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Review of Industry 4.0 Competencies and Virtual Learning Environment in Engineering Education*

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Universities all over the world are considering the utilization of virtual learning environments (VLEs) in engineering education to meet the demands of Industry 4.0 for future employment. A systematic review was conducted to display the current state-of-knowledge in strengthening educational competencies, tackling the challenges of Industry 4.0. This article was designed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses and the Joanna Briggs Institute Method for Systematic Review. Articles published from 2004 to 2019 were sought from six electronic databases: *SCOPUS*, *Science Direct*, *Emerald Insight*, *Ebscohost*, *ERIC*, and *IEEE*. All papers were critically appraised, and quality assessment was performed. Eight studies were selected for potential eligibility. Data were extracted and synthesized using a narrative juxtaposition to provide a consolidated, comprehensive, and summarized evidence. Compared with physical or other types of online learning, the review recognizes the effectiveness of VLEs in enhancing knowledge and cross-functional skills needed for real-world industry settings. Therefore, it is paramount that engineering education courses required to be integrated with VLE targeting the development of competencies towards Industry 4.0.

Keywords: virtual learning environment; Industry 4.0; competency; engineering education

1. Introduction

Over the last few years, the fourth industrial revolution, also known as Industry 4.0, has received much attention not only in the manufacturing process of the industry but also in higher education sectors [1–3]. Highly developed automation and digitization processes mark the Industry 4.0. The internet and supporting technologies serve as a backbone to integrate human and machines, materials, products, production lines, and processes within and beyond organizational boundaries [4]. Thus, a new kind of intelligent, connected, and agile value chain network fulfills a particular customer demand achieving unprecedented levels of operational efficiency and productivity [5]. There are, however, barriers in the aspects of Industry 4.0 and human-machine collaboration, where continuous learning and innovation in an organization depend on people and the enterprise's capabilities adoption to successful implementation [6]. Assuming that this process will continue over the decades, the educational perspective will become as crucial as the technology-driven ones [7]. For this reason, the technological advancement of the industry has a significant effect on changing the current educational competencies to cope with the increasing complexity of future manufacturing and production systems. The identification of competencies gained in such learning environments presents an important question to be evaluated in preparing students for Industry 4.0.

Significant developments are taking place on the internet, and computer technology had been frequently utilized in all areas of higher education and training. The idea of Industry 4.0 should be integrated into the course of the students for the formation of background in the concept of its principles [8]. New competency fields, which require interdisciplinary thinking and excellent skills in social and technical domains play an essential role [9]. Therefore, a system that supports students' active learning is needed to gain competencies in the sense of being able to solve real-world problems and a subsequent solution finding process [5, 7]. In this context, engineering-related disciplines must adopt new and emerging learning technologies and methodologies [10].

The industry relies on distinctive skills to innovate and compete. Engineering students should be prepared to meet the demands of Industry 4.0 in consideration of future employment. Academic institutions must introduce them to appropriate technologies for their successful transformation into the industry [11]. To use new technologies for engineering education in a proper way, deeper insights in reception, cognition, and communication in virtual environments are necessary [12]. The virtual lab provides more insight into the learning and training process for the realization of hands-on

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experience of digitized educational settings and the integration of competencies [13]. Practical laboratory demonstration is an essential part of the learning experience of engineering students where virtual laboratories can supplement physical laboratories to reinforce crucial concepts in the courses [14]. Virtual laboratories (e.g., simulation and remote lab) in engineering education must be designed to enhance the practical knowledge, ability to investigate, solve engineering problems and demonstrate reporting technical information with appropriate levels of independent thought and creativity [15].

Parallel to the accelerated technological change and innovations in the industry, and now the era of the fourth industrial revolution, utilization of VLEs in higher education became more widespread. VLEs are needed for students to be immersed in a real and virtual world of information as part of their curricula and disciplines. This type of learning environment will develop technological knowledge as well as collaborative skills within the fourth industrial revolution [16]. VLE is a computer-aided and web-based educational technology designed to support teaching and learning across a broad range of applications provided that the users are registered and can access the internet [14, 17]. Since it was first introduced, various commercial VLE products or systems such as Blackboard, Moodle, Edmodo, Frog, COSE, Learnwise, WebCT and VIEW have been developed to suit the miscellaneous educational settings including higher institutions and schools [18]. With this increasing number of VLEs, students can perform a wide range of exercises, including tasks that cannot be practiced in real life [19]. VLE allows online discussion, feedback, communication, uploading, and sharing of materials which impact student's engagement and learning [20]. Moreover, this overcomes the limitation of traditional face-to-face learning and defies the barriers of geographical location and time as it allows asynchronous teaching and learning [17, 18].

To further build upon the progress made with previous studies on the use of VLE in engineering education, a systematic literature review has been conducted. The objective of this paper is to present a literature review of virtual learning environments as applied to Industry 4.0. This study displays the current state-of-knowledge in strengthening educational competencies and qualifications, tackling the challenges of Industry 4.0. The key competencies for Industry 4.0 include technical (e.g., knowledge, media skills, coding skills, etc.), managerial (e.g., conflict and problem solving, decision making, analytical and research skills, creativity, etc.) and social (e.g., values, ability to transfer knowledge, leadership skills, ability to work in team etc.) competencies [21]. To this end, as part of evidence synthesis for engineering education, we focused on VLE as one of the web-based learning modalities. A strong evidence base is needed to support the effective use of these technologies for future engineering professions. Development of skills and qualifications will become the key to the success of a highly innovative factory. Adaption of engineering education to the required competencies of Industry 4.0 is an essential task in preparation for the new era of industrialization.

2. Methods

2.1 Design

To cope with the new challenges regarding Industry 4.0 is the adaption of higher education in specifying needed changes to the curriculum, laboratories, and student activities that highlight the use of VLE in different universities. A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement and the Joanna Briggs Institute Method for Systematic Review [22] process. These checklists and guidelines can facilitate transparent reporting of review and synthesis of all the available literature to determine the effectiveness of a given practice. Formulation of the analysis was developed using the Population, Intervention, Comparison, Outcomes, and Study design (PICOS) to accommodate terms relating to quantitative and qualitative models [23] concerning 'How effective are VLEs in preparation for the required competencies of Industry 4.0 in engineering education?'.

2.2 Data Sources and Search Strategy

A comprehensive search of the literature was carried out using scientific research, databases, journal articles, conference papers, and other documents pertinent to the study from 2004 to 2019. Electronic databases were used, namely *SCOPUS*, *Science Direct, Emerald Insight, Ebscohost, ERIC*, and *IEEE*. A systematic search strategy was developed and refined, using key search terms or in combination which includes 'virtual learning environment,' 'digitization,' 'Industry 4.0', 'engineering education,' and 'competencies.' The electronic database searches were supplemented with a review of articles cited in recent researches on VLE implementation in education. A hand search was also performed from the reference list to identify additional materials related to the topic as these address the review question that meets the inclusion criteria of the present review.

2.3 Screening Process: Inclusion and Exclusion Criteria

The inclusion criteria were (1) articles that focus on virtual learning environment in engineering education that enables students to experience the concept of Industry 4.0 like production and manufacturing environments, (2) contrast conditions in terms of use of virtual learning environment (e.g., VLE vs. face-to-face or physical learning), (3) includes descriptions of study design, (4) reported learning outcomes for both contrast conditions which include knowledge, skills, attitudes, etc. of the engineering students and (5) effectiveness of the virtual learning environment. The exclusion criteria were (1) VLE in vocational education applied in the concept of Industry 4.0; (2) review, survey or policy papers on Industry 4.0; (3) papers that tend to support challenges, issues, or trends of Industry 4.0; (4) papers that discuss the current and future perspective or sustainability of Industry 4.0; and (5) acceptance or perception studies on the use of VLE.

2.4 Critical Appraisal

The quality of each article was assessed with the use of the JBI appraisal method (QARI) for both qualitative and quantitative research to determine the validity of interpretive or critical studies. Critical appraisal was performed by two reviewers to establish and maintain a consistent and high standard of methodological rigor. Hence, minimizes the risk of an inconclusive review resulting from excessive variation in the quality of the studies. Disagreements between review authors were resolved by discussion.

2.5 Data Extraction and Synthesis

Data were summarized using the JBI extraction form according to the author, participant, interventions, and outcomes of the study. Studies were categorized and classified by attained competencies. Comparators included face-to-face learning and other forms of virtual education. After data extraction, a synopsis table was prepared to bring together all the data for easy reference. A narrative summary was performed to integrate qualitative and quantitative evidence.

3. Results

The searched strategy resulted in 1,267 (*SCOPUS* = *665*, *Science Direct = 543, Emerald Insight = 4*, *Ebscohost = 46, ERIC = 5* and *IEEE = 4*) records after removal of duplicates using a reference manager software (Mendeley). By relevance of the titles and abstracts, 78 full-text records were retrieved. Overall, eight studies met the inclusion criteria for the systematic review in Industry 4.0 and VLE in engineering education. Detail of the searched strategy is illustrated in Fig. 1 using the PRISMA flow diagram. The results are presented in six themes: author, engineering students involved, virtual type of intervention, outcome, category, and classification of acquired competencies (Table 1). Two studies each originated from the United States [24, 25] and Ireland [26, 27]. One study each from Austria [28], Brazil [29], Saudi Arabia [30], and Turkey [31]. Majority of the studies compared the physical and virtual laboratories [24, 25, 28–30], while other studies compared other online with virtual learning systems [26, 27, 30].

Virtual learning environments were used to develop knowledge and skills in production and manufacturing processes, which is an essential part of Industry 4.0 transferred to the context of

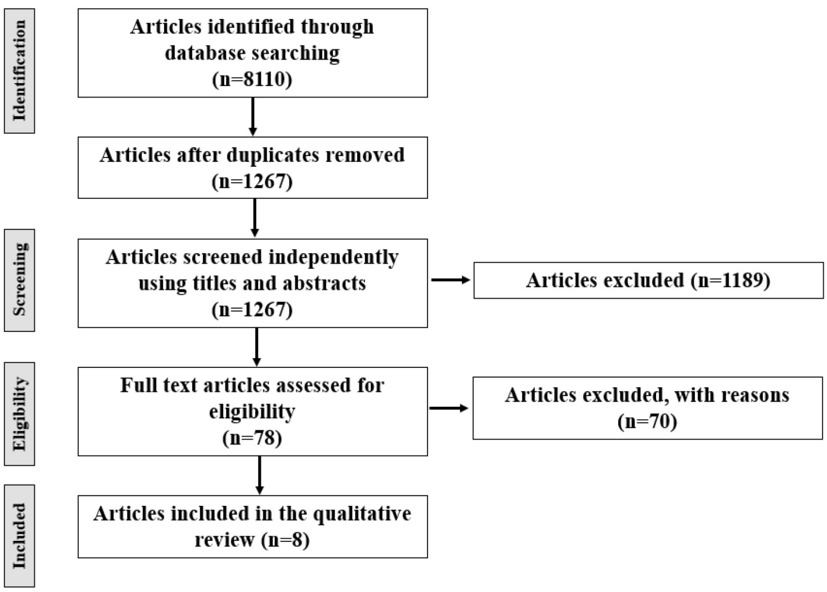

Fig. 1. PRISMA flowchart.

Table 1. Characteristics of the Studies in Industry 4.0 and VLE in Engineering Education

Author	Population	Intervention	Project Design	Outcome	Category	Competencies
Bell, J. T., & Fogler, H. C. (2004) [25].	Chemical Engineering, University of Illinois, U.S.	Virtual reality-based educational platforms which include virtual chemical plants, virtual laboratory accidents, and virtual UIC campus.	Development of virtual chemical plants designed to reinforce topics in chemical kinetics and reactor. Simulation of different accidents to allow users to experience the consequences of not following proper lab safety procedures. Virtual reality-based simulation of UIC campus with an increasing number of buildings and areas.	Virtual chemical plants provide guided exploration of domains (e.g., interior of operating reactors and microscopic reaction mechanisms). Virtual laboratory accidents promote safety by demonstrating the consequences of not following proper lab safety procedures. Virtual UIC campus provides valuable guidance for (foreign) visitors.	Technical, methodological, and personal competencies.	Knowledge, analytical skills, intercultural, and compliance.
Benselama, A. S., Hennache, A. S., & Saleh, M. S. B. (2009) [30].	Electrical Engineering, Riyadh College of Technology, Saudi Arabia.	Online Experiments and Virtual Laboratory (LABVIEW, Data socket, Applet view, LAB VNC, Measurement Studio).	Comparison of different software technologies, and determine competencies acquired in a virtual laboratory.	Student's feedback is very positive with acquired competencies including respect for personnel recommendations, follow experiment's protocol, familiarity for each type of equipment, develop a setup of experiment from drawing or description; design a schematic as required; choose adequate equipment regarding reference; analyze and compare the results to theoretical values; and identify the parameters that affect the phenomena.	Technical, methodological, and social competencies.	Knowledge; process understanding; creativity; problem and conflict saving; analytical skills, and compliance.
Callaghan, M. J., McCusker, K., Losada, J. L., Harkin, J. G., & Wilson, S. (2009) [26].	Electronics and Electrical Engineering, University of Ulster, Northern Ireland.	Engineering Education Island with the use of Second Life, MOODLE, SLOODLE.	Interactive demonstrations (e.g., direct current electric motor) and simulations (e.g., CPU) with an introduced error or faulty demo.	Students understand the operation of a DC electric motor, its components, their interaction and effects of magnetic fields. Students work collaboratively by groups of remotely and diversely located students.	Methodological, social and personal competencies.	Analytical, intercultural, and communication skills; ability to work in team and flexibility.
Callaghan, M. J., McCusker, K., Losada, J. L., Harkin, J., & Wilson, S. (2013) [27].	Electronics and Electrical Engineering, University of Ulster, Northern Ireland.	Circuit Warz (game-based learning).	Gamification in the educational setting that presents the characteristics of electronic circuits (e.g., parallel/series resistance, RC circuits, and oscillator circuits), and phenomena in the virtual world which facilitate student engagement, peer-learning, and assessment.	Students enjoyed the collaborative-competitive group aspect of the project, and the ability to interact and run simulations visualizing circuit theory/operation with a given time constraint applying their practical knowledge.	Technical, social, methodological and personal competencies.	Knowledge; analytical and communication skills; work in a team; and ability to work under pressure.
Coşkun, S., Kayıkcı, Y., & Gençay, E. (2019) [31].	Engineering, Turkish German University, Instanbul, Turkey.	The generic framework of Industry 4.0 engineering education surrounded by Kolb's Experiential Learning.	Introduce new study modules for curriculum (e.g., intelligent systems, IT security and hardware systems), laboratory concept (e.g., visual production lab, lego-lab), and student club activities to complement changes defined in curriculum and laboratory.	It was feasible to apply Industry 4.0 Engineering Education framework with the underlying theory of Kolb. The students acquire hands-on experience on industrial applications following step-by-step instructions for assembly line planning with mixed-model scenarios.	Technical, methodological, social, and personal competencies.	Knowledge; process understanding; creativity; analytical, research, and intercultural skills; ability to work in a team.

Table 1 (*cont.*)

Author	Population	Intervention	Project Design	Outcome	Category	Competencies
Karre, H., Hammer, M., Kleindienst, M., & Ramsauer, C. (2017) [28].	Industrial Engineering, Graz University of Technology, Austria.	Assemble a fully functional, market available scooter (consisting of 60 pieces) in 14 working steps taking 12 minutes and 50 seconds.	TU Graz scooter is assembled under suboptimal conditions in terms of workspace, material, and information flows.	Increased industrial management skills and qualifications of students and industrial personnel by learning how to operate the process themselves and also the methods to discover improvement opportunities.	Technical, methodological, social, and personal competencies.	Knowledge; process understanding; technical, analytical, and research skills; ability to work – in a team and – under pressure
Pereira, C. E., Paladini, S., & Schaf, F. M. (2012) [29].	Control and Automation Engineering Students, Brazil.	GCAR-3DAutoSysLab (MOODLE, OpenSim).	Comparison of hands-on, simulated, remote, virtual worlds/ laboratories, and evaluation of GCAR e-learning system project through feedback and performance scores.	Students were able to use different software tools, increased processing power, simulations reduce time to complete one experiment, students simulate the process to review and understand it better, increased student performance and motivation, immersive collaborative learning.	Technical, methodological, social, and personal competencies.	Knowledge; process understanding; analytical skills; ability to work in a team; flexibility; motivation; and compliance.
Wiesner, T. F., & Lan, W. (2004) [24].	Chemical Engineering Students, Texas Tech University, U.S.	Computer-based Experiments through LabVIEW software.	Evaluation of student's performance (e.g., comprehensive exam, ABET Engineering Criterion 3 questionnaire) in a mixed physical-virtual unit operation associated with significant pieces of process equipment in a laboratory (e.g., double-pipe heat exchanger, ammonia absorber and cooling tower), including safety concerns.	Students in a virtual laboratory had high scores in theory and were able to experiment humidification, gas absorption, and heat transfer; contributed considerably in all areas of ABET Engineering Criterion 3 especially on the improvement of "speaking skills" and "appreciation of professional behavior."	Technical, social, and personal competencies.	Knowledge; language and communication skills; and motivation to learn.

engineering education. Physical and virtual laboratories can achieve similar objectives and learning outcomes. However, there is no doubt that the latter can significantly enhance the understanding of real-world industry settings. Universities that support this virtual laboratory practices in their curriculum, taking into consideration the Industry 4.0 principles or concepts, have improved their effectiveness in teaching. Thus, students who can perform theoretical and practical applications toward this new trend are more recognized.

Although few studies met the inclusion criteria, the integration of VLEs in engineering education still proves to be effective in attaining the concrete required competencies. These include social, technical, methodological, and personal domains. Virtual activities demonstrate a close correspondence to the technological dynamics of Industry 4.0. Thus, some of the required specific competencies could be attained in preparation for the future work of engineering students. This study indicates that an engineer requires cross-functional skills associated with knowledge of Industry 4.0. Based on the results of this search, application of VLE creates an interactive, compelling, engaging, and immersive student learning experience for students that promote acquisition and improvement of knowledge and understanding, develop skills and attitudes, flexibility, and timesaving under extreme tasks. It also attests that students were able to solve real problems and give a deep insight into the current technological world in a more efficient way. Besides, engineering students provided with experiential learning within the frame of Industry 4.0 vision bring change in behavior and attitude, which facilitates flexible and competitive student-to-student interactions.

4. Discussion

Many industrialized countries have already begun with adapting their industrial infrastructure to meet the requirements of Industry 4.0 [29]. Face with the challenges of Industry 4.0, the higher education processes of engineering disciplines must build an efficient laboratory web-based remote-control system technology suitable for control education [32]. Different universities started transforming their education-delivery methods in terms of virtual learning. Their curricula provide Industry 4.0 experience, focusing on building specific capabilities or competencies. An affordance of virtual laboratories is that reality can be adapted. Students can conduct activities about unobservable phenomena with lengthy investigations [33]. Remote laboratory-based learning using Industry 4.0 technologies is an effective platform to supplement theory. Students can able to practice laboratories multiple times to review their work, reflect on it, test different scenarios, and discuss the results with their peers and instructors [34].

With the implementation of VLE, it had considerably improved the productivity of student's learning when theoretical knowledge has been applied to real industrial problems. It develops their creativity, innovation, communication, problem-solving, and team-working skills. Also, virtual resources enable the students to build crucial competencies, especially if they are allowed to conduct experiments in virtual settings. Required competencies for Industry 4.0 can be categorized and classified based on human resource development at an employee level [35]. Similarly, the required competencies for future production can also be classified based on an output-oriented model [36]. The same applies to engineering students that must perform and fulfill specific tasks related to future production or manufacturing processes. Educational institutions should then consider adapting quickly in response to the challenges of Industry 4.0.

Virtual collaboration in Industry 4.0 is highly essential in the context of a dynamic and digitized working world [37]. The implementation of web-based tools enhanced student learning in spite of rising class size that would still help them improve their skills and understanding [38]. Collaborative learning is also considered the very essence of social competency. Active support for collaboration and multi-perspectivity is required to solve complex engineering problems. Humans should interact employing self-critiquing/reflection, inquiring, and arguing skills which propel knowledge building [39]. Collaborative problem-based learning develops skills and attitudes such as teamwork and communication skills, and respect for divergent ideas which promote the acquisition of knowledge [40]. Besides, collaboration and communication are common deficiencies in conventional learning system in engineering education, which upon using e-learning tools such as simulations, animations and virtualized demonstrations in laboratories sufficiently improved student's performance [41]. Aside from collaborative learning, the virtual laboratory also enhances autonomous and interactive learning [42]. Other research findings compared the effectiveness of several different traditional physical education with that of the virtual learning – that both can be equivalent in terms of the attainment of learning outcomes [14, 43, 44].

Future workers need to demonstrate foresight in navigating a rapidly shifting landscape of organizational forms and skill requirements such as critical thinking, insight, analysis capabilities, new-media literacy, and soft skills-ability to collaborate, work in groups and respond adaptively [45]. Combination of new cross-functional roles for future 21st-century employees needs both technical and social and analytical skills [46]. Aside from creativity and interpersonal skills, a higher degree of cognitive abilities such as creativity, logical reasoning, and problem sensitivity should also be part of their core skill set. Similarly, recommended skillsets for the future workforce should consist of various technical (e.g., knowledge, abilities, and skills in different areas) and personal skills (e.g., time and self-management) [47]. New attitudes and behaviors will also be needed, founded on flexibility, resilience, collaboration, enterprise, creativity, and response to change [48].

The vision of Industry 4.0 brings significant change for both industry and university. Initiatives must be sought through the inclusion of a virtual learning environment under the concepts of Industry 4.0 on the curriculum of engineering programs. The virtual learning environment has the potential in attaining the required competencies in preparation for future's world of work. Our findings show that when compared with physical or other types of online learning, VLE may improve knowledge and cross-functional skills. This study also suggests that we need to encourage the use of VLE in the higher education system, especially in engineering courses targeting the development of competencies towards Industry 4.0. Further research should evaluate the challenges faced by the students in the implementation of such platforms.

5. Conclusion

The review provides insightful information on the use of virtual learning environment in engineering education for the preparation of the required competencies of Industry 4.0. Higher education must adapt to the requirements of this vision by integrating VLE in its learning programs. The study examines a series of works that demonstrate new laboratory concepts or implementing scenarios that enable the engineering students to experience Industry 4.0. Literature has pointed out that virtual learning offers accessibility, convenience, flexibility, responsiveness, and alternative means to take up the courses. VLE has the potential to improve knowledge and skill outcomes. With higher interactivity as compared to traditional education, VLE could be of great advantage for engineering education, responding to the future requirements of Industry 4.0.

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