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Current state of research in application of disruptive technologies in engineering education

Dr. ArtiSiddhpura, Indumathi V, Dr. MilindSiddhpura

Engineering Institute of Technology, 1031 Wellington St, West Perth, 6005, Australia

Abstract

Disruptive innovation technologies have made their way in the field of academia during the past few years. A plethora of literature exists investigating the applications of various disruptive technologies in the field of engineering education. The directions for future research however are still obscured by the copious amount of literature having split opinions and conflicting results which necessitates a review of current state of the research. This paper clarifies the underlying concept of the theory. The authors then critique and summarize the research on present state of implementation mainly focusing on the field of engineering education. The future scope for the research is also discussed keeping in the mind the upcoming new technologies such as mobilecomputing, wearable technologiesand internet of things combined with machine learning.

*Keywords:*Disruptive Technologies; Engineering Education; Virtual Reality;MOOCs; Augmented Reality; Artificial Intelligence

1. Introduction

The theory of disruptive innovation was coined by [1]in 1997 which explains that a disruptive technology is the one that disrupts the traditional practices usually starting with a small number of users and then growing over time in such a way that it displaces a well-established and prominent practice. Vygotsky's theory of human development [2] underpins the concepts of Activity Theory which illustrates that human beings do not interact directly with their environment but rather use tool as mediators [3]. As explained by [4], disruptive technologies can serve as a tool to facilitate learning and achieve intended outcome. The recent trends in education such as learning-by-doing, competency-based learning, leadership, active methodologies learning, creativity, project-based learning, and gamification in learning etc. have received a lot of positive attention. As suggested by [5] in their editorial article, the traditional education models need change because students get bored in the traditional classrooms and sometimes cannot understand the lectures especially when the content being taught is out of context. Monotony of the

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traditional delivery makes this worse as opposed to the wide range of interactive and audiovisual stimuli the students nowadays are accustomed to.Thus, implementation of such stimuli in the classroom with the help of disruptive technologies can help in improving student engagement, motivation and retention of knowledge [5].

This paper aims to review the application of the four most prevailing disruptive innovation practices in engineering education context:

1: Virtual Reality (VR): Work related with implementation of VR in engineering classrooms like [6], [7] and [8] suggests that this is an extremely useful tool to teach some high-risk engineering concepts like lasers and helping students visualize cost-effectively. This will be investigated further.

2. MOOCs: [9], [10] and [11] suggest that MOOCs can be used to develop new innovative business model for teaching and learning. The further potential of MOOCs will be explored.

3: Augmented Reality (AR): A lot of research has been carried out in the field of application of Augmented Reality to higher education sector [[12], [13], [14], [15] and [16]]. These will be reviewed critically for applicability in the field of engineering education.

4: Artificial Intelligence (AI): The paper will explore the existing research [[17], [18] and [19]] and further possibility of application of Artificial Intelligence in the field of engineering education.

2. The Context

The economic powerhouse of any country is based on the educational system and hence it becomes imperative to consider the factors influencing the role of higher education. Technological innovations and efforts to embed them in higher education systems lead to disruptive technologies which are among many factors that have a major impact on the higher education system[20]. The existing model of higher education is becoming more and more expensive resulting in inaccessibility for millions of potential learners seeking opportunities for higher education. The higher education institutions are investing significant sums in learning technologies to keep abreast with the current industrial trends and this is partially responsible for ever-increasing costs. So, it is worthwhile to investigate the effectiveness of the current technologies and cost-effective alternatives for quality higher education. According to Christensen's theory of Disruptive Innovation, these disruptive technologies are not designed explicitly to support learning and teaching in higher education but have educational potential[3]. So, a gainful insight can answer the question that if disruptive technologies are enhancing the current model of higher education

3. Disruptive Technologies in the Higher Education

3.1 Virtual Reality (VR):

Virtual Reality can be defined as "inducing targeted behavior in an organism by using artificial sensory stimulation, while the organism has little or no awareness of the interference" by [21] or as "an interactive computer simulation which transfers sensory information to a user who perceives it as substituted or augmented"[22]. Virtual reality is an emerging technology that can help improve the way students are educated in many fields. Despite being new in the field of higher education, VR has been used in the field of training for quite some time. VR is popularin many fields including entertainment, military, healthcare, education and engineering. With the help of computer technology, a simulated environment is created and presented to the user in such a way, that user starts to feel like in real environment [7]. VR offer affordances of gaining real world experience on topics that are too dangerous or environments that the students can't physically visit [2]. It also offers a platform for more engaging collaboration between the educator and student, using the various functionalities that are available within. Some examples of functionalities include, recording, first person view, simulation, hands-free access, gamification and instant feedback. As summarized by [6], VR can also be used when the mistakes made by the learner could be devastating, harmful, wasteful of material or expensive. VR enables the users to interact which is the most fundamental aspect in learning and can help promote a better understanding [7].As documented by [5], the methodologies and technologies developed using adequate strategies and with accepted pedagogical approaches, can motivate students to change their attitude which is conducive for fruitful learning thus improving student participation and retention of knowledge.

In their extensive review, [23] provides a complete picture of implementation of VR in the field of construction engineering. Out of all, the most popular application of VR is for architectural visualization mainly through Building Information Modeling (BIM). Construction Safety Training was described as the second largest application area of VR in construction engineering. VR based safety training can eliminate the risk component and improve students' motivation and engagement as compared to tradition approaches of using slides and videos.[24] tested the application of VR in mechanical and electrical engineering education and this prototype study reported that students benefited with positive effects on understanding and memorization. Improvement in engagement and retention of knowledge was also reported by [25], [26], [27] and [28].A comparative study of two university engineering courses was carried outby [27]to present the difference between the effect of virtual reality (VR)-based teaching and traditional teaching on learning robotics. The study reported that VR application increasingly motivated students to investigate problems and formulate solutions and concluded that VR helped improve and develop a certain scope of competencies in a basic engineering course.

Despite the above discussed benefits and successful implementation through model and laboratory studies, VR technology is still in its infancy. One of the main hindrances in implementing this technology on a larger scale is the cost. Another limiting aspect is the reaction of human bodies when exposed to immersive feeling and dynamic virtual environment which can cause dizziness [29].VR technologies need to be further studied for their suitability of being integrated with emerging teaching and learning trends like flipped classrooms. In a flipped classroom setting, students are required to self-learn through online teaching material during off-class time which enables them to participate and interact during the live class. VR can enhance the interaction between students and passive learning material in a traditional classroom setting[30].Further research can help design VR – based educational systems that can shift learning styles from teacher-centered to student-centered learning[23].

3.2 MOOCs:

The acronym for MOOC is Massive Open Online Course (MOOC) which was coined by [31] and can be defined as the online course that is aimed at unlimited participation of large number of students from geographically different locations. In addition to traditional teaching material, MOOCs also provide interactive courses supported by user forums to facilitate communication among the students and the academics as well as instant feedback through quizzes. The MOOCsbecame popular very quickly. An example is Stanford's University's Artificial Intelligence course which was launched in the fall of 2011 with over 160,000 registrants. The registrants for various courses through Udacity reached 200,000 by September 2012, 370,000 for fall 2012 courses for edX and more than 1.7 million students for Coursera as of November 2012. 2012 was declared as "the year of the MOOC" by the New York Times [9].A list of prestigious universities offering various engineering courses through MOOCs and various engineering courses available as MOOCs through other platforms have been provided by [9]. As described by [32],MOOCs represent the classic phenomenon—disruptive education—which may prove to be a threat to higher education, or conversely, go the way of other short-lived educational trends and simply disappear.Many researchers fear that the MOOCs model have the capability to completely revolutionize the current educational models [32], [33] and [34].

Although engineering education relies heavily on theoretical concept building, practice forms the key element in engineering profession [35].It is important to augment theory with hands-on training and the theory-to-practice gap in online education can be filled in by the virtual and remote laboratories. Engineering Institute of Technology is one such online engineering education provider in Australia which has successfully implemented the blended delivery by combining traditional approach with flipped classrooms and remote laboratories [36]. Millions of enrolments to major MOOC providers advocate not only popularity but effectiveness and success of

MOOCs. Several universities are considering awarding credit to MOOCs. Antioch University is the first US institution to offer college credit for MOOCs [37]. The Georgia Institute of Technology is the first university to introduce a whole MOOC-based degree [38]. We are not far from a future where; many universities will consider offering credit and non-credit online courses or start awarding credits based on completed MOOCs towards entry in the higher-level programs.

MOOCs have opened learning opportunities and given access of knowledge to masses that was previously unimaginable [39]. It is believed that the MOOCs can be the vehicles for democratizing higher education with a potential to lift people out of poverty [35]. Using online technologies, MOOCs can transform education in access, quality, and scalability.

Passive classrooms, teacher-centered pedagogy and lack of rapid feedback are the main shortcomings of the traditional education which are overcome by the MOOCs. The MOOCs are based on the ideas of active learning, instant feedback, self-paced and peer learning. When students interact with the material at their own pace, they learn better [35]. However, the MOOCs still have a long way to go and must overcome quite a few challenges like quality assurance, completion rate, highly motivated students who can self-regulate, assurance of academic integrity, authenticating students and prevention of plagiarism to name a few [9].

3.3 Augmented Reality (AR):

AR is a promising technology which amalgamates virtual world with real environments. AR system combines real content (observed through IP cameras and displays) and virtual computer-generated content, adequately superimposed on the real content [40]. Between totally real and totally virtual situations, there is a continuum, which can be defined as mixed reality concept known as virtual continuum [41] which cover both AR and augmented virtuality (AV), which combines real and virtual worlds.

AR is becoming a technological trend in diverse fields such as advertising, architecture, leisure, marketing, medicine and military [42]. AR has been used to teach mechanical engineering, where students could interact with 3D content using AR-VR techniques [43]. AR has also been used for tourists visiting museums and other historic buildings which provided them artifact visualization [44], [45]. Some researchers have used AR to develop remote access of their physical laboratories through AR-supported visualization [12], [46]–[50].

In higher education field such as engineering, AR experiments have been developed to study land and town planning [51], [52] which has shown promising outcomes mainly indicating better academic performance if design of AR experiments are slightly improved. AR also could also save instructor’s time on repetitive lessons or revisions as students could use AR enabled content for enhance their understanding [14].

From this literature review, it is evident that AR is being trialed all around the world in engineering education. However, there are some unanswered questions: Does AR have full potential to become mainstream technology in engineering education? Can it fully replace traditional classroom environment (instructors and equipment)?

3.4 Artificial Intelligence (AI):

Various AI techniques (Neural network, Fuzzy logic, Decision tree, Genetic algorithm and Hidden Markov Models) for adaptive educational systems within e-learning platforms were surveyed by [53] anditwas reported that these can imitate the process of human reasoning and decision-making.

In [53], a variety of techniques including AI was used to create a road map for adapting engineering education to achieve industry 4.0 visions through cyber-physical systems and Internet of Things. [54]Proposed a framework of a software tool which utilized AI to compare learning models to determine most suitable learning style for students in each environment. In collaborative learning space, peer assessment is widely being utilized and it has improved student learning in various disciplines [55], [56]. [57] Automated the evaluation of peer assessment using AI, in which several metrics were used for measuring the quality of reviews and predicted the usefulness of a review to an author by assigning a score.

AI systems have made in-roads into education by associating intelligence with machines, which can think strategically [58]. From this literature review, it is evident that educational use of AI has made substantial progress in theory and practice of engineering education. There are diverse paths and possibilities of integrating AI to educational processes, especially in online and distance education [59]. [60] Examined artificial intelligence in terms of education and concluded that (1) adaptive learning, personalization and learning styles, (2) expert systems and intelligent tutoring systems, and (3) AI as future components of educational processes.

4 Future Scope and Conclusion

4.1 Conclusion

This conclusion presents some closing thoughts on the review covered in the preceding sections of this paper. The review has summarized the current state of research and implementation of four key technologies, virtual reality, MOOCs, augmented reality and artificial intelligence. While these technologies provide a value and benefit in enhancing education, studies reveal the limitations they face in the educational context. There are also limited number of studies that explore the pedagogical aspects or teacher and student's attitude towards the use of technology for learning enhancement. Beyond evaluating effectiveness of technology in education, studies should be designed to focus on developing appropriate framework, design implementation models and development of sound teaching materials. The uses of robotics, artificial intelligence (AI), additive and cognitive technologies are already being adopted in the workplace fortraining as well as performing daily duties [69]. The demand for skilled workforce and high trained professionals will grow with the adoption of AI solutions. Educators and particularly educational institutions will need to rise to the challenge of bridging the gap between education and professional practice.The current higher education environment cannot remain stagnant amongst the rapidly evolving technological landscape.Thus, whilst considering study limitations and confounding conclusions, the benefits and values of these technologies can still be applied in enhancing the learner experience.

4.2 Future Scope

Rapidly evolving technologies have not only changed the way we live, work, communicate, and connect but is also revolutionizing the education sector. The new era of learning has progressively extended from e-learning to Mobile learning (m-learning) allowing for a vibrant online learning experience [3],[61]. The rise of m-learning has led to another shift from digital simulation to digital augmentation, with mobile computing, IoT, machine learning and wearable computers gaining momentum. Speed of wireless technology is getting faster, cost of computing cheaper and size of Nano technology smaller.

As defined by [63], IoTis a system to integrate all devices into the network, managed via the web and in turn, provide real time information and interaction with its users. It has been widely used in transportation, health, engineering, education,and so on[64],[65].IoT has already opened the door to smart classrooms with devices such as Microsoft Kinect, learning management systems (LMS), Google Glass and Raspberry Pi integrated into project based learning and interactive classrooms, taking learning beyond the walls of classrooms.

[66]Boldly predicts that advancement in technology will allow for seamless integration of electronics into textiles and fabrics allowing for more organic application of wearables.Intelligent devices in the form of wearables with embedded sensors are continuously and in real time providing sensor-collected data to consumers, enabling a new era of smart living.Wearables have been extensively used in health, lifestyle and

fitness but not so frequently in learning contexts [67].There isvaluein thinking about wearables from an integrated system of wearables than any individual piece alone. Working collectively to gather data analyzed through machine learningcan provide validated and personalized solutions.

The fourth industrial revolution or industry 4.0 is also creating new demands for changes in educational systems [71]. The most obvious implication is the nature of work and job market and how educational institutions need to adapt the learning nature to this context to produce successful members of society [70].Thisis an interesting potential where technology could complement learning and assist in the learning process.Electroencephalography(EEG) or eye tracking for attention detection, smart watches for location-based content, virtual and augmented reality for anywhere anytime experiences, arejust some of the technologies waiting to disrupt the future of education.

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