Some Insights on Engineering Education 4.0

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Abstract

In this era of the fourth industrial revolution, modernization, sustainability, research and innovations are primary interventions in all segments of commercial and social activities. Higher education is being globalized and the role of information and communication technologies especially in engineering education is prominent. Engineering education 4.0 is a pedagogical approach inspired by the fourth industrial revolution for flawlessness, satisfaction, time saving, skill development, and efficiency enhancement in engineering education. From curriculum development to assessment, generation of results, and student feedback, all important tasks and activities are accomplished by the assistance of information and communication technologies. The roles and responsibilities of the stakeholders for the success of engineering education 4.0 are manifolds. Engineering education 4.0 is only possible when instructors, learners, institutes, and universities understand, adopt, disseminate and promote modern teaching and learning technologies to be internationally competitive and sustainable. This paper introduces engineering education 4.0 and discusses the roles and responsibilities of the stakeholders along with shedding lights on the future opportunities. It also reports and discusses some of the innovative and modern engineering education 4.0 teaching-learning techniques and their impact on engineering education. In essence, engineering education 4.0 is being recognized and implemented worldwide, but further efforts and encouragement are required for teachers and learners to adopt it at a large scale and higher level. The paper aims to encourage innovative future attempts in engineering education for the development of students who may stay competitive and contribute towards the fourth industrial revolution.

Keywords
Education, Engineering, Industry 4.0, Learning, Teaching

1. Introduction

Universities and educational institutes play a major role in the sustenance of the fourth industrial revolution which requires competent and skilled engineers. The fourth industrial revolution or Industry 4.0 is a current trend of automation and data exchange in manufacturing technologies and majorly includes cyber-physical systems, the internet of things, cloud computing and cognitive computing (Coskun et al, 2019). The skilled technocrats and engineers are required who may contribute to the success of Industry 4.0. Cyber skills and technological knowledge are two extra characteristics essentially required for Industry 4.0 ready engineers. Competency building and development of the required skills are the responsibilities of the institutes/universities where they are educated. To build industry 4.0 ready engineers and technocrats, it needs a revolutionary transformation in engineering education. This transformation is underway where traditional lecture halls are being replaced by ultra-modern classrooms, digital tablets and gadgets are being given considerable importance over student's backpacks, e-books are the best alternate of the hard copy lecture notes, and information and communication technology (ICT) interventions in all segments of engineering education are being prioritized. Whether the African universities or European institutes, all are busy adopting, encouraging, and disseminating Industry 4.0 based education. Hence, engineering education 4.0 is a pedagogical approach that assists to meet the requirements of Industry 4.0 vision. The engineering education 4.0 interventions facilitate all stakeholders and help to achieve growth, progress and sustainability. All the stakeholders have certain roles to play and responsibilities to bear, which are discussed in the subsequent sections of this paper. It is worth mentioning about some education 4.0 techniques which are based on ICT interventions, such as, E-learning, game-based education, and teaching integrated with virtual reality etc. Moreover, incorporating Youtube videos, using social sites and media, and online blackboard type communication tool also play effective role in engineering

education 4.0. Technology enabled education is the demand of the current scenario. It facilitates cognitive learning where students are engaged and enabled to visualize the course contents. They learn by sharing, listening, watching, and doing. Virtual reality based education where virtual lab is recognized as the most powerful tool providing the actual learning environment as the physical laboratories and facilitating learners where they can learn being located remotely. Similarly game based education helps to develop skills and achieve learning outcomes along with confirming the graduate attributes such as independent working, collaboration or team skills, and professionalism etc.
The next section discusses some engineering education 4.0 based techniques and also sheds light on the roles and responsibilities of the stakeholders for the implementation, progress, and sustenance.

2. Discussion

2.1 Challenges

The current challenges towards technology enabled teaching-learning and engineering education 4.0 can be as follows:

- It needs initial extensive involvement in exploring, training, and understanding the aspects of technology in order to prepare for its implementation.
- Demotivation of the students and stakeholders, as their interest and comfort zone both lie around the traditional methods and techniques.
- Cost is also a big factor, for the successful functioning of engineering education 4.0.
- Implementation is followed by sustenance which is very difficult, as it needs continuous motivation, transfer of skills, and funding.

Still there is a lack of information and understanding among teachers and learners of the current technologies and their benefits. Especially in the higher education system, although ICT interventions have been encouraged, but it appears that complete replacement of the tradition chalk-board teaching-learning environment where the comfort zone of most of the teachers and learners lies is not possible. On the other hand, some teachers and learners have a better understanding and make use of laptops, digital devices, and internet and communication technologies for reading, writing, and exchange of notes, content understanding and learning. They are making use of social sites/apps such as Facebook and WhatsApp etc. to communicate with the learners. There are examples of the classroom environments where digital stories, effective power point slides, animations, gaming, and virtual techniques are being used for the enhanced teaching and learning.

2.2 Engineering education 4.0 techniques

Cognitive learning or cognitivism based teaching practices and techniques facilitate the content understanding and information processing, improve problem-solving skills, and enhance learning (Fig. 1). It results in terms of increased interest and participation of the students, enhanced learning, and good performance in the exams (Hergenhahn and Olson, 2005; Schunn and Silk, 2011). It is a well-known fact that all subjects need different pedagogy skills and approach. Specifically for the subjects such as manufacturing engineering, the intervention of cognitivism-based techniques is the most appropriate approach, because it fulfils the requirement of connecting students with the subject contents and providing realistic experience. Game based learning, virtual and augmented reality based teaching and learning, and e-leaning are some engineering education 4.0 based techniques (Fig. 2).
Game-based learning has been widely accepted an effective technique that has potential to support deeper learning by using games (Koivisto and Hamari, 2019). Games turn a tedious task into an engagement activity. Puzzle games, adventure games, simulation games, real time strategy games, and edutainment etc. are some of the important game types used in teaching and learning. The selection of game to support a particular learning context is a very important task. A classroom is characterized gamified when the learners are engaged in the fun playing and challenging tasks, received prizes for accomplishing tasks, collaborated for problem solving. Gamification or game-based learning brings following significant benefits-

- The students feel free at their own pace and convenience.
- Fun and joyful learning.
- Team working, problem solving, and interpersonal skills are also developed.
- The students are fee to make mistakes and fail, in order to understand, learn, correct and redo the tasks.
- It prompts lifelong learning.

There have been some studies conducted in engineering where game-based learning was found entertaining, effective, engaging and informative to the students/learners (Alberto et al., 2017; Gomez-Jauregui et al., 2018; Kosmadoudi et al., 2013; Li et al., 2012). However, work in manufacturing engineering type courses is rather limited.

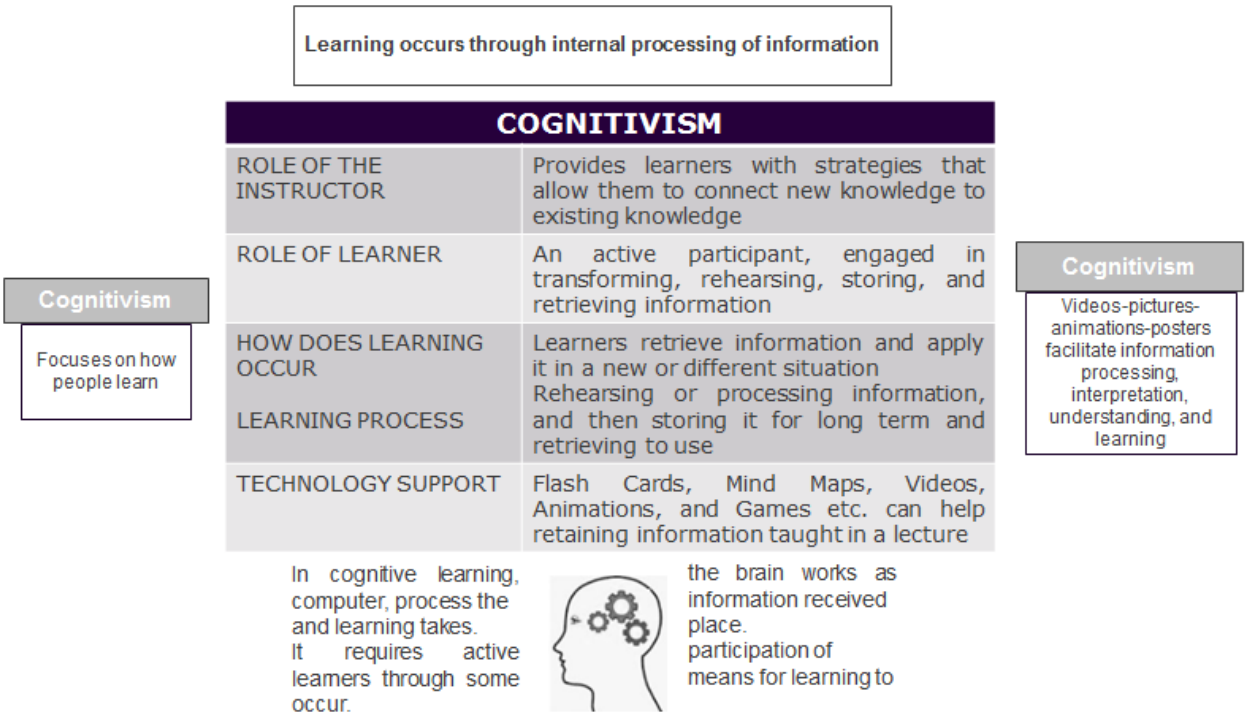

Figure 1. Cognitive learning

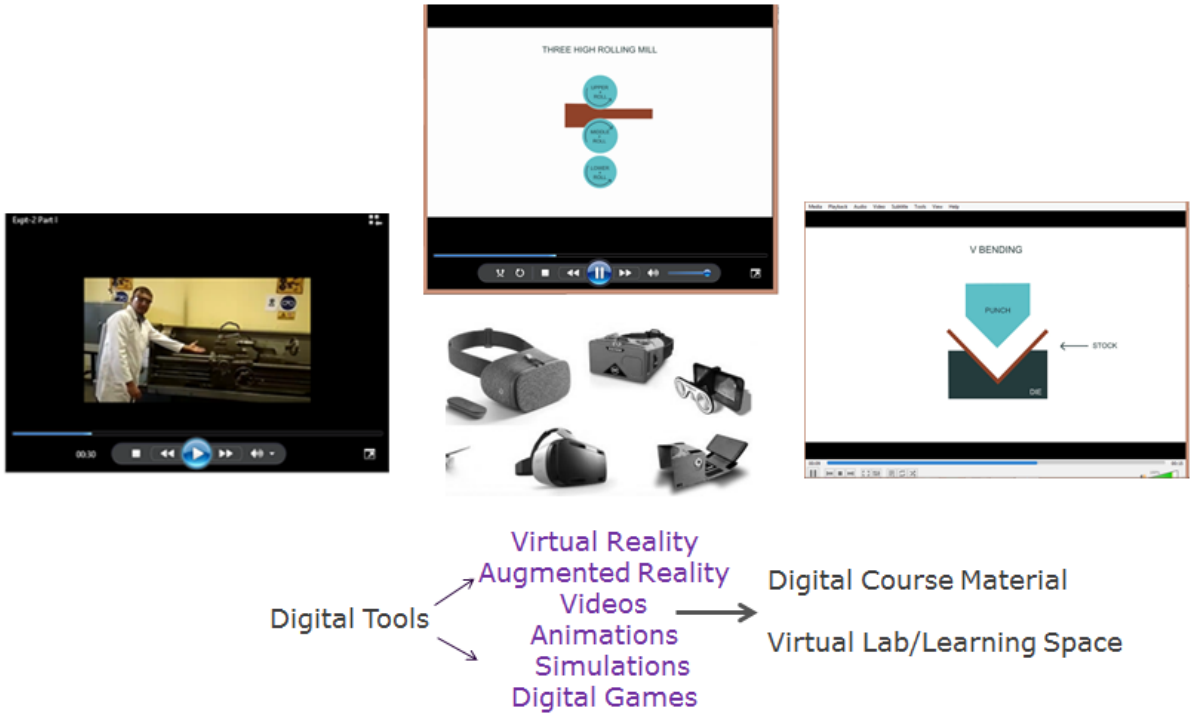

Figure 2. Technologies used in engineering education 4.0

Virtual reality based education is also gaining wider acceptance where especially virtual labs are built to overcome the limitations of unavailability of expensive machines and equipment, giant infrastructure and skilled technicians (Gupta et al., 2019). The virtual laboratory sessions mimic working of physical labs and create actual learning experience. There are many successful past work on implementation and effectiveness of virtual labs. In an interesting study, a virtual lab was developed for fluid mechanics subject of mechanical engineering (Richards et al., 2015). It facilitated the users/learners by providing remote access where they could perform experiments by triggering. Dobrzanski and Honysz (2007) developed material science virtual laboratory for analysis of microstructure of wide range of engineering materials. Another important case of virtual lab development is of a pharmaceutical tablet manufacturing virtual lab that was found very effective by the students (Mattsson et al., 2016). German universities are extensively developing and utilizing virtual labs in engineering education under 'Excellent Teaching and Learning in Engineering Science' project (Grodotzki et al., 2018). A recent work on development of industry 4.0 virtual lab for manufacturing engineering education is reported in (Gupta et al., 2019). It is reported that virtual lab equipped with a comprehensive learning management system having fundamental theory, videos and quizzes for various manufacturing process and operations extensively helped the students to understand the subject contents such as process principles, mechanisms, and product manufacturing. The results of qualitative and quantitative feedback study were found encouraging and helped to further improve the learning management system of the virtual lab.

2.3 Roles and responsibilities

Every stakeholder i.e. universities/institutes, teachers, and learners has certain roles to play and responsibilities to bear with. Educational institutes and universities have organizational powers to inforce education 4.0 based activities. Universities can start specialized short courses and diplomas on engineering education 4.0. Government's funding and schemes for sub-continental and bilateral projects are necessary for research, development, and innovations in this. The role of lecturers is very important in engineering education 4.0 transformations, as they act as a link between university and students. Lecturers directly participate and contribute in the planning and implementation of techniques and activities, train, supervise, get feedback, evaluate effectiveness, analyze, and advise. It is recommended that teaching, learning, and assessment should be informed by research. The lecturers should make more use of technology to get the activities and tasks related to both done efficiently. They may start by identifying the problems and challenges faced by the students by interacting with them. Further, it is necessitated to find the solutions to overcome the challenges by implementing engineering education 4.0 activities and techniques for knowledge enrichment, learning enhancement and success of the students. Teachers can develop interactive games and activities to clear the concepts or topics/contents, design and develop virtual labs equipped with a learning management system, make use of animations and projects or problems for deeper and quicker learning. Learners or students also have certain responsibilities towards their own learning. It is essential for them to cooperate with the teacher/instructor for engineering education 4.0 interventions, actively participate in the relevant engagements, activities, and trainings. Learners can also assist the instructors by some mini projects or contribute in the research, development, and innovations of the teachers in engineering education 4.0.

3. Current Uptake of Technology and Contribution to Engineering Education 4.0

During the last two decades, higher education in SA, in-fact in the whole world has been revolutionized. There are sincere attempts from the government and agencies to make higher education system technologically enabled, for example, traditional backpacks are being replaced by laptops and tablets; use of social media, microphones, smartphones, and digital devices and software/apps is being encouraged; online blended learning and assessment systems are being implemented to facilitate both teachers and learners.

The review of the available literature indicates that in this era of the 4th industrial revolution, significant efforts are being made by the united nation agencies, NGOs, governments, universities and institutes to make education affordable, fast, easy, and available with the intervention of technology in order to enable engineering education 4.0. There has been tremendous growth in the online courses in the universities worldwide. Online education is suiting today's students who might not otherwise be able to get to the campus, and it help prepare the students for professional world which is expanding in online space and digital environment. A survey conducted in the USA, indicates a significant increase with rapid rate in the students enrolment for online courses.

The term engineering education 4.0 recently coined, where the African universities or European institutes, all are busy adopting, encouraging, and disseminating Industry 4.0 based education. Engineering education 4.0 is a pedagogical approach that assists to meet the requirements of Industry 4.0 vision. As discussed before that engineering education 4.0 interventions facilitate all stakeholders and help to achieve growth, progress and sustainability. It is worth mentioning that education 4.0 techniques are based on ICT interventions, such as, E-

learning, game-based education, and teaching integrated with virtual reality etc. Technology enabled education is the demand of the current scenario. It facilitates cognitive learning where students are engaged and enabled to visualize the course contents.

Through various funding schemes and projects, E-learning, MOOCs (massive open online courses), and smart classroom practices etc. are given considerable importance at higher education level.

However, still there is a lack of information and understanding among teachers and learners of the current technologies and their benefits. Especially in the higher education system, although ICT interventions have been encouraged, but it appears that complete replacement of the tradition chalk-board teaching-learning environment where the comfort zone of most of the teachers and learners lies is not possible. On the other hand, some teachers and learners have a better understanding and make use of laptops, digital devices, and internet and communication technologies for reading, writing, and exchange of notes, content understanding and learning. I am also known of some teachers who are making use of social sites/apps such as Facebook and WhatsApp etc. to communicate with the learners. There are examples of the classroom environments where digital stories, effective power point slides, animations, gaming, and virtual techniques are being used for the enhanced teaching and learning. At a large scale, many South African universities have launched MOOCs platforms and made learners available for free.

A case study conducted on the effectiveness of blended learning in an Australian education scenario, reveals the successful training of teaching staff for enhancing their digital literacy by overcoming various challenges (Mirriahi et al., 2015). Benefits of including videos, flipped-classroom teaching, MOOCs, online assessments and short tests etc. were highlighted as main features of technology-enabled teaching.

In essence, the current uptake of technology both at SA and global level is at advanced stage, however further efforts towards collaborative attempts, global funding, projects and schemes, and encouragement to the learners and teachers are required to be done. It is essential to understand the imperatives (customization, interaction, and control) of the technologies driving the changes in education (Collins and Halverson, 2009). Providing knowledge as per the level and time of requirement (customization), immediate and timely feedback with the help of ICT tools, AND opportunities to have command and control (i.e. ownership) on self-learning and related activities are major imperatives.

At University of Johannesburg (UJ), the faculty of engineering and built environment and the department Dept. of Mechanical and Industrial Engineering Technology, the use of technology is in full swing. After including Industry 4.0 based education and research into UJ's strategic objectives, there has been an accelerated emphasis on technology enabled teaching and learning. Online short learning programmes or massive open online courses, virtual labs, augmented reality based teaching, game-based education, educational apps, and e-learning etc. have been increased in teaching and learning practices at UJ. At institutional level, various funding schemes (like teaching innovation funds) are giving considerable importance to the technology based projects. It is worth mentioning that I myself have got funding since last two year for two technology based projects i.e. Project based learning for Industry 4.0 education and development of industry 4.0 based virtual labs. At university level, all faculties are being encouraged to use technological tools in teaching, learning and research activities. Seminars and workshops on blended learning, online assessment, and e-learning etc. are being conducted to encourage and train lecturers.

Well, the UJ online platform Blackboard is extensively being utilized in my faculty and dept. to share the lecture slides and class notes with the learners, to communicate with the learners regarding teaching matters. Most of the instructors use power point slides for lecturing. The students are encouraged to bring laptops, smart phones, and tablets for them to keep the slides/notes opened during lecture. The use of software is also recommended for lab work and the students are trained for their successful functioning. Few of the faculties (including me) who are busy doing teaching innovation projects and research in technology enabled teaching, also make use of digital stories, video lectures, and effective power point presentations for the enhanced learning. I myself also use dropbox and WhatsApp with students for exchange of notes and information. I also make use of indigenously developed virtual labs equipped with a dedicated learning management system for the practical aspects i.e. subject labs and much better understanding of the course contents. Our institutional environment also encourages students to use e-books. Recently, a lecturer started virtual lecturing via webcams and makes sure the availability of the tutors in class for the assistance of the students. In mechanical department, virtual labs have been developed for better understanding of manufacturing engineering subjects. Mining department is making use of augmented reality to train the students for mining work.

For teaching and learning purposes, I extensively use technology or am very much reliant on technology for my teaching, as I deliver lectures using power point slides, make use of online BB to communicate with the students, give them assignments, evaluate them and provide feedback online. I refer e-books and internet resources for content preparation of my lectures. I incorporate relevant videos, animations, posters and pictures to explain particular topics to the learners. I make use of UJ's Blackboard platform to share notes, information, and solutions

with the learners. I also use dropbox, especially to communicate with PG students. Recently, I have developed a virtual lab for the practical/experiments of manufacturing engineering subject. The learning management system of this virtual lab is designed using various tools and techniques of ICT. In this virtual lab, online material is available to the students which they can access being stayed anywhere with their pace and convenience. Along with theoretical details, animations, videos and salient features are communicated to the learner via this virtual lab using technology. I also made some videos and put in this virtual lab for better understanding of the manufacturing processes. I provide access to this virtual lab to my students via blackboard and examine them through multiple choice questions at the end of each lab and also collect their feedback. I have also started using digital stories in some subjects, it is especially for those students who have missed the class or registered late. They may access the digital stories of the units/chapters and prepare themselves for the exams. For quick learning and revision during exam time, I provide my students with digital mind maps where the contents/notes of the complete chapter are provided on a single page for easy and quick look. Considering the significant benefits of online assessments, I recently started giving online assessments to my students. I give them assessment problems online, they submit their assessment online, and I evaluate and provide feedback to the students online.

I have experienced the following significant benefits and successes of technology usages and recorded them via feedback of the students, by module and teaching evaluations, and students performance in the assessments-

- Better understanding of the topics and contents
- Increased students interest and class attendance
- Increased interactive and collaborative learning
- Improved performance in the assessments
- Quick and easy access
- Saving of lot of efforts, time and resources

4. Summary

In this paper various aspects of engineering education 4.0 are discussed. Technology enabled or in other words information and communication technologies (ICT) based education can make it possible. From students to lecturers all the stakeholders play major roles and bear certain responsibilities in this. A comprehensive detail on current uptake of technology (at global, South African and local i.e. university level) considering engineering education 4.0 is also given in this paper. E-learning, virtual reality integrated teaching, game-based education, and use of social media etc. have been found very effective and beneficial for the lecturers and students. Most of the ICT based techniques prompt cognitive learning and learners can have a better understanding and gain the knowledge with comparatively less time. Engaging students with the intervention of these tools and techniques, supports cognition and promotes cognitive learning by creating a learning environment that connects them with the topic and enables them to visualize the process/operation/mechanism/system being taught. Globally, the uptake of technology and efforts and contribution to enable engineering education 4.0 is underway. However, sincere future efforts and encouragements are required to be done where awards and prizes to motivate lecturers and students to work towards engineering education 4.0, dissemination of the education 4.0 concept and related programmes, and funding from the unions and governments, etc. could be some sincere future endeavors.

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Biography

Kapil Gupta is working as Associate Professor in the Dept. of Mechanical and Industrial Engineering Technology at the University of Johannesburg. He obtained Ph.D. in mechanical engineering with specialization in Advanced Manufacturing from Indian Institute of Technology Indore, India in 2014. Advanced machining processes, sustainable manufacturing, green machining, precision engineering and gear technology are the areas of his interest. He has authored several SCI/ISI Journal and International Conference articles. He also authored and edited 10 international books on hybrid machining, advanced gear manufacturing, micro and precision manufacturing, and sustainable manufacturing with the renowned international publishers. He has also successfully guest edited special issues of a Scopus indexed journals and he is currently editing a series of handbooks on Advanced Manufacturing as a series editor. He is a recognized reviewer of many international journals and in the advisor/technical committees of international conferences. He has also delivered invited speeches in international conferences and symposiums, and seminar talks at international universities. Kapil Gupta is a NRF [National Research Foundation] rated Researcher in South Africa. Currently, he is supervising some postdoctoral fellows and postgraduate students who are busy conducting research in advanced manufacturing and industrial engineering fields. He has obtained PG Diploma in higher education and conducting research in engineering education. He is working on implementation of innovative teaching techniques for the enhanced learning of engineering students. Recently, he also developed a manufacturing engineering virtual lab.