profession and Industry 4.0 skills development, and to identify gaps that could give direction to future research.

This section is organised as follows: Section 3.1 outlines the research questions, and Section 3.2 gives the inclusion and exclusion criteria used in this study. The SLR method is presented in Section 3.3.

3.1 Research questions

To accomplish the objective of this study, which is to identify Industry 4.0 skills requirements in the engineering profession and skills development in meeting Industry 4.0 requirements, research questions (RQ) 1 to 3 were formulated:

- RQ 1: What Industry 4.0 skills are required in the engineering profession?
- RQ 2: What skills are required for each engineering profession level?
- RQ 3: How can these skills be developed?

3.2 Inclusion and exclusion criteria

Using the work of Liao, Deschamps, Loures, and Ramos and Liao, Loures, Deschamps, Brezinski, and Venancio [39, 40], inclusion and exclusion criteria were formulated to maintain objectivity in the assessment of the collected research papers. Table 2 presents an overview of the inclusion and exclusion criteria used in this study.

Table 2: Inclusion and exclusion criteria [39, 40].

Exclusion/ Inclusion	Criteria	Description
Exclusion	Duplication **(DP)**	The paper appears more than once in the same search criteria
	Language compatibility **(LC)**	The full text of the paper is not in English, except for the title, abstract, and key words
	No full-text **(NF)**	The full text of the paper cannot be accessed
	Non-related **(NR)**	**NR1:** The research paper is not a peer-reviewed academic article **NR2:** The research paper is not related to Industry 4.0 and skills requirements
	Casually applied **(CA)**	**CA1:** The paper uses the terms 'Industry 4.0' and 'skills' and their synonyms loosely **CA2:** The research paper addresses Industry 4.0, but does not focus on skills requirements **CA3:** The research paper addresses skills requirements not related to Industry 4.0
Inclusion	Partially related **(PR)**	**PR:** The research focuses on Industry 4.0 skills and competencies in general, but not specifically on the engineering profession
	Closely related **(CR)**	**CR1:** The research paper explicitly discusses Industry 4.0 skills required in the engineering profession **CR2:** The research paper focuses on Industry 4.0 skills development

3.3 Systematic literature review method

This study is carried out under the guidelines adopted from Kitchenham [36] and Brereton *et al.* [37], in combination with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method used by Moher, Liberati, Tetzlaff, and Altman [41]. Section 3.3.1 presents the search strategy, and the study selection is outlined in Section 3.3.2. Section 3.3.3 and Section 3.3.4 report the data collection and data analysis respectively.

3.3.1 Search strategy

The search terms are selected by identifying key terms from the research questions that can be applied to the issues to be addressed. The key terms chosen for inclusion in the search are 'Industry 4.0' and 'skills'. To accommodate variations in the spellings and the use of synonyms, alternative words were identified, as shown in Table 3.

Table 3: Search term alternative spellings and synonyms

Search term	Alternative search words
'Industry 4.0'	'Fourth Industrial revolution', '4th Industrial revolution', 'I4.0', 'Industry 4.0'
Skills	Competencies, abilities

Aliyu [42] points out that the use of a Boolean search string increases the probability of the search returning relevant research papers. To achieve a thorough collection of research papers, a Boolean search string was constructed using the search terms in Table 3, the Boolean operator AND, which restricts retention to papers with all relevant key terms, and the operator OR to accommodate alternative spelling and synonyms [36, 42]. The search string applied in the study was: ("Industry 4.0" OR "fourth industrial revolution" OR "4th Industrial revolution") AND skill*.

The systematic literature search was conducted on Scopus online databases. The concept of Industry 4.0 was initiated in Germany at the Hanover Fair in 2011 [27]; thus, for this research output, the period from January 2012 to March 2019 was considered.

3.3.2 Study selection

To select the papers to be included in this study, the exclusion and inclusion criteria presented in Table 4 were applied. Figure 2 presents the SLR stages followed using the PRISMA approach.

The first step in selecting the research papers was to remove identified duplicate (DP) papers. The initial screening process excluded all papers that were not in English (LC) (except for the title, abstract, and keywords), and papers to which there was no full access (NF).

Research papers that qualified for inclusion after the initial screening process were further examined to check their eligibility for inclusion. The second screening stage eliminated papers that were not peer-reviewed academic articles (NR1), and those that were not related to Industry 4.0 and skills requirements (NR2). The papers that loosely used the terms Industry 4.0 and skills (CA1), addressed Industry 4.0 but did not focus on skills requirements (CA2), or addressed skills requirements outside the context of Industry 4.0 (CA3) were eliminated at this stage.

The papers that passed the exclusion criteria were deemed eligible and were scrutinised and reviewed in detail. The eligible papers were classified according to three inclusion criteria: papers that focus on Industry 4.0 skills and competencies in general, but not specifically in the engineering profession (PR), papers that explicitly discuss Industry 4.0 skills required in the engineering profession (CR1), and papers that focus on Industry 4.0 skills development (CR2).

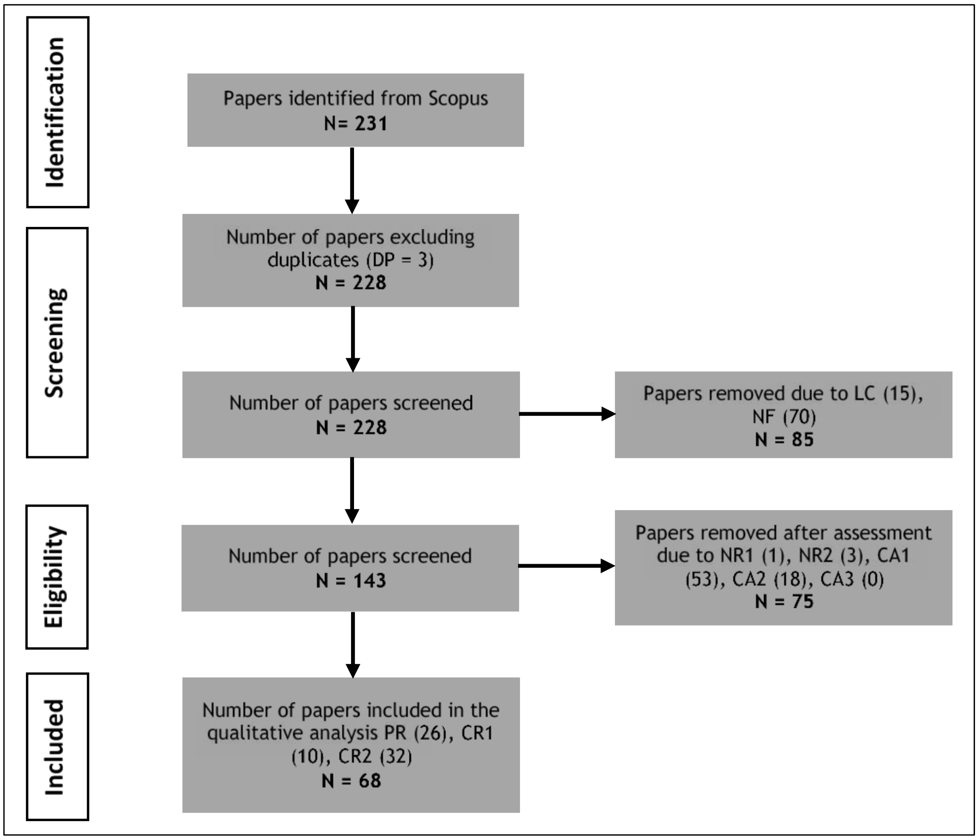

Figure 2: Systematic literature review stages using PRISMA approach [39-41]

3.3.3 Data collection

In response to the research questions presented in section 3.1, the data extracted from the papers that were included incorporate the engineering profession skills required in the Industry 4.0 era, the skills required for each specific engineering professional level, and methods for developing these skills.

3.3.4 Data analysis

The collected data were analysed using the qualitative method by applying descriptive codes. This was done with the objective of identifying the skills required in the engineering profession in the Industry 4.0 era. The analysis sought to identify the specific skills required for each engineering profession category.

4 SYSTEMATIC LITERATURE REVIEW RESULTS

4.1 Industry 4.0 skills requirements SLR results

The essential skills for Industry 4.0, presented in Table 1, were extracted from the research papers that satisfied the eligibility criteria discussed in section 3.3.2. All the skills deemed necessary for Industry 4.0 were considered, thus providing a wide set of skills. Each skills category was divided into sub-categories, which then showed the skills required with the related references.

Table 4: SLR skills requirements results

Skills category	Skills sub-category	Skills set	References
Technical skills	Technological skills	• Designing skills that incorporate virtualising, simulating, interoperability, modularising, decentralising capabilities.	[4, 43, 44]
		• Fault and error recovery skills	[45]
		• Application and use of technological skills	[46]
		• Process digitalisation and understanding	[31, 46, 47]
		• Ability to work with the Internet of Things, autonomous robots, 3D printing, and other advanced technologies • Interaction with modern interfaces	[44]
	Programming skills	• Computational skills	[48]
		• Simulation skills	[44]
		• Coding	[31, 45, 47, 48]
		• Computer and software programming skills • Software development	[4, 46-51]
	Digital skills	• Data analytics/data processing	[4, 43, 44, 46, 47, 49-54]
		• IT/data/cyber security	[31, 43, 45-47, 50, 53]
		• Cloud computing skills	[43]
		• IT knowledge and abilities	[43, 47, 55, 56]
		• Artificial intelligence skills	[43]
		• Digital content creation skills	[46]
Non-technical skills/soft skills	Thinking skills	• Creativity, innovation, practical ingenuity	[4, 6, 33, 43, 46, 48-50, 54, 57-65]
		• Critical and logical thinking	[41] [46, 48, 52-54, 60, 61, 64, 65]
		• Flexibility	[31, 43-45, 49, 52, 54, 62, 65]
		• Complex problem solving, trouble-shooting	[4, 6, 43, 45, 46, 48-50, 52-54, 60, 61, 63-66]
		• Analytical thinking skills	[4, 49, 53]
		• Technical and literate communication	[4, 6, 31, 33, 43, 44, 46, 47, 49-51, 53-57, 64, 66, 67]
		• Collaboration (including machine-human)	[45, 46, 48, 50, 52, 54, 55, 66-68]
		• Interdisciplinary skills	[45, 47, 49, 51, 53]
	Social skills	• Teamwork	[4, 6, 31, 33, 43, 44, 46, 47, 49, 52, 57, 64]
		• Perspective-taking	[42]
		• Professional ethics	[43, 57]
		• Understanding of diversity	[43]
		• Self-awareness, self-organisation	[6, 45, 47, 56]
		• Interpersonal skills	[43] [52, 66, 68]
		• Intercultural skills	[31, 55]
	Personal skills	• Social responsibility and accountability	[43] [47]
		• Lifelong learning skills	[33, 47, 49, 50, 53, 63, 64]
		• Leadership skills/people management	[4, 31, 33, 44, 46, 51, 54, 64, 65]
		• Emotional intelligence	[46, 54, 55, 63, 65]
		• Negotiation skills	[46, 55, 63, 65, 68]
		• Entrepreneurship	[62-64]
		• Adaptability	[44, 47, 50, 54]

4.2 Skills development SLR results

Table 5 presents the skills development approaches that were identified from the papers that satisfied inclusion criterion CR2 presented in Table 2. Each skills development approach is coupled with a summary of the findings and the related references.

Table 5: SLR skills development approach

Skills development approach	Summary	References
Apply artificial intelligence in education	• To develop AI skills in engineers, the authors advocated for intelligent tutoring systems, automated teaching assistants, and the use of educational data mining and learning analytics	[69]
Learning factories/teaching factory	• Learning factories using virtual factory-based training to develop problem-solving skills • Incorporation of augmented reality and virtual reality in learning factories to develop technical skills in robotics, cybernetics, and data analysis • Linking industry and educational institutions in developing Industry 4.0 skills requirements • Developing both technical and non-technical skills essential for Industry 4.0 • Virtual training using advanced technologies of the factory of the future in knowledge and skills transfer • Promoting interdisciplinary training • Learning factories depicting real learning environments, with emphasis on hands-on training and the development of social skills	[9, 32, 47, 70-79]
Smart education	• Using smart education to develop critical Industry 4.0 skills in engineers	[80]
Education 4.0	• Learning and skills development in both real and virtual worlds using augmented reality and virtual reality • Integrating the Internet of Things and augmented reality technologies in educational institutions' laboratories to develop skills required in Industry 4.0 • Use of Information and Communication Technology and massive open online courses facilitates non-discriminatory participation in developing skills required for Industry 4.0 • Using cyber physical education for developing skills and building competencies. E-learning and e-training	[71, 73, 74, 81-83]
Apprenticeship degrees	• Pointing to the need for degree apprenticeships to develop knowledge and impart industrial experience, and practical hands-on skills to reduce skills gap and skills mismatch • Increasing collaboration between industry and institutions of higher learning	[32]
Interdisciplinary training/ multidisciplinary training	• Teaching content focuses on multidisciplinary knowledge to develop industry skills • Multi-literacies approach facilitates development of three critical skills in Industry 4.0: critical thinking, technological competencies, and teamwork	[84-87] [47]
Hi-tech FABlabs	• Use of hands-on laboratories integrated with class instruction to develop Information Technology and Operations Technology required to design, secure, implement, and maintain systems	[84, 85]
Gaming	• Advocates use of gaming to develop Industry 4.0 skills requirements • Caters for Generation Y and Millennials by using digital gaming-based learning in developing Industry 4.0	[88, 89]

5 DISCUSSION

5.1 Discussion of SLR

The findings of the SLR pointed out that non-technical skills, also referred to as 'soft' skills, are increasingly required in engineers in the Industry 4.0 era. Thus, to be competent and remain relevant, it is necessary to balance technical and non-technical skills in the employees of the future.

A considerable number of soft skills cannot easily be automated; thus they will remain significant in Industry 4.0.

Because of the rapid change in technological advances that demand relatively new skills sets, lifelong learning abilities become essential in the workforce of the future, which must constantly upgrade its skills in response to the demand for new skills.

Industry 4.0 advanced technologies and automated systems are increasing the level of skills complexity required in the workforce of the future. This can be seen, for example, in piloting an aeroplane or monitoring nuclear power plants. Increasing use of artificial intelligence demands strong man-machine interaction to achieve improved productivity. This interaction demands strong non-technical skills, such as emotional intelligence, critical thinking, creativity, innovation communication, collaboration, leadership, and teamwork.

Technical skills will significantly important in the engineers of the future. Technological skills, programming skills, and digital skills are relevant in Industry 4.0. Digital skills that were pointed out as outstandingly significant include data analytics and cyber security skills. The use of learning factories was identified as having the capability of balancing the skills required in the workforce of the future.

A strong partnership between industry and educational institutions is required to reshape Industry 4.0 skills requirements. Learning factories, also referred to as 'teaching factories', could possibly provide a link between industry and educational institutions. It was noted that education is slowly adopting 'Education 4.0', a term coined after Industry 4.0.

The incorporation of interdisciplinary and multidisciplinary approaches in skills development could generate the skills required for Industry 4.0. A significant number of authors point out that multidisciplinary knowledge is required in the workforce of the future.

The SLR revealed that, although a noticeable number of research papers discussed Industry 4.0, there was little discussion of the skills required for each engineering profession level. Daling, Schroder, Haberstroh, and Hees [49] classified skills for managers and workers in the production environment. Mourtzis [73] categorised competencies for Industry 4.0, and ranked their importance for different roles in production enterprises. He argued that technical competencies and methodological competencies are of significant importance to the technical workforce. It was highlighted that non-technical competencies are also clearly important to the technical workforce, production engineers, and executives [73].

5.2 Impact on technical vs academic institutions

Perhaps the most important question to ask is how this study could promote change in academic and technical institutions. One of the approaches that could be followed is to evaluate the existing curricula of BEng and BEng.Tech degrees to see how well they satisfy the recommended criteria in Table 4. This could also highlight both institution-specific and overall deficiencies that need attention.

One of the often-overlooked elements is the students themselves. Understanding their current skill levels and incorporating their inputs could prove meaningful in designing a comprehensive strategy to help institutions to adapt and flourish in Industry 4.0.

5.3 South African context

Because of the social and economic issues facing South Africa and the need for cultural unity, a true solution to the skills challenges will have to include cross-pollination and collaboration between technical and academic institutes. An appreciation of the role and value that each engineering professional expertise level can contribute is vital.

Funding mechanisms such as Technology and Human Resources for Industry Programme (THRIP) THRIP already suggest this type of collaboration by requiring institutions from differing social and academic backgrounds to work together on initiatives and proposals. They also require strong collaboration with industry, with both technical and academic graduates, and with workplace placements.

6 CONCLUSION

The SLR review answered research questions 1 and 3, which ask which Industry 4.0 skills are required in the engineering profession and how these can be developed. The study pointed out that non-technical skills are as important as technical skills in the engineering profession in the Industry 4.0 era.

Advanced technologies are not intended to replace humans for improved productivity; rather, there must be tight human-machine collaboration. Technical and academic institutions must open lines for lifelong learning to meet the challenge of the rapid change in skills requirements in Industry 4.0. Interdisciplinary skills development could be necessary in Industry 4.0 to ascertain the effectiveness of employees in the engineering profession.

The SLR exposed a gap in the literature on the specific skills required for different engineering profession levels. There is also a deficiency in the literature discussing specific Industry 4.0 skills in South Africa. In this regard, future work will focus on developing a model detailing conceptual skills requirements for different engineering professional levels. Detailed research on a skills development framework that seeks to bridge the gap between relevant Industry 4.0 skills requirements and development in South Africa will be undertaken.

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