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Simulation-Based STEM Learning for Vocational High School Students on Wave Rectifiers

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Abstract

The STEM (Science, Technology, Engineering, and Mathematics) approach significantly enhances practice-based learning in vocational high schools. This study aims to analyze the working principles, performance, and average voltage of three types of rectifiers: half-wave, full-wave center-tapped, and full-wave bridge rectifiers using NI Multisim 13.0 simulation software. Through the STEM approach, students can visualize the working principles of rectifiers, analyze simulation results, and understand the performance differences between each type. The simulation results show that full-wave rectifiers produce more stable DC voltages compared to half-wave rectifiers. This study also provides graphical representations of the input and output waveforms for each type of rectifier, supporting the enhancement of students' critical thinking and technological literacy skills. These findings are expected to serve as relevant teaching materials for STEM-based learning in Vocational High School, particularly in the topic of rectifiers.

Keywords: electronics simulation, STEM approach, vocational education

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INTRODUCTION

The development of the world marked by the emergence of an era known as the industrial era 4.0 has various impacts on human life (Mourtzis et al., 2022). Globalization and internationalization of the economy and science, for example, require those in the world of education (higher education) to take it seriously (Tran et al., 2023). In the context of vocational education, especially in Vocational High Schools, STEM-based learning (Science, Technology, Engineering, and Mathematics) is a relevant approach to support the strengthening of teachers' literacy and numeracy skills (Huang et al., 2022; Mäkelä et al., 2022). The term STEM was coined by the National Science Foundation (NSF) of the United States in the 1990s, representing "Science, Technology, Engineering, & Mathematics" (Beals, 2021). The STEM approach can provide a practical foundation in understanding scientific concepts that are relevant to industrial needs, one of which is wave rectifier material which consists of a rectifier circuit (Hamad et al., 2022). A rectifier circuit is an attempt to change the direction of an AC circuit that moves back and forth, into a DC circuit that moves in one direction by providing obstacles that specifically block the current and voltage from one direction only (Miao et al., 2019). Wave rectifiers, as important elements in power electronics systems, have a wide range of applications in the technology and industrial sectors, especially in converting AC electric current into DC to support the needs of electronic devices (Kotb et al., 2023; Yu et al., 2023).

Wave rectifiers are divided into two, namely half-wave rectifier and full-wave rectifier (Li et al., 2020). The half-wave rectifier circuit is a circuit that has simple components because it only has one diode (Golod & Krasnov, 2022). Meanwhile, the full-wave rectifier utilizes both sides of the AC wave to produce a more stable direct current. There are two main types of full-wave rectifier configurations, namely the center-tapped transformer type and the bridge type (bridge rectifier). In the center-tapped type, a center-tapped transformer is used along with two diodes to process each half-wave cycle. Meanwhile, the bridge type uses four diodes arranged in a bridge shape without the need for a center tap.

In the pedagogical context, there is a gap between the theory taught in class and students' ability to understand and apply the concepts in a practical context (Furman Shaharabani & Yarden, 2019). For example, students often struggle to identify the performance and efficiency differences between half-wave rectifiers and full-wave rectifiers (Nawaz et al., 2020). In addition, the lack of simulation and experimentation facilities in some vocational schools results in learning focusing more on memorization rather than deep understanding (Lytvyn et al., 2019). Pedagogical competence is key to the success of a teacher which involves the ability to plan and implement effective learning, understand various teaching models and methods, and be able to adjust learning strategies according to student needs (Fakhrutdinova et al., 2020; König et al., 2021). Until now, no articles have been found that discuss the analysis of wave rectifier circuits by utilizing NI Multisim 13.0 software, which has the potential to become STEM-based learning material for vocational students..

A STEM approach can be a solution to bridge this gap. By integrating technology-based simulations and experiments, students can more easily visualize the working principles of wave rectifiers, analyze performance differences, and relate them to industry needs (Hirakawa & Shinohara, 2021; Magrabi, 2022). In addition, this approach encourages critical thinking and collaboration skills, which are important aspects in 21st century learning. This research aims to analyze the working principle, performance differences, and efficiency of the three types of wave rectifiers based on simulation testing. In addition, this research will also provide an overview of the input and output waveforms for each type of rectifier. These findings are expected to be relevant teaching materials to support STEM learning in vocational schools, especially in improving students' conceptual understanding of wave rectifier material.

METHOD

This research uses the STEM (Science, Technology, Engineering, and Mathematics) approach as the main framework in analyzing the simulation results of wave rectifiers using NI Multisim 13.0 software. The STEM approach is applied to evaluate the performance of the rectifier through the following stages.

The first thing that needs to be done is to study the basic theory of wave rectifiers, including the working principle of diodes and the conversion of AC current to DC. In its application, the diode works like a blockade on a highway that makes current and voltage only flow in one direction and cannot move in the opposite direction, but if the pressure of current and voltage is too high and exceeds the capacity of the diode, the diode will be damaged and the rectifier function will be lost (Agna et al., 2023). This stage is a theoretical basis for understanding the simulation results.

The next stage is to design a series of wave rectifiers which are divided into three types, namely half-wave rectifiers, center-tapped full-wave rectifiers, and four-bridge full-wave rectifiers. The design is done by utilizing simulation software, namely NI Multism 13.0. The circuit designed in NI Multism 13.0 will produce a visualization of the input and output waveforms to facilitate analysis and understanding of the wave rectifier concept. The following is a picture of three kinds of wave rectifier circuits in NI Multism 13.0 software.

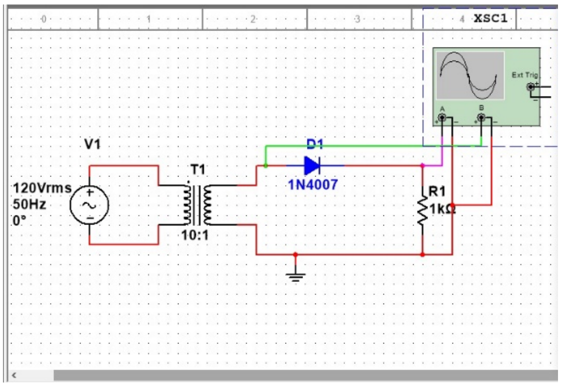


Figure 1. Half-wave circuit

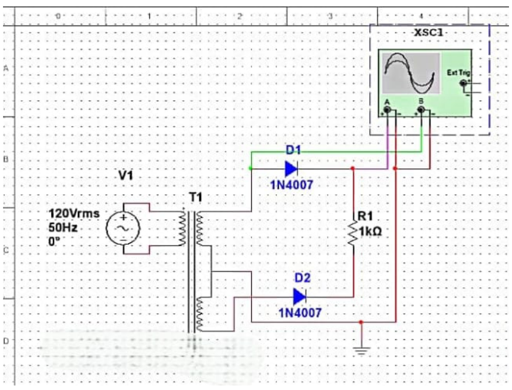


Figure 2. Center-Tapped Full Wave Circuit

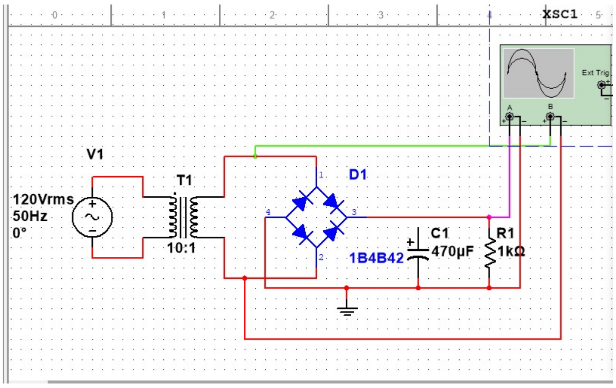


Figure 3. 4-Bridge Full-Wave Circuit

The last stage, which is to analyze the circuit that has been made then perform mathematical calculations to determine the average voltage of the wave rectifier circuit. The following is the average voltage equation of the half-wave rectifier circuit.

$$V_{avg} = \frac{V_m}{\pi} \tag{1}$$

With $V_m = \sqrt{2} \times V_{rms} = \sqrt{2} \times 120 = 169{,}706\,V$, then $V_{avg} = \frac{169{,}706}{3{,}14} = 54{,}0465\,V$. Pada The full wave rectifier circuit uses a different equation, namely:

$$V_{avg} = \frac{2V_m}{\pi} \tag{2}$$

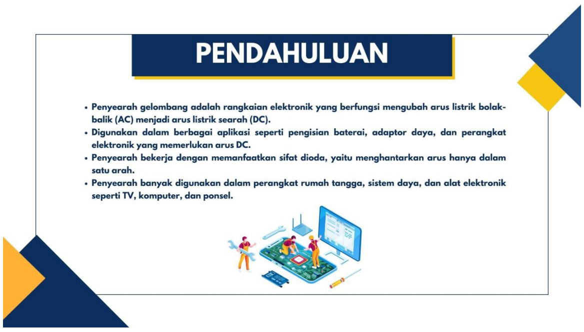
Therefore, $V_{avg} = \frac{2\,(169{,}706)}{3{,}14} = 108{,}09299\,V$. For a full-wave rectifier circuit with a capacitor filter, the following equation can be used.

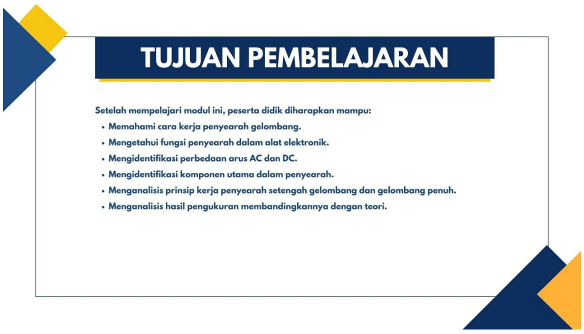
$$V_{avg} \approx V_m - \Delta V \tag{3}$$

RESULTS AND DISCUSSION

This research produces teaching materials in the form of a learning PowerPoint with a STEM (Science, Technology, Engineering, and Mathematics) approach to help students understand basic operational amplifier circuit material. This PowerPoint is designed using Canva, so that it can be accessed via the web or application, and once downloaded, it can be used offline on various devices such as PCs, computers, smartphones, or tablets. With easy access and features that support learning, this teaching material is designed to provide an interactive and effective learning experience for students. This teaching material is specifically made to support the process of material exposure in the classroom by presenting various main components as follows.

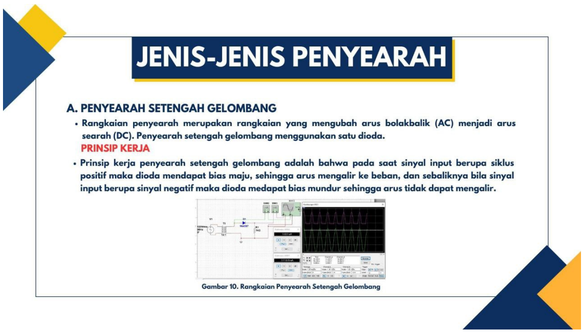

RANGKAIAN PENYEARAH GELOMBANG
Disusun Oleh: Kelompok 5

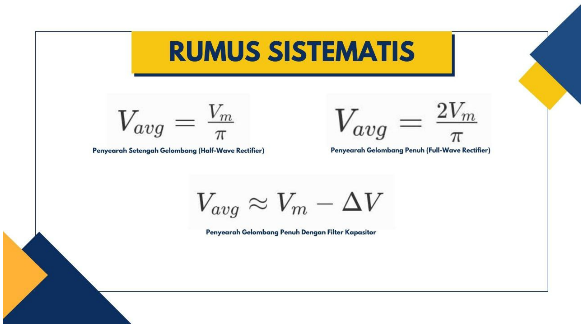

PENDAHULUAN
• Penyearah gelombang adalah rangkaian elektronik yang berfungsi mengubah arus listrik bolak-balik (AC) menjadi arus listrik searah (DC).
• Digunakan dalam berbagai aplikasi seperti pengisian baterai, adaptor daya, dan perangkat elektronik yang memerlukan arus DC.
• Penyearah bekerja dengan memanfaatkan sifat dioda, yaitu menghantarkan arus hanya dalam satu arah.
• Penyearah banyak digunakan dalam perangkat rumah tangga, sistem daya, dan alat elektronik seperti TV, komputer, dan ponsel.

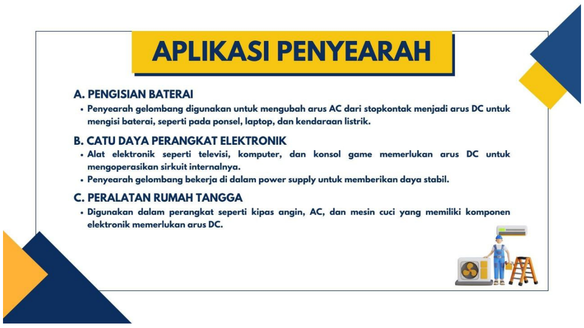

TUJUAN PEMBELAJARAN
Setelah mempelajari modul ini, peserta didik diharapkan mampu:
• Memahami cara kerja penyearah gelombang.
• Mengetahui fungsi penyearah dalam alat elektronik.
• Mengidentifikasi perbedaan arus AC dan DC.
• Mengidentifikasi komponen utama dalam penyearah.
• Menganalisis prinsip kerja penyearah setengah gelombang dan gelombang penuh.
• Menganalisis hasil pengukuran membandingkannya dengan teori.

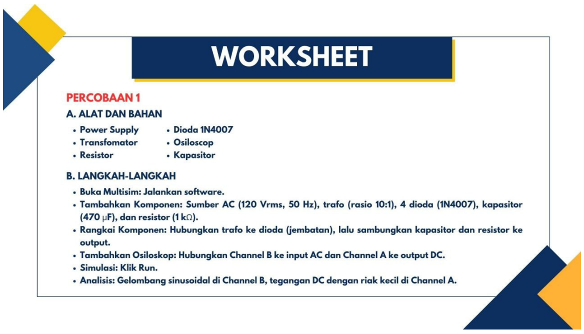

KONSEP DASAR
• Sebagian besar perangkat elektronik membutuhkan arus searah (DC) untuk dapat beroperasi.
• Penyearah digunakan dalam adaptor daya yang berfungsi mengubah arus listrik dari stop kontak menjadi DC untuk perangkat elektronik. Kemudian pengisian baterai untuk mengisi ulang baterai ponsel, laptop, dan kendaraan listrik. Dan catu daya komputer untuk memberikan arus DC yang stabil untuk komponen internal.
• Tanpa penyearah, perangkat elektronik tidak dapat bekerja dengan baik.
V = A.C
D1
D2
D3
D4
R
V = D.C
Volt
Input Voltage
Time
Output Voltage
Gambar 2. Sirkuit penyearah gelombang penuh


KOMPONEN UTAMA
A. DIODA
• Dioda adalah komponen elektronik yang hanya menghantarkan arus listrik dalam satu arah.
• Rangkaian penyearah menggunakan dioda sebagai komponen utama.
• Prinsip kerja dioda adalah forward bias (mengantarkan arus) dan reverse bias (menahan arus).
• Dioda mengubah arus bolak-balik (AC) menjadi arus searah (DC) dengan memblokir arus pada setengah siklus tertentu.
P
N
I
VS
Forward bias
Reverse bias
Gambar 3. Bias Maju dan Mundur Pada Dioda
Gambar 4. Dioda


JENIS-JENIS PENYEARAH
A. PENYEARAH SETENGAH GELOMBANG
• Rangkaian penyearah merupakan rangkaian yang mengubah arus bolakbalik (AC) menjadi arus searah (DC). Penyearah setengah gelombang menggunakan satu dioda.
PRINSIP KERJA
• Prinsip kerja penyearah setengah gelombang adalah bahwa pada saat sinyal input berupa siklus positif maka dioda mendapat bias maju, sehingga arus mengalir ke beban, dan sebaliknya bila sinyal input berupa sinyal negatif maka dioda medapat bias mundur sehingga arus tidak dapat mengalir.
Gambar 10. Rangkaian Penyearah Setengah Gelombang


RUMUS SISTEMATIS
$V_{avg} = \frac{V_m}{\pi}$
Penyearah Setengah Gelombang (Half-Wave Rectifier)
$V_{avg} = \frac{2V_m}{\pi}$
Penyearah Gelombang Penuh (Full-Wave Rectifier)
$V_{avg} \approx V_m - \Delta V$
Penyearah Gelombang Penuh Dengan Filter Kapasitor


APLIKASI PENYEARAH
A. PENGISIAN BATERAI
• Penyearah gelombang digunakan untuk mengubah arus AC dari stopkontak menjadi arus DC untuk mengisi baterai, seperti pada ponsel, laptop, dan kendaraan listrik.
B. CATU DAYA PERANGKAT ELEKTRONIK
• Alat elektronik seperti televisi, komputer, dan konsol game memerlukan arus DC untuk mengoperasikan sirkuit internalnya.
• Penyearah gelombang bekerja di dalam power supply untuk memberikan daya stabil.
C. PERALATAN RUMAH TANGGA
• Digunakan dalam perangkat seperti kipas angin, AC, dan mesin cuci yang memiliki komponen elektronik memerlukan arus DC.



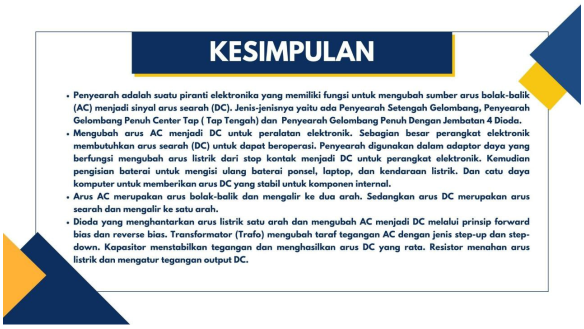


Figure 4. Learning Media with PowerPoint

Table 1. STEM Implementation on Wave Rectifier Material

Science	Explain the basic concepts of wave rectifiers
Technology	Apply to Software with NI Multism 13.0
Engineering	Discuss circuit design and performance
Mathematics	Calculating the average voltage

This development of this teaching material paved the way for the interactive PowerPoint presentation based on the STEM (Science, Technology, Engineering, and Mathematics) approach. This learning material aims to assist vocational high school students in comprehending the fundamental concepts of wave rectifiers. The content is designed to facilitate step-by-step learning, starting from the fundamentals of rectifier theory to its application. Through the inclusion of the STEM approach, the content ensures a comprehensive learning experience that connects theoretical knowledge and practical applications. The teaching content covers three major types of rectifiers: half-wave rectifiers, center-tapped full-wave rectifiers, and bridge full-wave rectifiers. Each type is covered in line with its circuit arrangement, working principles, and output characteristics. Furthermore, the material presents a complete explanation of diode operation, illustrating how diodes regulate current flow in all rectifier types. To further supplement student understanding, an efficiency analysis is included to compare the performance of each rectifier circuit in terms of voltage stability and power conversion.

Under the STEM approach, science forms the basis of rectifier theory, explaining their operation in electrical circuits. The technology aspect is enhanced through the running of NI Multisim 13.0 simulations, allowing students to graphically display waveforms and examine circuit behavior dynamically. Engineering is introduced through circuit design and performance analysis, forcing students to critically compare the advantages and disadvantages of each rectifier type. Mathematics is also essential in the calculation of average output voltage and efficiency, affirming students' problem-solving capabilities in the analysis of circuit performance. This cross-disciplinary process not only strengthens students' conceptual understanding but also their problem-solving and critical thinking abilities. By simulation learning, students get to experience first-hand circuit behavior analysis in real-time, and this develops a deeper appreciation of rectifiers' operation in electronic systems. The following section addresses the key elements incorporated in the PowerPoint teaching material, ensuring that vocational high school students are exposed to a balanced and interesting learning experience in wave rectifiers.

The results obtained from the making of this teaching material are in the form of PowerPoint whose learning uses the STEM (Science, Technology, Engineering, and Mathematics) approach to help students understand the concept of wave rectifiers. The material presented includes types of rectifiers, namely half-wave rectifiers, center-tapped full-wave rectifiers, and four-bridge full-wave rectifiers. Equipped with diode working principles and efficiency analysis of each circuit. In the STEM component, science explains the theoretical basis of rectifiers, technology is realized through interactive PowerPoint media and NI Multism 13.0 simulations, engineering discusses circuit design and performance, while mathematics is used to calculate the average voltage. This approach not only strengthens student understanding, but also trains critical thinking and problem-solving skills. The following are the components contained in the PowerPoint of Wave Rectifier Teaching Materials for Vocational Schools using the STEM approach.

CONCLUSION

Learning with this STEM learning approach is very effective for discussing the concept of wave rectifier circuits for learning materials in vocational schools. Students can learn the design and analysis of half-wave rectifier circuits, center-tapped full-wave rectifiers, and 4-bridge full-wave rectifiers through simulations on NI Multism 13.0 software. In addition to strengthening students' theoretical understanding of the basic concepts of wave rectifiers, this STEM approach learning method can also hone practical skills, such as designing circuits, analyzing, and calculating average voltage.

The development of STEM-based teaching materials in the form of PowerPoint presentations supports the learning process by presenting theory, application, and worksheets to measure students' level of understanding. Through the integration of science, technology, engineering, and mathematics elements, the STEM approach is able to improve students' analytical skills, creativity, and innovation, making them better prepared to face the demands of the industrial revolution 4.0 era.

REFERENCES

Beals, R. A. (2021). Transformative Education in Science, Technology, Engineering, and Mathematics: Empowering the Next Generation of Scientists. *Journal of Hispanic Higher Education*, *21*(4), 385–401. https://doi.org/10.1177/1538192719877414

Fakhrutdinova, A. V., Ziganshina, M. R., Mendelson, V. A., & Chumarova, L. G. (2020). Pedagogical Competence of the High School Teacher. *International Journal of Higher Education*, *9*(8), 84. https://doi.org/10.5430/ijhe.v9n8p84

Furman Shaharabani, Y., & Yarden, A. (2019). Toward narrowing the theory–practice gap: characterizing evidence from in-service biology teachers' questions asked during an academic course. *International Journal of STEM Education*, *6*(1). https://doi.org/10.1186/s40594-019-0174-3

Golod, T., & Krasnov, V. M. (2022). Demonstration of a superconducting diode-with-memory, operational at zero magnetic field with switchable nonreciprocity. *Nature Communications*, *13*(1). https://doi.org/10.1038/s41467-022-31256-w

Hamad, S., Tairab, H., Wardat, Y., Rabbani, L., AlArabi, K., Yousif, M., Abu-Al-Aish, A., & Stoica, G. (2022). Understanding Science Teachers' Implementations of Integrated STEM: Teacher Perceptions and Practice. *Sustainability*, *14*(6), 3594. https://doi.org/10.3390/su14063594

Hirakawa, T., & Shinohara, N. (2021). Theoretical Analysis and Novel Simulation for Single Shunt Rectifiers. *IEEE Access*, *9*, 16615–16622. https://doi.org/10.1109/access.2021.3053251

Huang, B., Siu-Yung Jong, M., Tu, Y.-F., Hwang, G.-J., Chai, C. S., & Yi-Chao Jiang, M. (2022). Trends and exemplary practices of STEM teacher professional development programs in K-12 contexts: A systematic review of empirical studies. *Computers & Education*, *189*, 104577. https://doi.org/10.1016/j.compedu.2022.104577

König, J., Blömeke, S., Jentsch, A., Schlesinger, L., née Nehls, C. F., Musekamp, F., & Kaiser, G. (2021). The links between pedagogical competence, instructional quality, and mathematics achievement in the lower secondary classroom. *Educational Studies in Mathematics*, *107*(1), 189–212. https://doi.org/10.1007/s10649-020-10021-0

Kotb, R., Chakraborty, S., Tran, D.-D., Abramushkina, E., El Baghdadi, M., & Hegazy, O. (2023). Power Electronics Converters for Electric Vehicle Auxiliaries: State of the Art and Future Trends. *Energies*, *16*(4), 1753. https://doi.org/10.3390/en16041753

Li, T., Bandari, V. K., Hantusch, M., Xin, J., Kuhrt, R., Ravishankar, R., Xu, L., Zhang, J., Knupfer, M., Zhu, F., Yan, D., & Schmidt, O. G. (2020). Integrated molecular diode as 10 MHz half-wave rectifier based on an organic nanostructure heterojunction. *Nature Communications*, *11*(1). https://doi.org/10.1038/s41467-020-17352-9

Lytvyn, A., Lytvyn, V., Rudenko, L., Pelekh, Y., Didenko, O., Muszkieta, R., & Żukow, W. (2019). Informatization of technical vocational schools: Theoretical foundations and practical approaches. *Education and Information Technologies*, *25*(1), 583–609. https://doi.org/10.1007/s10639-019-09966-4

Magrabi, S. A. R. (2022). Technology Enabled Active Learning in Electrical Engineering. *IntechOpen EBooks*. https://doi.org/10.5772/intechopen.95930

Mäkelä, T., Fenyvesi, K., Kankaanranta, M., Pnevmatikos, D., & Christodoulou, P. (2022). Co-designing a pedagogical framework and principles for a hybrid STEM learning environment design. *Educational Technology Research and Development*, *70*(4), 1329–1357. https://doi.org/10.1007/s11423-022-10114-y

Miao, T., Yu, D., Xing, L., Li, D., Jiao, L., Ma, W., & Zhang, X. (2019). Current Rectification in a Structure: ReSe2/Au Contacts on Both Sides of ReSe2. *Nanoscale Research Letters*, *14*(1). https://doi.org/10.1186/s11671-018-2843-4

Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, *15*(17), 6276.

Nawaz, S., Kennedy, G., Bailey, J., & Mead, C. (2020). Moments of Confusion in Simulation-Based Learning Environments. *Journal of Learning Analytics*, *7*(3), 118–137. https://doi.org/10.18608/jla.2020.73.9

Tran, L. T., Jung, J., Unangst, L., & Marshall, S. (2023). New developments in internationalisation of higher education. *Higher Education Research & Development*, *42*(5), 1033–1041. https://doi.org/10.1080/07294360.2023.2216062

Yu, W., Ma, R., Xu, D., Huang, L., & Wang, S. (2023). A Novel Multiport Hybrid Wave Energy System for Grid-Connected and Off-Grid Applications. *Sustainability*, *15*(3), 2175–2175. https://doi.org/10.3390/su15032175