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The Role of Augmented and Virtual Reality in Electrical Engineering: From Education to Industry 5.0.

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ABSTRACT

Augmented Reality (AR) and Virtual Reality (VR) are revolutionizing various industries, and electrical engineering is no exception. This paper explores the transformative potential of AR and VR in this field. By delving into specific applications and highlighting the benefits of AR and VR in electrical engineering education, this paper underscores their pivotal role in shaping the future of the profession. The age of human-machine interaction will be emphasised in the fifth industrial revolution. Workers are free to provide clients with value-added activities based on customisation and the usage of collaborative robots. Several cutting-edge technologies and applications are being developed, which help Industry 5.0 boost production and axiomatically supply goods tailored to individual customers. Augmented Reality (AR) and Virtual Reality (VR) are two of the most significant technological developments in the last ten years. These applications are expanding quickly in many different types of settings. This paper reviews the use of VR and AR in electrical engineering education and discusses the obstacles and constraints of Industry 4.0.

KEYWORDS *: Augmented Reality, Virtual Reality, engineering education, electrical engineering, Industrial revolution.*

INTRODUCTION

Industry 4.0 refers to integrating servers, Artificial Intelligence (AI), cybernetic systems, and the Internet of Things (IoT) at the production flow level in companies and industrial processes. The idea of Industry 4.0 suggests a significant renovation of the whole production chain concerning the present industrial environment. The first part of this entails using digital technology and the Internet in existing industry. As part of the fourth industrial revolution, new digital technologies such as hardware and software are becoming widely integrated with existing ones, industrial process data and its controlling equipment are being gathered on a massive scale, and production flow has been optimised to boost output while lowering pollution. To optimise and maximise the integrity of the factory production flow, the fourth industrial revolution's concept extends beyond manufacturing procedures in the factory. It can be used to offer control over all factory processes via the Internet or AI systems.

The demands of business, technical developments, educational objectives, and wider economic, environmental and social concerns all have an impact on the electrical engineering curriculum in addition to the previously mentioned issues. The curriculum must satisfy the accreditation requirements established by its official professional organisation and address each of these criteria. There are some instances where the existing curriculum falls short of the 4.0 industry criteria. To meet the demands of Industry 4.0, future employment, and ease the industry's existing skills crisis, future graduates need not only interdisciplinary and entrepreneurial abilities but also electrical engineering skills. The electrical engineering curriculum has the potential to promote a multifaceted strategy that incorporates cutting-edge technology,

ethical issues, and sustainable practices by tackling the unique problems and demands presented by Industry 4.0. This calls for in-depth knowledge of the rapidly changing business environment, new market trends, and the moral ramifications of using cutting-edge engineering innovations.

Additionally, to guarantee that graduates have technical proficiency together with analytical thinking, problem-solving, interpersonal, and teamwork abilities, the process of developing a curriculum must consider the changing demands of businesses and employers. Students should be able to implement their understanding skills in real-world situations, get practical experience, and collaborate with industry professionals through the curriculum. The idea of AR appears to be the most pertinent at this point in the development of education. Let's take a closer look at what is meant by "AR". Technologies that allow real-time digital material to be projected into the actual environment are collectively referred to as AR. The capabilities of the programmes and devices are being employed and restrict the potential applications of AR. To present more information and improve the perception of information, hypothetical items are added to the real environment, creating AR. Depending on the user's actual location, the virtual data is fixed accordingly. The foundation for future virtualization of content is laid by its integration into the physical environment. In contrast to AR, VR uses computer technology to simulate an interactive three-dimensional environment where things have a spatial existence. AR/VR technologies are extensively employed in a variety of fields, including industrial, medical, surgical, and the military, for training purposes. VR and AR have been increasingly popular in education in recent years, offering a multitude of ways to take advantage of technology-enhanced learning. (Tan et al, 2022) VR and AR are developing ground-breaking techniques in the rapidly changing technological world that have the potential to completely transform the electrical engineering profession. There are nearly 17 research on VR applications in engineering education conducted between 2015 and 2019 and found that the best four streams were industrial, mechanical, electrical, and civil engineering (Lanzo et al, 2020).

INDUSTRY EVOLUTION IN ELECTRICAL ENGINEERING

The invention of mechanical power using steam, water, and fossil fuels in the 1780s marked the start of the First Industrial Revolution. A second similar revolution took place in the 1870s when mass production and assembly line manufacturers began to embrace electrical energy. Electronics and Information Technology (IT) were used in the 1970s to bring the notion of automation to the industrial industries as part of the Third Industrial Revolution. Cyber-physical systems, also referred to as real-time interfaces between the physical and virtual worlds, are made possible by Industry 4.0 and the fourth revolution through the usage of cloud computing and the IoT (Mourtzis et al, 2018). The first three industrial revolutions occurred over hundreds of years, while the "fourth industrial revolution" was in 2011. The emergence of digitalization is a crucial feature, driven by advancements in technologies such as AI, big data, and IoT (Mourtzis et al, 2020). Industry 5.0, which fully integrates human interaction into corporate processes and intelligent systems, is set to overtake Industry 4.0, which is still at the forefront of technological decentralization and connectivity. When people and machines collaborate, it is anticipated that the cognitive abilities of knowledgeable managers will be combined with the enhanced precision and repeatability of complete automation (European Commission, 2021).

IR 4.0 IMPLICATIONS FOR ELECTRICAL ENGINEERING EDUCATION

Many sectors are predicted to undergo substantial changes because of the Fourth Industrial Revolution (4IR), which may have an impact on the jobs and skill sets needed in the workplace. The education of electrical engineers is one area that is most affected. The 4IR places significant emphasis on technologies like cloud computing, AI, big data, machine learning and edge computing. As a result, it is evident that electrical engineering education must adapt to this new industrial landscape and will equip for this in future (K. Menon and G. Castrillón, 2019) & (Lupanda, 2023).

The Fourth Industrial Revolution has enormous and revolutionary consequences for education, especially in

the discipline of electrical engineering. The planning, development, and management of creative solutions that propel technology advancements become ever more dependent on the expertise of electrical engineering professionals as the globe grows more digitally linked and interconnected. To equip students with the abilities they need to thrive in the rapidly changing industrial world, the field of electrical engineering education needs to modify its curriculum to incorporate these cutting-edge technologies. The following are a few implications:

- Programmes in electrical engineering should be flexible enough to embrace new developments while maintaining an adequate foundation in fundamental concepts (Marwala, 2023).
- Provide students with the necessary abilities to address real-world problems, electrical engineering courses should incorporate disciplines such as AI, machine learning, cybersecurity, and data science (Bainbridge & Roco, 2016).
- Solve complicated challenges, collaborations between electrical engineers and experts from other fields including biology, computer science and materials science will increase
- In the Fourth Industrial Revolution, the capacity for critical thought and creative problem-solving will be more valuable than the recall of information. To build these crucial abilities, electrical engineering education needs to emphasize practical experiences and hands-on projects (Gleason, 2018).
- Electrical engineers will need to learn new things constantly to stay up to date with technology during their careers. Higher education institutions ought to support and enable chances for lifelong learning for industry professionals. (Naudé, 2017).
- The increasing prevalence of technology necessitates careful examination of ethical issues. To address concerns like the security of data, bias in AI, and the societal ramifications of technology advancements, ethics classes must be included in the electrical engineering curriculum.
- Environmental impact and sustainability are also becoming more widely recognised as a result of the Fourth Industrial Revolution. To solve global issues like climate change, electrical engineering programs have to place a strong emphasis on sustainable practices and green technology.

The curriculum and technology integrated teaching methods need to be administered to comply with the requirements of the Industrial revolution. The graduate attributes including lifelong learning, interdisciplinary learning, technology integration in the classroom, and adaptability develops the graduates of electrical engineering programmes ready for the rapidly changing technological innovations landscape.

AR/VR IN ELECTRICAL ENGINEERING EDUCATION

The integration of Augmented and Virtual Reality into electrical engineering curricula marks a pivotal shift from passive learning to active, immersive engagement with complex physical and theoretical systems. AR and VR helps the learners (Dixit et al,2025)::

- Visualization of Complex Concepts
- Hands-On Learning in a Virtual Environment
- Simulating Real-world Scenarios
- Enhancing Collaboration and Remote Learning
- Designing and Testing with Digital Twins

Augmented Reality in Electrical Engineering

Technologies that allow real-time digital material to be projected into the actual environment are collectively referred to as AR. The capabilities of the tools and applications restrict the potential applications of AR. The foundation for future virtualization of content is laid by its integration into the physical environment. The process of incorporating imaginary things into the actual environment to show more data and improve information perception is known as AR. Virtual symbols appearing on a pilot's helmet or the cockpit glass is a well-known application of AR. The pilot can navigate the terrain with the aid of these icons. The pilot's response time will be shortened by using these icons as he won't have to spend as much time looking over the dashboard.

The electricity sector is now using a similar solution. These are the "smart helmets" worn by power line

maintenance crew members. These employees have an application loaded on their tablet computers that provides details on the items they are serving. A label that is physically attached to the actual item is used to choose certain information. Applications that translate words from other languages using AR are a renowned example of their utilization. Smartphones frequently employ these kinds of apps. This program works based on the user pointing the camera of his smartphone at an inscription written in a foreign language. The text on the screen is then translated into the user's selected language. The language barrier is broken between individuals from different countries using AR. To accomplish well-defined educational objectives, the usage of AR in the classroom needs to be carefully controlled. Here, the wow factor turns into a diversion. However, it has been demonstrated that using AR in conjunction with conventional teaching techniques offers benefits over using eLearning and conventional teaching techniques alone (Makarova et al, 2018). This supports the Moscow State University rector's well-known theory that worse educational quality results from granting students total autonomy in selecting their online course materials. AR is currently being used in computer science, physics, chemistry, history, and astronomy classes at educational institutions (Kirgizova et al, 2020). As a result of faculty members lacking the interest to develop relevant information, AR is rarely used in higher education (Vanin et al, 2018), (Nesterov, 2017), (Nesterov, 2017, P.117), (Muzyleva et al, 2019).

Augmented Reality Working Principle

The physical world and the virtual world can be connected through AR. The Google Lens app, which is integrated with Google Photos and Google's Assistant interactive learning environment, is one method to put such a bridge into practice. It assists in scanning everything that is aimed at by the smartphone camera. This leads to the recognition of many things, including plants, animals, buildings, logos, and QR codes; moreover, phrases are spoken and translated. Figure 1 depicts the flow of information in popular AR apps.

The following three characteristics describe AR:

1. AR integrates virtual and real-world data.
2. Real-world interaction is possible with AR.
3. AR can function and be used in three-dimensional spaces.

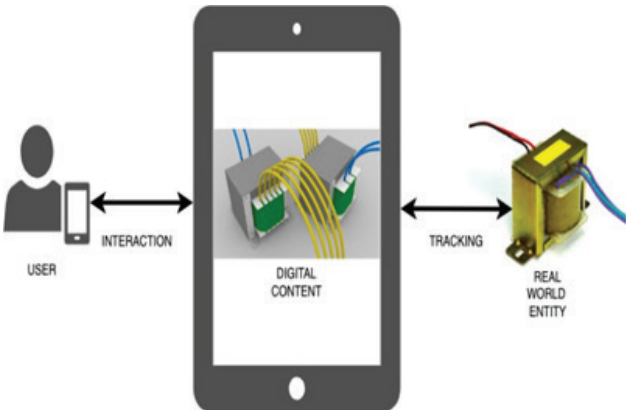


Fig. 1. Information movement in well-known AR applications

AR aims to enable real-time user interaction between the virtual and physical worlds. The virtual environment will seem real to users. AR enables the augmentation of the physical environment with digital material, such as 2D and 3D animation. There are two types of tracking capabilities that a gadget can have marker tracking and markerless tracking. An item or picture is designated as the 3D object's exit location in marker tracking (Aprinaldi et al, 2019) & (Aditya & Trisno, 2018). The terms "trackable" refer to the items or pictures. A predefined shape or several colours can be detected by the system while using markerless tracking. The primary applications in electrical engineering are depicted in Figure 2.

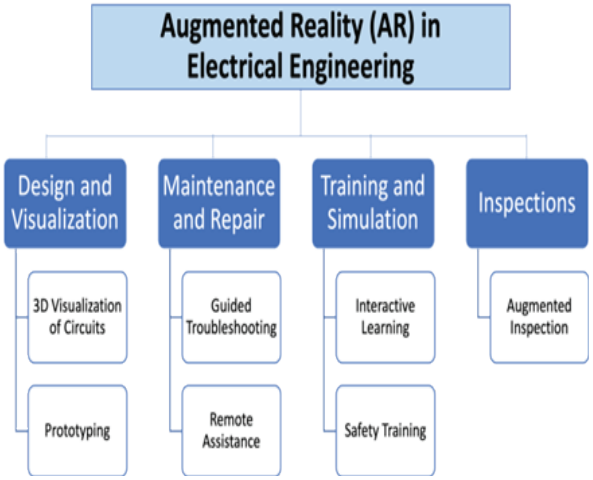


Fig. 2. The AR main applications in Electrical Engineering

Virtual Reality in Electrical Engineering

A computer-generated environment is interactive and often has a dynamically changing scene that allows users to view and move about is called VR. VR allows a user to interact with a constructed world and replicate their actual presence in it. Subsequently, these sectors employ the greatest numbers of people using VR headsets, majority of VR apps and solutions concentrate on the gaming and commercial businesses. However, VR's applications extend beyond games. VR has gained popularity and may now be used in a wide range of fields, including education, psychology, medicine, and in armed forces. It has been discovered that using information and communication technology helps students' attitudes towards studying. VR also has a significant impact on education, offering captivating and exciting methods of learning. Its graphical style, coupled with an exploratory methodology, tangible interactions, and user-friendly interfaces, can aid educators in clarifying complicated concepts.

In power engineering, VR technology is used to educate students on various power principles or to give tours of facilities that are generally inaccessible. The researchers used cloud-based architecture to create a non-immersive VR application that teaches first-year engineering students about solar array installation, photovoltaic cell technology, and solar module technology (Abichandani et al, 2019).

Virtual Reality Working Principle

VR technology is frequently used in industry to teach workers about high-voltage machinery or to train them in a particular environment. A non-immersive application created by the European business E.ON is covered in reference (Kvasznicza et al, 2019). Students studying electrical engineering may learn about high- and medium-voltage substations using this programme. It equips students with the knowledge and abilities needed to operate at E.ON. An industrial VR application for assembling and viewing a control cabinet containing power transformers and their components using multimodal channels was developed in (Shao et al, 2020) These channels provide real-time video contact between the staff and the training teacher, as well as collision detection and object capture functionality. A digital duplicate of a grid control station was created to teach staff members in a variety of scenarios, including transformer failure and back feed in electrical grids (Liegmann et al, 2022). To reduce expenses during the COVID-19 epidemic, a VR tool was created to teach staff members how to construct a transformer and its numerous components in a short time (Jiang et al, 2021). Employees were trained on the 10 kV line breaker technique for relay protection with the use of VR technology (Xu et al, 2019). An immersive VR program for switches, circuit breakers, and transformers was used to instruct electricians in Brazil (Tanaka et al, 2017). The hydropower station was created with immersive VR that allows users to practice emergency procedures, learn station maintenance, and identify defects (Liu, 2021). The number of power line accidents was reduced by teaching medium-tension live-line operators over 40 maintenance techniques using a non-immersive program developed for this purpose (Perez-Ramirez et al, 2021). An instructional instrument to assist electricians to service and maintain electrical systems was created by the authors (Górski et al, 2021). A VR operator training application for a 500kV substation was developed (Liao et al, 2017).

The 3D VR program instructs pupils on the functioning of asynchronous machines (Kvasznicza, 2017). Students may study motors, their components, and one-phase transformers with the aid of the VR laboratory simulator for electric machines known as V-LAB (Hasan et al, 2020). Students can learn about condition-based maintenance of induction motors using an immersive technology created by the authors. (Checa et al, 2021) A VR system with gamification was created to teach motor maintenance personnel for a mining firm in Brazil (Oliveira et al, 2020). Students studying mechatronics engineering were taught the components of an electric motor using immersive VR (Mahdi & Akin, 2021). One desktop VR program that instructs students on how to operate full wave rectifier circuits is called VD-Circuit (Ogbuanya & Onele, 2018). In comparison to conventional classroom teaching and learning, the authors assessed the efficacy of VR technology. The VR primary applications in electrical engineering are depicted in Figure 3.

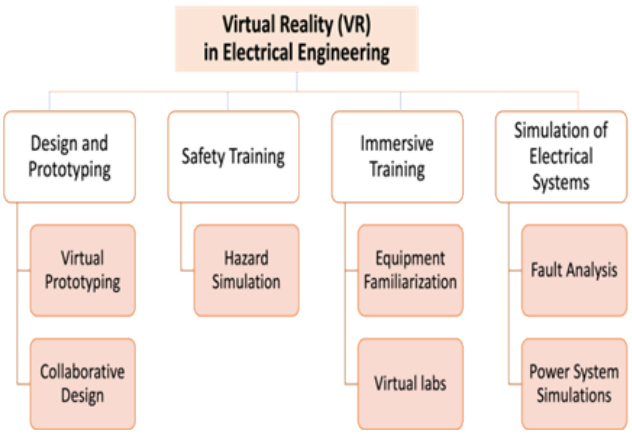


Fig. 3. VR applications in Electrical Engineering

CHALLENGES

Technological issues are the primary difficulty. These include inclement weather conditions with high light levels and smartphone incompatibility (Kaur et al, 2021), (Sendari et al, 2020) & (Sendari et al, 2021). The simultaneous recognition of several markers presented issues for AR applications (Dutta et al, 2022) & (Estrada et al, 2022). The AR application's tracking accuracy for showing the circuit analogies was low and the markers' scanning speed was decreased (Kreienbühl et al, 2020). Students reported that the AR application's reaction time was sluggish (Lucas et al, 2018). The most significant disadvantage of AR is that the programme crashes, which irritates students (Opriş et al, 2019).

The second difficulty is the level of development expertise required to make apps. This task was only referenced in two publications. The authors stated that creating a successful AR application requires prior game design skills (Tuli et al, 2022). A limitation (Martin et al, 2020) was the inability of teachers to create AR apps due to the false detection of markers. This is due to the necessity of having a basic understanding of programming languages. The authors used patterns on the marker to make them stand out from other markers to tackle the false detection problem.

The third difficulty is feeling unpleasant and uncomfortable. This problem is addressed by five VR applications and one AR application. Cognitive overload in the AR environment might result from an abundance of information (Kapp et al, 2021). Almost 45% of participants in the VR environment reported feeling unwell from cyberspace. Few people suffered from cybersickness due to the low refresh rate (measured in frames per second), which made it difficult for participants to navigate the VR environment. (Tanaka et al, 2017) The cyber illness affected 4 of the 30 participants. According to Wu et al, only a small percentage of participants felt that the HMD's weight was difficult on their eyes.

While Augmented Reality (AR) and Virtual Reality (VR) are recognized as transformative tools in pedagogy, significant barriers hinder their widespread adoption. High capital expenditure for hardware remains a primary obstacle for many academic institutions. Furthermore, the steep learning curve associated with complex system designs often results in resistance from both educators and students who lack prior technical literacy in Extended Reality (XR) environments.

Technical reliability also remains a concern; the requirement for constant hardware maintenance and software calibration increases the risk of instructional disruption. From a cognitive perspective, the highly immersive nature of these tools can occasionally become counter-productive, leading to "digital distraction" rather than enhanced retention. Within the framework of Industry 4.0, the rapid evolution of these technologies often outpaces the ability of educational curricula to adapt, necessitating costly industry-academic collaborations. Table 1 summarizes the specific challenges identified in recent literature.

Table 1: Literature on AR and VR Implementation Challenges

Methodology & Author	Key Results/ Contributions	Identified Challenges
HMD Marker T racking (Murauer et al., 2018)	Reduced error rates; scan-glove integration expedites task execution.	Increased cognitive load depending on the scanning system; visual fatigue.
Projection-Based (Doshi et al., 2017)	Reduced spot weld position dispersion (15% –52% improvement).	Precision is highly dependent on the quality of visual cues.

HMD VR (Scavarelli et al., 2021)	Explored social learning theories and advancements in VR/AR social spaces.	Mobility constraints; lack of accessibility for users with visual or motor impairments.
Multi-modal XR (Zwoliński et al., 2022)	Established XR-based learning environments using diverse hardware.	Struggles with maintaining a high "reflection of realism."
CFD & AR/ VR Integration (Solmaz & Van Gerven, 2022)	Proposed component-oriented architecture and data simulation.	Difficulties in remote data synchronization for end-user applications.
Projection-Based (Funk et al., 2017)	Improved learning curves for novices; lower NASA-TLX scores for trainees.	Significant distractions for expert workers; declining reward curves over time.

DISCUSSION ON RESEARCH GAP

To address these gaps, this review focuses specifically on the application of AR and VR within electrical engineering education, lacked a comprehensive synthesis of hardware, software, and pedagogical assessment techniques.

The proposed solution lies in the transition from the rigid automation of Industry 4.0 to the human-centric approach of Industry 5.0. While Industry 4.0 emphasizes IoT and Big Data often resulting in "over-automation" that can alienate the learner, Industry 5.0 seeks to harmonize human intuition with machine precision. By integrating AR/VR tools under the Industry 5.0 paradigm, we shift the focus toward:

- Collaborative Intelligence: Using AR/ VR to facilitate human-robot interaction rather than replacement.
- Sustainability & Resilience: Designing educational tools that are adaptable to social and environmental needs.
- Critical Thinking: Leveraging the immersive nature of AR /VR to foster high-level problem-solving rather than rote procedural tasks.

This approach mitigates the "complexity" gap identified in Industry 4.0 by prioritizing user-centric design and inclusive technological advancement.

CONCLUSION

The role of AR and VR in electrical engineering is transformative, offering educators and students innovative tools to enhance learning, visualization, and practical application of complex concepts. As these technologies continue to advance, their integration into educational curricula will be crucial in preparing the next generation of electrical engineers for a rapidly evolving and technologically driven future. The immersive nature of AR and VR not only enriches the educational experience but also equips students with the skills and insights needed to excel in the dynamic field of electrical engineering. This paper discusses the application of AR and VR in Electrical Engineering and highlights the evident need for training electrical engineering teachers in these technologies, given their potential to transform the educational landscape. Equipping educators with the tools and skills to integrate AR and VR into their teaching methodologies ensures that the next generation of electrical engineers is well-prepared for the challenges of the digital era. Embracing these technologies not only enhances the learning experience but also advances and strengthens the competitiveness of electrical engineering education.

REFERENCES

1. Abichandani, P., Mcintyre, W., Fligor, W., & Lobo, D. (2019). Solar energy education through a cloud-based desktop virtual reality system. IEEE Access, 7, 147081–147093. doi: 10.1109/ACCESS.2019.29457001
2. Aditya, F., & Trisno, B. (2018). Learning Media Based on Augmented Reality Applied on the Lesson of Electrical Network Protection System. IOP Conference Series: Materials Science and Engineering, 384(1), 012075. doi: 10.1088/1757-899X/384/1/0120756
3. Aprinaldi, A., Rahmawati, Y., & Komaro, M. (2019). Implementation of Augmented Reality (AR) android based in learning. Journal of Physics: Conference Series, 1402(7), 077045. doi: 10.1088/1742-6596/1402/7/0770454
4. Bainbridge, W. S., & Roco, M. C. (2016). Science and technology convergence: with emphasis for

nanotechnology-inspired convergence. Journal of Nanoparticle Research, 18(7). https://doi.org/10.1007/s11051-016-3520-0

5. Checa, D., Bustillo, A., Saucedo-Dorantes, J. J., Osornio-Rios, R. A., & Cruz-Albarran, I. A. (2021, October). Virtual reality-based tool applied in the teaching and training of condition-based maintenance in induction motors. In Proceedings of the IEEE 8th International Conference on e-Learning in Industrial Electronics (ICELIE) (pp. 1-6). Toronto, ON, Canada. doi:10.1109/ICELIE53900.2021.9765543

6. Di Lanzo, J. A., Valentine, A., Sohel, F., Yapp, A. Y. T., Muparadzi, K. C., & Abdelmalek, M. (2020). A review of the uses of virtual reality in engineering education. Computer Applications in Engineering Education, 28(3), 748–763. https://doi.org/10.1002/cae.22243

7. Dixit, P., & Waghmode, D. S. (2025). Virtual electrical labs powered by AR. International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, 13(6). https://doi.org/10.17148/IJIREEICE.2025.13630

8. Doshi, A., Smith, R. T., Thomas, B. H., et al. (2017). Use of projector-based augmented reality to improve manual spot-welding precision and accuracy for automotive manufacturing. The International Journal of Advanced Manufacturing Technology, 89, 1279-1293.

9. Dutta, R., Mantri, A., & Singh, G. (2022). Evaluating system usability of mobile augmented reality application for teaching Karnaugh-maps. Smart Learning Environments, 9(1), 6. , doi: 10.1186/s40561-022-00189-8.

10. Estrada, J., Paheding, S., Yang, X., & Niyaz, Q. (2022). Deep-learning incorporated augmented reality application for engineering lab training. Applied Sciences, 12(10), 5159. doi:10.3390/app1210515

11. European Commission, Directorate-General for Research and Innovation, Breque, M., De Nul, L., Petridis, A. (2021). Industry 5.0: towards a sustainable, human-centric and resilient European industry, Publications Office of the European Union. https://data.europa.eu/doi/10.2777/308407

12. Funk, M., Bächler, A., Bächler, L., et al. (2017). Working with augmented reality? A long-term analysis of in-situ instructions at the assembly workplace. In Proceedings of the 10th International Conference on Pervasive Technologies Related to Assistive Environments (pp. 222-229).

13. Gleason N.W (2018) , "Higher Education in the Era of the Fourth Industrial Revolution," High. Educ. Era Fourth Ind. Revolut., pp. 1–229.

14. Górski, F., Grajewski, D., Bun, P., & Zawadzki, P. (2021). Study of interaction methods in virtual electrician training. IEEE Access, 9, 118242-118252. doi:10.1109/ACCESS.2021.3106826

15. Gottfried, M. A., & Plasman, J. S. (2018). Linking the timing of career and technical education coursetaking with high school dropout and college-going behavior. American Educational Research Journal, 55(2), 325–361

16. Hasan, B., Al-Quorashy, Y., Al-Mousa, S., Al-Sahhaf, Y., & El-Abd, M. (2020, April). V-LAB—The virtual electric machines laboratory. In Proceedings of the IEEE Global Engineering Education Conference (EDUCON) (pp. 72-77). Porto, Portugal. doi:10.1109/EDUCON45650.2020.9125349

17. Jiang, Z., Yang, Y., Yuan, Q., Leng, P., Liu, Y., & Pan, Z. (2021). Virtual reality training environment for electric systems. In Proc. IEEE 7th Int. Conf. Virtual Reality (ICVR) (pp. 314–318). Foshan, China. doi: 10.1109/ICVR51878.2021.9483825

18. Kapp, S., Lauer, F., Beil, F., Rheinländer, C. C., Wehn, N., & Kuhn, J. (2021). Smart sensors for augmented electrical experiments. Sensors, 22(1), 256. doi:10.3390/s22010256

19. Kaur, D. P., Mantri, A., & Horan, B. (2021). A framework utilizing augmented reality to enhance the teaching-learning experience of linear control systems. IETE Journal of Research, 67(2), 155-164. doi:10.1080/03772063.2018.1532822

20. Kirgizova, Ye. V., Shakirov, I. Sh., Zakharova, T. V., & Rubtsov, A. V. (2015). "Dopolnennaya Real'nost'": Innovatsionnaya Tekhnologiya Organizatsii Obrazovatel'nogo Protsessa Po Informatike ("Augmented Reality": Innovative Technology Of Organization Of The Educational Process In Informatics). Sovremennyye problemy nauki i obrazovaniya, 2-2. Retrieved from here (accessed: August 9, 2020).

21. Kreienbühl, T., Wetzel, R., Burgess, N., Schmid, A. M., & Brovelli, D. (2020, November). AR circuit constructor: Combining electricity building blocks and augmented reality for analogy-driven learning and experimentation. In Proceedings of the IEEE International Symposium on Mixed and Augmented

Reality Adjunct (ISMAR-Adjunct) (pp. 13-18). Recife, Brazil. doi:10.1109/ISMARAdjunct51615.2020.00019

22. Kvasznicza, Z. (2017, September). Teaching electrical machines in a 3D virtual space. In Proceedings of the 8th IEEE International Conference on Cognitive Infocommunications (CogInfoCom) (pp. 385-388). Debrecen, Hungary. https://doi.org/10.1109/coginfocom.2017.8268276

23. Kvasznicza, Z., Kovács, J., Maza, G., & Péli, M. (2019). VR based dual education at EON the win-win-win situation for companies, graduates and universities. In Proc. 10th IEEE Int. Conf. Cognit. Infocommunications (CogInfoCom) (pp. 479–482). Naples, Italy. doi: 10.1109/CogInfoCom47531.2019.90899612

24. Liao, X., Niu, J., Wang, H., & Du, B. (2017, October). Research on virtual reality simulation training system of the substation. In Proceedings of the International Conference on Virtual Reality and Visualization (ICVRV) (pp. 413-414). Zhengzhou, China. doi:10.1109/ICVRV.2017.00101

25. Liegmann, F., Schorge, L., Kelker, M., & Haubrock, J. (2022). Virtual reality grid control station for learning the operational management of real electrical grids on emergency situation. In Proc. IEEE German Educ. Conf. (GeCon) (pp. 1–6). Berlin, Germany. doi: 10.1109/GeCon55699.2022.99427534

26. Liu, W. (2021, December). Research and application of virtual reality technology in hydropower station production. In Proceedings of the IEEE Conference on Telecommunications, Optics and Computer Science (TOCS) (pp. 110-113). Shenyang, China. doi:10.1109/TOCS53301.2021.9688855

27. Lucas, P., Vaca, D., Domínguez, F., & Ochoa, X. (2018, July). Virtual circuits: An augmented reality circuit simulator for engineering students. In Proceedings of the IEEE 18th International Conference on Advanced Learning Technologies (ICALT) (pp. 380-384). Mumbai, India. doi:10.1109/ICALT.2018.00097

28. Lupanda,(2020) "The Impact of 4IR Technology Advancement on the Engineering Sector,". https://www.polity.org.za/article/the-impact-of-4ir-technology advancement-on-the-engineering-sector-2018-11-

29. Mahdi, S., & Akin, E. (2021). Virtual reality as a tool for electrical machines assembling and testing. International Journal of Science and Business, 5(6), 59-66. doi:10.5281/zenodo.4709807

30. Makarova, I., Shubenkova, K., & Pashkevich, A. (2018). Blended learning technologies in the automotive industry specialists' training. Proceedings - 32nd IEEE International Conference on Advanced Information Networking and Applications Workshops (WAINA 2018), 2018-January, 319–3241

31. Martin, S., Parra, G., Cubillo, J., Quintana, B., Gil, R., Perez, C., & Castro, M. (2020, July). Design of an augmented reality system for immersive learning of digital electronic. In Proceedings of the 14th Technology Applied to Electronics Teaching Conference (TAEE) (pp. 1-6). Porto, Portugal. doi:10.1109/TAEE46915.2020.9163704

32. Marwala T, (2020) "Education in the fourth industrial revolution - University of Johannesburg,". https://www.uj.ac.za/news/education-in-the-fourth industrial-revolution/

33. Menon, K., & Castrillón, G. (2019). Reimagining curricula for the fourth industrial revolution. The Independent Journal of Teaching and Learning, 14(2), 6-19.

34. Mourtzis D., (2020), Simulation in the Design and Operation of Manufacturing Systems: State of the Art and New Trends, International Journal of Production Research, 58/7, 1927–1949, DOI: https://doi.org/10.1080/- 00207543.2019.1636321

35. Murauer, N., Pflanz, N., & von Hassel, C. (2018). Comparison of scan-mechanisms in augmented reality-supported order picking processes. CEUR Workshop Proceedings, 2082, 69-76.

36. Muzyleva, I., Yazykova, L., & Penkov, V. (2019). Digitalization of the University - What is It? In 1st International Conference on Control Systems, Mathematical Modelling, Automation and Energy Efficiency (SUMMA) (pp. 335–337). Lipetsk, Russia. DOI:10.1109/SUMMA48161.2019.89475113

37. Naudé W. (2017), "Entrepreneurship, Education and the Fourth Industrial Revolution in Africa," IZA Discuss. Pap. No. 10855, no. 10855, pp. 1–25,

38. Nesterov, A. S., Kholodilin, I. Yu., Shishkov, A., & Vanin, P. (2017). Augmented reality in engineering education: Opportunities and advantages. Communications - Scientific Letters of the University of Zilina, 19(4), 117–1202

39. Oliveira, T. R. d., Martinelli, T. F., Bello, B. P., Batista, J. D., Silva, M. M. d., Rodrigues, B. B., Spinassé, R. A. N., Andreão, R. V., Mestria, M., & Schmidt, M. Q. (2020, November). Virtual reality system for industrial

motor maintenance training. In Proceedings of the 22nd Symposium on Virtual and Augmented Reality (SVR) (pp. 119-128). Porto de Galinhas, Brazil. doi:10.1109/SVR51698.2020.00031

40. Ogbuanya, T. C., & Onele, N. O. (2018). Investigating the effectiveness of desktop virtual reality for teaching and learning of electrical/electronics technology in universities. Computers in the Schools, 35(3), 226-248. doi:10.1080/07380569.2018.1492283

41. Orang, S. (2016). Aplikasi Augmented Reality Sebagai Media Simulasi Ikatan Kimia Berbasis Android Menggunakan Metode FAST CORNER DETECTION SKRIPSI Oleh: Mohammad Syahrofi Irsyad. Retrieved from here.

42. Opriş, I., Costinaş, S., Ionescu, C. S., & Nistoran, D. E. G. (2019, March). Experiencing augmented reality in power engineering education. In Proceedings of the 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE) (pp. 1-6). Bucharest, Romania. doi:10.1109/ATEE.2019.8724992

43. Perez-Ramirez, M., Arroyo-Figueroa, G., & Ayala, A. (2021). The use of a virtual reality training system to improve technical skill in the maintenance of live-line power distribution networks. Interactive Learning Environments, 29(4), 527-544. doi:10.1080/10494820.2019.1587636

44. Scavarelli, A., Arya, A., & Teather, R. J. (2021). Virtual reality and augmented reality in social learning spaces: A literature review. Virtual Reality, 25(1), 257-277.

45. Sendari, S., Anggreani, D., Jiono, M., Nurhandayani, A., & Suardi, C. (2020, September). Augmented reality performance in detecting hardware components using marker-based tracking method. In Proceedings of the 4th International Conference on Vocational Education and Training (ICOVET) (pp. 1-5). Malang, Indonesia. doi:10.1109/ICOVET50258.2020.9229895

46. Sendari, S., Wibawanto, S., Jasmine, J., Jiono, M., Puspitasari, P., Diantoro, M., & Nur, H. (2021, October). Integrating robo-PEM with AR application for introducing fuel cell implementation. In Proceedings of the 7th International Conference on Electrical, Electronics, and Information Engineering (ICEEIE) (pp. 145-150). Malang, Indonesia. doi:10.1109/ICEEIE52663.2021.9616683

47. Shao, X., Feng, X., Yu, Y., Wu, Z., & Mei, P. (2020). A natural interaction method of multi-sensory channels for virtual assembly system of power transformer control cabinet. IEEE Access, 8, 54699–54709. doi:10.1109/access.2020.29815393

48. Solmaz, S., & Van Gerven, T. (2022). Automated integration of extract-based CFD results with AR/VR in engineering education for practitioners. Multimedia Tools and Applications, 81(11), 14869-14891./

49. Tan, Y., Xu, W., Li, S., & Chen, K. (2022). Augmented and virtual reality (AR/VR) for education and training in the AEC industry: A systematic review of research and applications. Buildings, 12(10), 1529.

50. Tanaka, E. H., Paludo, J. A., Bacchetti, R., Gadbem, E. V., Domingues, L. R., Cordeiro, C. S., Giraldi, O., Gallo, G. A., da Silva, A. M., & Cascone, M. H. (2017, March). Immersive virtual training for substation electricians. In Proceedings of the IEEE Virtual Reality (VR) (pp. 451-452). Los Angeles, CA, USA. doi:10.1109/VR.2017.7892374

51. Tuli, N., Singh, G., Mantri, A., & Sharma, S. (2022). Augmented reality learning environment to aid engineering students in performing practical laboratory experiments in electronics engineering. Smart Learning Environments, 9(1), 26. doi:10.1186/s40561-022-00207-9

52. Vanin, P., Nesterov, A. S., & Kholodilin, I. (2018). Integration of IIoT and AR Technologies to Educational Process Through Laboratory Complex. Proceedings – 2018 Global Smart Industry Conference, GloSIC 2018

53. Ward S. (2017.), "The Impact of Shared Leadership on a Career and Technical Education Campus," vol. 13, no. 1

54. Wu, B., Hu, Y., & Wang, M. (2020). How do head-mounted displays and planning strategy influence problem-solving-based learning in introductory electrical circuit design? Educational Technology & Society, 23(3), 40-52. Retrieved from https://www.jstor.org/stable/26926425

55. Xu, X.,Shen, L., Li, S., & Wang, S. (2019, August). Research on 10 kV line breaker check training system based on virtual reality. In Proceedings of the International Conference on Smart Grid and Electrical Automation (ICSGEA) (pp. 18-21). Xiangtan, China. doi:10.1109/ICSGEA.2019.00013.