The Evolution of Teamwork in engineering workplace from First Industry Revolution to Industry 4.0: A Literature Review

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Introduction

Before the industrial revolution began, managing people was not an art and teamwork was not explicitly understood or studied in engineering workplaces. According to Egel and Danielson [1], the focus in engineering workplaces were more on wages and less on process including efficiency and motivation of people. Following the first industrial revolution, research began on understanding people and collaboration as an important aspect for productivity in engineering. During the Taylorism era of the early 19th century, relationship between supervisors and workers were established and cooperation was ensured to ensure efficiency in production [2]. However, the decision-making process were carried out by supervisors only. As the world shifted to the second industrial revolution, teams were formed with leaders and team members coordinating tasks together and helping each other to reach team goals [2]. Leaders had the authority to direct orders to team members ensuring proper coordination and control of tasks. By the beginning of the third industrial revolution, digitization and automation caused teams to become diverse and expand globally [3]. Hence the requirement of interdependence and effective communication was prominent in teams. Teamwork in this era became more complex which made researchers develop robust frameworks on teamwork to enhance productivity, efficiency and profit in engineering workplace.

The most recent industrial revolution, Industry 4.0 (4IR) has been introduced in several manufacturing industries globally which is characterized by the application of information and communication technologies. In this era of manufacturing, production systems will move towards automation through expansion of network connections and enhancement of communication with other facilities through by using disruptive technology. According to a report by Lund [4], there is a 64% potential of automation in manufacturing industries due to the impact of 4IR. Hence there will be a decrease in physical, manual and basic cognitive skills and increased demand in technological and social skills in Industry.

With the increase in demand for social skills, the requirement of complex collaboration and effective teamwork will further increase with the expansion of technological advancement in engineering workplaces shifting to 4IR. However, industry and academia have not agreed on what important teamwork aspects are necessary to comprehend the changes in Industry 4.0. There are several initiatives taken by engineering researchers to identify the important teamwork attributes required for engineering students to become effective team leaders [5] and adapt to solving complex problems [6]. However, research is required on how to further develop these attributes which can be useful for both industry and academic leaders and adapt to the new industry revolution.

The purpose of this study is to conduct a systematic review of the literature to identify a more comprehensive understanding of how teamwork has been used proposed in 4IR engineering workplaces and what have been the best practices reported in order to align with the changes in Industry 4.0. Therefore, the study addresses the following research question:

RQ: What aspects of teamwork have been proposed or studied in order to ensure effective teamwork for Industry 4.0 in engineering workplace?

To answer our research question conducted a systematic review of the literature. In the following sections we explain the literature that framed our study, the methods used in the review, and report our preliminary results. We provide implications for practice and research.

Literature Review

Industry leaders recognize professional skills as an important trait in order to be a successful in engineering workplace [7]. The importance of teamwork as a professional skill has also been highlighted by several employers in the engineering industry [8], [9]. As we shift towards the paradigm of 'smart manufacturing' in 4IR, there will be an increase in engineering responsibilities which are highly complex and will involve collaboration with machines to solve unstructured problems [10]–[13]. Table 1 shows the paradigm shift in manufacturing where engineers will have to work with large quantity of data, deal with new information and work with automated systems [14].

Table 1. Paradigm shift in manufacturing industries for industry 4.0 [14]

Cost Focus <1980	Quality Focus 1980-2010	Customization Focus 2010>
Mass Production	Lean Production	Smart Manufacturing
Push Policy	Just-in time	Economies of scope
Motion & time study	Pull Policy	Global manufacturing
Assembly line	Electronic data interchange	Agile manufacturing
Statistical sampling	TQM	Internet-based manufacturing
Inventory optimization	Baldridge award	Internet of Things
PERT/CPM	Kanban	Data Analytics

In spite of the shift in paradigm with multiple changes in engineering responsibilities, people skills which involve intelligence, creativity, empathy and flexibility among teams will remain important. Results from an empirical study conducted on manufacturing companies shifting to 4IR showed that 60.2% of respondents stated that 'human' work will continue in the future and 36.6% respondents believe that human work including teamwork will play a vital role in these manufacturing industries [15]. In another survey study on understanding the future competencies in a smart factory operating with 4IR concepts, results showed that biggest competency changes will apply to professional skills among which teamwork has been viewed as one of the most important competence required in the future [16].

The technological advancements in 4IR will increase the teamwork complexity as problem solving through virtual teams and hybrid collaboration between people and robots will increase

[7]. However, the biggest challenge will be to prepare engineering students and the engineering workforce to cope up with the changes in teamwork competencies as technology advances. Even though the need for technical competencies have been widely discussed in the literature, there is no clarity in engineering about the changes in teamwork competencies required to comprehend the demands of Industry 4.0. Therefore, this study explores the existing literature on best practices on teamwork used or proposed in industry to better understand the necessary attributes required to be an effective team player in the Industry 4.0 era.

Methodology

The aim of the study is to find out the best practices of teamwork used or proposed in engineering workplace which comprehends with Industry 4.0. Hence, we carried out a systematic literature review to identify the important teamwork attributes necessary for 4IR. This study follows Borrego et al. [17] structural approach of literature review in engineering education which begins with defining suitable search keywords aligning with the purpose of study, searching for relevant literature and performing necessary analysis in the end. For this study in particular, first, the relevant sources of publication including book chapters, academic journals, conference papers and published thesis were identified regarding teamwork practices for 4IR. We analyzed relevant sources using two search terms together, first key words related closely with teamwork including ‘teamwork’, ‘team’, ‘collaboration’, ‘professional skills’. Secondly, key words closely related with Industry 4.0 including ‘industry 4.0’, ‘fourth industrial revolution’, ‘smart manufacturing’ and ‘smart factory’.

Data Collection

To find out the relevant sources of publication on teamwork and industry 4.0, we referred to general databases including renowned publication sources like JSTOR, SCOPUS, Emerald, Taylor and Francis, Springer, IEEE and also other literature databases including American Society of Engineering Education (ASEE) conference proceedings, International Journal of Engineering Education (IJEE), European Journal of Engineering Education (EJEE) and Journal of Engineering Education (JEE). The initial search query using the relevant search terms resulted in more than 200 publications. In the next step, articles were filtered based on their alignment with the purpose of our study. The selection criteria to guide our review was to include papers that (i) included implementation of best teamwork practices in engineering workplace, (ii) included empirical research that mentioned the importance of teamwork in industry and (iii) included conceptual research studies that highlighted the necessity of teamwork for 4IR.

Data Analysis

After reviewing the abstracts for the initial publication query, we started identifying different aspects of teamwork which were relevant and important when developing teamwork skills for Industry 4.0 guided by Borrego et al. [17] technique for the systematic literature review. We looked for key words in the scholarly papers from the selected papers which were relevant towards our study on teamwork effectiveness in 4IR. This process yielded a total of 50 scholarly papers which were used for the final step of the systematic review.

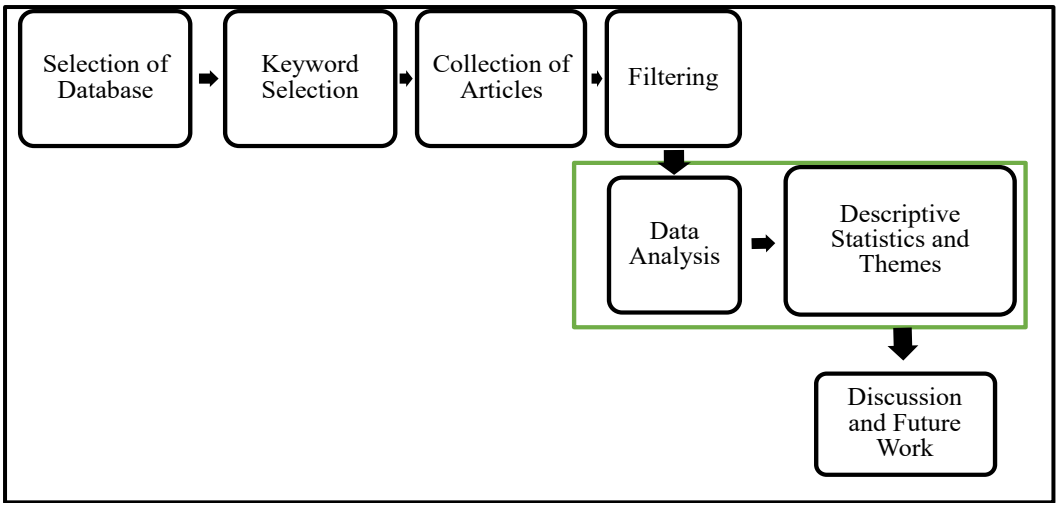

Figure 2. The process for the systematic literature review for this study

Figure 2 elaborates the steps of our review process where the final step was the synthesis of our systematic review which involved descriptive statistics and identification of important teamwork attributes from the scholarly papers.

Results

The data analysis of our study yielded 50 scholarly papers which were relevant towards understanding the importance of teamwork for 4IR. In terms of scholarly paper types, the selected papers were mostly from Journal articles and Conference proceedings. Figure 3 shows the breakdown of the scholarly papers where 86% were yielded from journal articles and conference papers and 14% were from book chapters and published thesis.

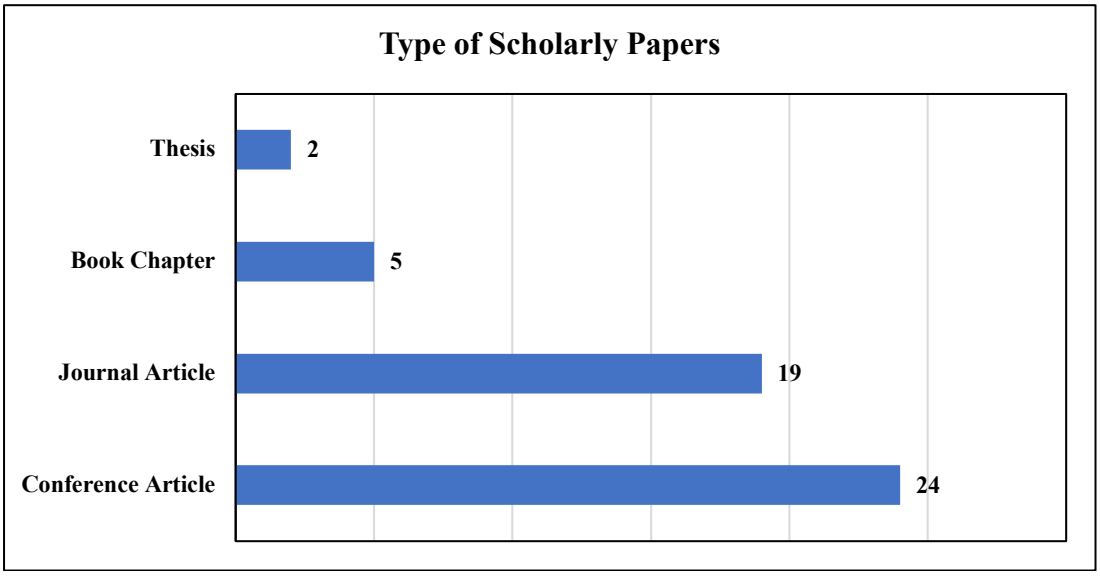

Figure 3. Type of Scholarly papers published relevant to teamwork in 4IR

In terms of year wise publication, there is an upward trend regarding total scholarly paper published in the field of Industry 4.0 mentioning the importance teamwork. Specifically, there was a sharp rise of publications from 2017 until recently as shown in figure 4. Figure 4 also breaks down the different types of scholarly papers in recent years. There is an upward trend of Journal article publications in the last 5 years. However, the number of conference articles have declined in recent years.

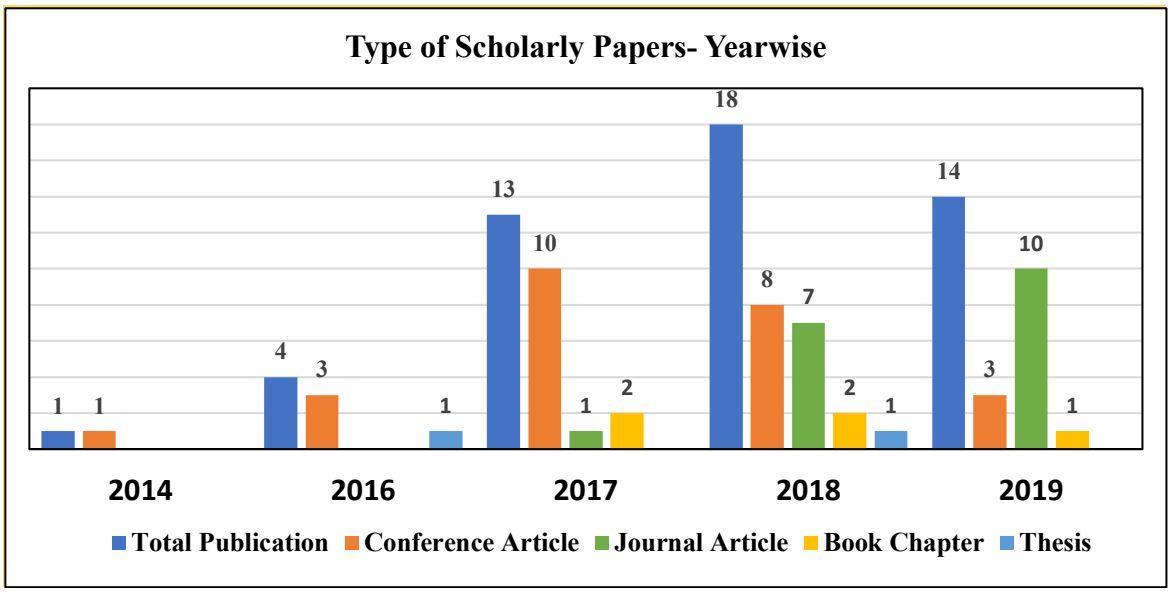

Figure 4. Year wise trend of total publications and the type of scholarly papers

Similarly, Figure 5 shows the distribution of the 50 scholarly papers by the methodology they used. Literature review was the highest in terms of research method used for these scholarly papers at 32%. There were also 18% case studies methodology used in industries and beyond which resulted in publications. Few examples of literature review included finding out core-competencies required for engineering workforce to comprehend with Industry 4.0 from which the teamwork skills were highlighted. In addition, case studies included in-depth analysis of assessment and core-competencies required by employees for Industry 4.0.

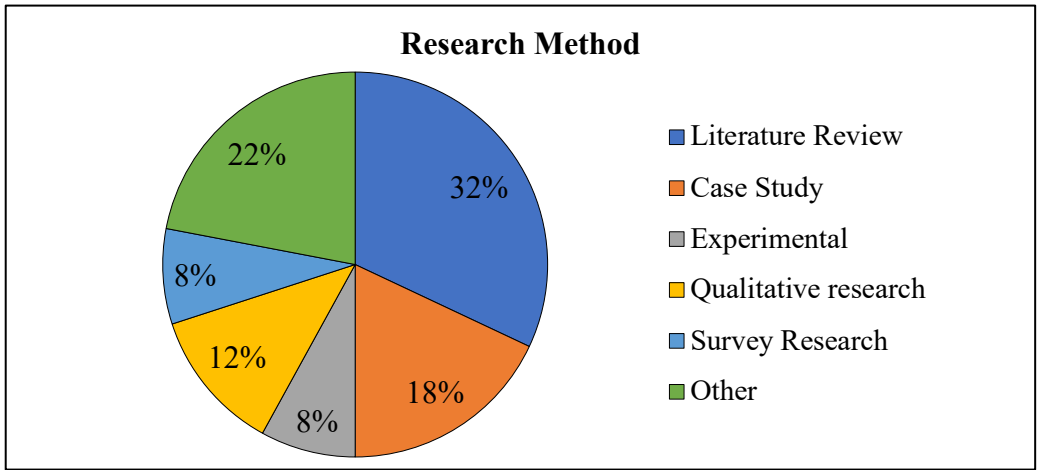

Figure 5. Distribution of scholarly papers with respect to research methods

The total number of authors who were affiliated with the scholarly papers in our study from different countries were also extracted. Figure 6 shows the distribution of the total number of author affiliation by country and continent. In terms of continent, Europe dominated the list with 57% of the authors contributing in these scholarly papers. Among the countries, Germany had the highest number of author affiliations with 20 authors contributing in this research field. Spain, Poland and India are the next in the list with greater than 10 authors contributing in the scholarly papers. This shows that Europe has dominated the list of research contribution relevant to our study.

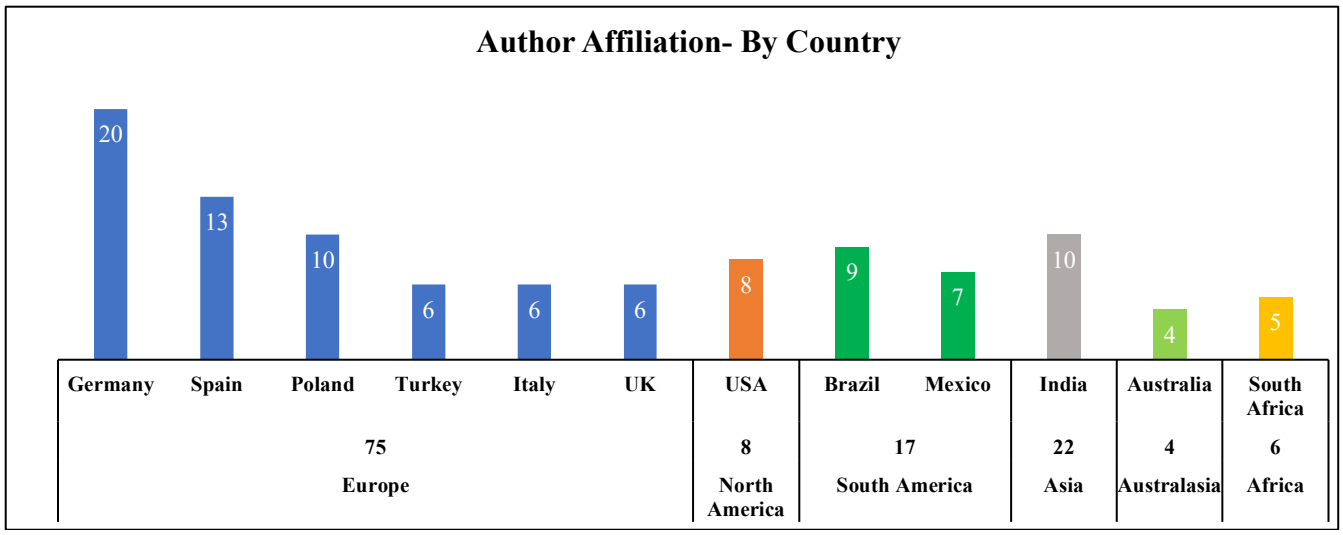

Figure 6. Total number of authors affiliated by country

The countries from which the scholarly papers were published (at least 4 papers), and the corresponding paper type is shown in figure 7. Germany and Spain have the highest number of papers published with 5 scholarly papers published that was relevant to our study.

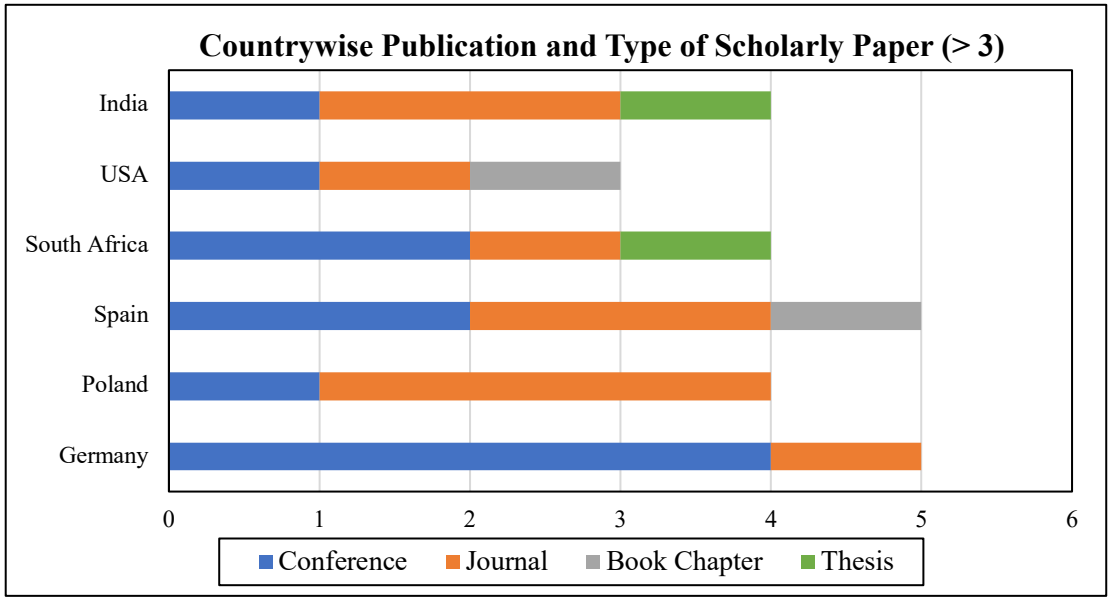

Figure 7. Scholarly papers published by country (at least 4)

Teamwork Attributes

In order to identify key themes for effective teamwork in industry 4.0, we analyzed the 50 scholarly papers mentioned previously and find out common themes. From our systematic review, we were able to identify 6 teamwork attributes which were highlighted and elaborated as a necessity for effective teamwork in engineering workplace. The following section explains the key teamwork attributes in detail. Table 2 provides an overview of what each teamwork attribute means in the context of industry 4.0 and the sources that cite them.

Table 2. Teamwork Attributes and their corresponding description and author reference

No.	Teamwork Attribute	Description	Authors
1	Hybrid Collaboration	Expanding the idea of collaboration in Industry 4.0 where communication, coordination and cooperation in engineering workplace will be carried out in three different levels: human-human, human-machine and machine-machine.	[18]; [7]; [19]; [20]; [10]; [11]; [12]; [13]; [21]; [22]; [23]; [24]; [25]; [26]
2	High Interpersonal skills	Industry 4.0 requires members who specialize in sophisticated skills and can build complex relationships and coordinate with other members which cannot be carried out using machines	[14]; [27]; [28]; [29]; [30]; [31]; [32]; [33]; [34]; [35]; [36]
3	Complex Team Composition	Team structure in Industry 4.0 will expand globally with increases in size, diversity and virtual teams to solve complex and challenging team goals	[7]; [37]; [38]; [39]; [40]; [41]; [42]
4	Social Competency	The right mindset of team members to create conscious and intelligent actions on their own emotional response, managing other team members reaction to build positive relationship and mentoring other members in the team to achieve team success	[43]; [27]; [44]; [37]; [21]; [38]; [45]; [39]; [23]; [46]; [47]; [48]; [49]; [34]; [25]; [50]; [51]; [52]; [53]
5	Interdisciplinary Team Process	Industry 4.0 will involve members working in interdisciplinary teams, implementing interdisciplinary tasks and providing creative ideas and insights from separate disciplines to solve complex problems	[53]; [54]; [55]; [30]; [37]; [56]; [57]; [58]; [41]; [59]; [26]; [42]; [60]
6	Intelligent Communication	With increase in digital appliances and involvement of machines, team members will still need to possess the capacity to communicate effectively in different working environments, constant process changes and overcome conflicts smartly	[14]; [31]; [35]; [27]; [45]; [12]; [42]

Hybrid Collaboration

The introduction of smart manufacturing in Industry 4.0 will result in increasing collaboration among people and beyond. According to Schuh et al. [18] and Kapp [21], the advancement in technology in industries will expand the idea of collaboration into three different levels: human-

human, human-machine and machine-machine. Specifically, Piñol et al. [10] highlights the importance of being flexible while working with machine networks and quickly adapt to changes in order to develop technological skills like Internet of Things (IOT), autonomous robots and big data analytics. In addition, two experimental studies were carried out to understand different insights into human-robot collaboration and the task fulfillment process [7], [23]. The findings from the studies highlighted the importance of preparing students and the engineering workforce to develop teamwork competencies for an effective hybrid collaboration in all the three levels. However, with the increase in autonomous system Hoeschl et al. [19] recommended a different perspective on hybrid collaboration in industries. According to Hoeschl et al. [19], humans should always have control over autonomous systems to some extent in case of any extreme events that might cause ethical conflicts during collaboration.

High Interpersonal Skills

Some of the team roles will require members to go beyond the use of machines, such as interacting with other members of the team or supervisors in the team which supports development of interpersonal skills [29]. According to Sallati et al. [34], the shift in industry 4.0 will prompt more occupations which involve building complex relationships with people especially while dealing with clients and other stakeholders to provide personalized services. Industry 4.0 requires engineers to work with their team members by establishing regular forums, that gives opportunities for people at all different levels to share their thoughts and ideas openly to bring in ideas and innovations into the workplace [14]. The complex relationships will develop when members collaborate beyond their own teams and proactively get involved in idea sharing, learning and transferring knowledge [14], [27], [28]. In terms of leadership roles for 4IR, they should be responsible in empowering their team members for decision making process and information sharing through open-mind that would help boost their confidence and develop high interpersonal skills in the team [36]. From an engineering education perspective, Jeganathan et al. [31] proposed a framework for Industry 4.0 considering current technological changes in order to meet future demands of engineers and considered interpersonal skills as an important attribute embedded in the curriculum. In addition, Perez-Perez et al. [32]developed a training tool which would help develop interpersonal skills as part of teamwork development for engineering students to comprehend with the changes in 4IR.

Social Competency

The need for high social competency skills have been emphasized as a key teamwork attribute for Industry 4.0. Social competency includes the art of persuasion, team member's emotional intelligence and the ability to act both as mentors and mentees in the workplace. According to a survey study conducted among 95 manufacturing industries, social competency was one of the most important attributes mentioned in the survey and also highlighted that this competency is highly desired by employers shifting to Industry 4.0 manufacturing industries [45]. A high degree of emotional intelligence is also an important trait for social competency. According to Oosthuizen's [53] Fourth Industrial Revolution Intelligence framework, a high degree of emotional intelligence will create positive relations and trust among team members and will make teams more creative, agile, resilient in a fast-changing workplace environment. Furthermore, in an empirical study on employee competency for Industry 4.0, experts in this

field have claimed that social competency will have direct impact in 4IR industries. However, they also suggest interdisciplinary mentoring, well-facilitated training and practicing among teams to ensure effectiveness [42].

Complex Team Composition

The shift to Industry 4.0, will change the team structure in engineering workplace. Teams will become large, diverse and virtual with highly sophisticated specialists unpacking complex and challenging projects. According to Agolla [38], workplaces in Industry 4.0 will become more diverse which will include creative, conventional and innovative members. Hence, the complexity of successful collaboration among these diverse team members will increase and ensuring teamwork effectiveness will become a challenge. To overcome the challenge, Agolla [38] suggests strong evidence of the important human capital which can be used with the 4IR.

The 4IR will also require members in teams to collaborate virtually. There are several virtual tools already used in engineering workplace to help members interact faster and efficiently regardless of their geographical location [42]. However, Bermudez et al. [40] elaborated the necessity of training engineers to collaborate virtually among the teams efficiently, similar to the way we train engineering students to work in teams by exposing them to team projects.

Industry 4.0 will also require careful selection of team members possessing individual expertise during project management. Hence, to make decision-making process more efficient, leaders will try to form teams by branching interdisciplinary experts together who would be well versed in their own fields [41]. This also will require that engineering students, and future engineering graduates understand how to effectively work with people from multiple disciplines.

Interdisciplinary Team Process

Industry 4.0 will involve several engineering disciplines including mechanical engineering, electronics engineering, industrial engineering and computer science, but also will require interactions with several other disciplines like law, healthcare, business, finance, human resources. The multiple fields involvement of 4IR will require projects to be implemented in interdisciplinary teams, comprehending interdisciplinary tasks and thinking process [60]. According to an experiment conducted on understanding the team process in Industry 4.0, a team was formed with people from technical backgrounds including computer science and mechanical engineering and also experts from sales, marketing and project management [42]. From the study, it was found that in order to implement complex solutions effectively in the 4IR, high-level knowledge and expertise from different fields is mandatory [42].

Intelligent Communication

Teams in Industry 4.0 will become global, diverse and complex. Team members will need to learn different languages to ensure effective communication among global teams [35]. In addition, with the change in technologies interactions will become more complex and will also involve more digital appliances as communication tools, team members will need to start communicating information and data more critically and effectively [12], [14]. According to

Veile et al. [42] framework, with the increase in complexities, companies shifting to 4IR will need to have openness in communication and flexibility among team members to ensure faster decision-making process and handle conflict management smartly.

Discussion

Our data analysis yielded 50 scholarly papers using a systematic review approach which was relevant to the research purpose. In terms of the descriptive statistics, the majority of the scholarly papers were either conference or journal articles. In addition, considering the publication trend by the years, our results suggest that the research focusing on teamwork in Industry 4.0 is relatively new with publications emerging in the last five years. However, looking at the upward trend for the research in this important aspect of engineering, we assume that there will more research and publications relevant to our study. Looking at the trend of type of articles published by year, we can see an increase in journal articles published relevant to our research. This might possibly mean that the research on teamwork in Industry 4.0 is evolving from academic and industry forums, group discussions, knowledge sharing to more vigorous research, in-depth analysis and are subject to extensive review by expert and peers.

The breakdown of the research method types shows that most of the research either uses literature review or case study as their primary research approach. This could also possibly mean that the research on teamwork and industry 4.0 is relatively new and still in the exploratory stage. In terms of total author affiliations involved in publishing the scholarly articles, Europe is dominant in this research area with Germany, Spain and Poland being the top 3 nations where authors publish from. In addition, Germany and Spain lead in the number of papers published relevant to our study. From the U.S. perspective, the number of authors affiliation and total number of papers published in this area of research are far low compared to European or Asian countries. The reason might be because companies in the U.S. are still in the transition phase of 4IR.

Our systematic review resulted identifying 6 important teamwork attributes which were highlighted and elaborated as a necessity for effective teamwork in engineering workplace. The attributes are relatively similar to our previous study; however, the definitions of each attributes have evolved with respect to the change in dynamics of Industry 4.0 [5]. For instance, the necessity of hybrid collaboration is a new attribute that is only applicable for industries in 4IR but equally important for effective teamwork, this proposes moving away from the traditional "divide and conquer" collaborative approach to a more meaningful approach where individual competencies become complemented by other peers' individual competencies to solve problems. Attributes including interpersonal skills, team composition, team process and communication are all commonly used attributes for effective teamwork, however there is a change in the way we define these attributes which are very specific to Industry 4.0 that we need to take into consideration when training engineering students.

Our findings provide engineering educators and engineering leaders with information on the things that need to be considered moving forward as we see the implementation of Industry 4.0 around the world. As we can observe, most teamwork attributes identified are already being developed by engineering students and practitioners, however, they require a different

understanding and approach. The way engineers are required to collaborate, communicate, value multidisciplinary perspectives, develop global competencies, and understand the use of technology and virtual platforms will require that engineering programs and workforce trainers adapt to these trends and offer similar experiences in educational settings.

Conclusion

Industry 4.0 is bringing along a shift in the core competencies needed in engineering workplace. Among the core competencies, one of the most important derived from this paper is teamwork. From the systematic literature review, we can see that there will be a change in teamwork dynamics in engineering workplaces as we enter 4IR. To prevent a crisis in the workforce, all stakeholders including academic and industry leaders must participate in the retraining and upskilling of the workforce. This systematic review was established to promote cooperation among academic and industry leaders and fast movement of professional competency-related information on teamwork changes. As we think of the future engineering students who will be transitioning to Industry 4.0 workplaces, their demands for working in global, virtual and diverse interdisciplinary teams with both human and machines will increase and now is the time to train them to be highly competent and empowered in order to comprehend with these demands.

Industry leaders need to approach Industry 4.0 critically and understand the changes in the dynamics of teamwork necessary to comprehend with this new revolution that could have a potential impact towards organizational effectiveness and success. Also, academic leaders should consider the connection between Industry 4.0 and the changes in the teamwork aspects. The changes in these attributes should be acknowledged among engineering educators and act as a guidance when integrating teamwork into their pedagogical practices.

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