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# **Transformasi Pendidikan IPA Berbasis Keberlanjutan**



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## **PRAKATA**

Puji syukur kami panjatkan ke hadirat Tuhan Yang Maha Esa, karena atas rahmat dan karunia-Nya, buku Transformasi Pendidikan IPA Berbasis Keberlanjutan ini dapat diselesaikan dan hadir sebagai bagian dari ikhtiar akademik untuk merespons tantangan pendidikan masa kini dan masa depan.

Buku ini lahir dari kesadaran bahwa pendidikan IPA tidak lagi cukup diposisikan hanya sebagai sarana penguasaan konsep, prinsip, dan keterampilan ilmiah semata. Di tengah semakin kompleksnya persoalan global, seperti perubahan iklim, krisis energi, degradasi lingkungan, ketimpangan sosial, serta disrupsi teknologi, pendidikan IPA dituntut untuk mengambil peran yang lebih strategis. Pendidikan IPA perlu bergerak menuju paradigma yang lebih transformatif, yaitu pendidikan yang tidak hanya membangun pemahaman ilmiah, tetapi juga menumbuhkan cara berpikir sistemik, kesadaran keberlanjutan, kemampuan berkolaborasi, literasi masa depan, dan kapasitas bertindak secara bertanggung jawab dalam menghadapi berbagai persoalan nyata.

Dalam konteks tersebut, buku ini disusun untuk menghadirkan gagasan, refleksi, dan inovasi pembelajaran yang berangkat dari semangat Education for Sustainable Development (ESD) sebagai fondasi penting dalam transformasi pendidikan IPA. Buku ini merupakan hasil pengembangan pemikiran akademik sekaligus translasi ilmiah dari pengalaman riset dan refleksi para penulis dalam bidang Pendidikan IPA, yang kemudian dirumuskan kembali

dalam format yang lebih komunikatif, aplikatif, dan relevan bagi pengembangan pembelajaran di sekolah maupun perguruan tinggi.

Secara substantif, buku ini terdiri atas lima bab utama yang saling terkait dan membentuk satu kesatuan narasi tentang transformasi pendidikan IPA berbasis keberlanjutan. Bab I berfungsi sebagai pendahuluan yang memaparkan landasan pemikiran mengenai urgensi transformasi pendidikan IPA di tengah tantangan global abad ke-21. Bab II membahas pembelajaran berorientasi masa depan dalam konteks perubahan iklim sebagai salah satu arah penting penguatan literasi keberlanjutan dalam pendidikan IPA. Bab III menyoroti program pelatihan ESD untuk penguatan kompetensi guru IPA sebagai aktor kunci dalam mengimplementasikan pembelajaran yang transformatif. Bab IV menyajikan pembelajaran STEM-LCE sebagai pendekatan integratif untuk mengembangkan kompetensi abad ke-21, khususnya 4C, sekaligus memperkuat kesadaran keberlanjutan peserta didik. Selanjutnya, Bab V mengangkat pemanfaatan media pembelajaran berbasis Internet of Things (IoT) sebagai bentuk inovasi pedagogis yang mendukung pendidikan berkelanjutan di era digital.

Dengan susunan tersebut, buku ini tidak dimaksudkan sebagai kumpulan tulisan yang berdiri sendiri, melainkan sebagai sebuah karya tematik yang menegaskan bahwa transformasi pendidikan IPA berbasis keberlanjutan memerlukan sinergi antara paradigma, kompetensi guru, model pembelajaran, dan inovasi teknologi pendidikan. Kami berharap setiap bab dalam buku ini dapat memberikan kontribusi konseptual sekaligus inspirasi praktis bagi

dosen, mahasiswa, guru IPA, peneliti, pengembang kurikulum, serta para pemangku kepentingan pendidikan yang memiliki perhatian terhadap masa depan pendidikan sains yang lebih relevan, kontekstual, dan berorientasi keberlanjutan.

Kami meyakini bahwa transformasi pendidikan tidak pernah berlangsung secara parsial. Ia menuntut keterhubungan antara pengetahuan, nilai, kebijakan, praktik pembelajaran, serta keberanian untuk merancang masa depan pendidikan yang lebih adil, tangguh, dan berkelanjutan. Karena itu, buku ini kami hadirkan bukan sebagai jawaban final, melainkan sebagai undangan untuk terus berdialog, berefleksi, mengembangkan inovasi, dan memperkuat kolaborasi dalam membangun pendidikan IPA yang lebih bermakna bagi generasi masa depan.

Ucapan terima kasih kami sampaikan kepada seluruh pihak yang telah memberikan dukungan akademik, intelektual, dan moral dalam proses penyusunan buku ini. Apresiasi khusus kami sampaikan kepada penerbit CV Dharma Samakta Edukhatulistiwa atas kepercayaan dan kerja sama yang baik dalam proses penerbitan karya ini. Kami juga menyampaikan penghargaan kepada berbagai lingkungan akademik yang telah menjadi ruang bertumbuh bagi gagasan-gagasan yang kemudian berkembang menjadi bagian dari buku ini.

Akhirnya, kami menyadari bahwa buku ini masih memiliki keterbatasan. Oleh karena itu, kami terbuka terhadap kritik, masukan, dan saran yang konstruktif demi penyempurnaan pada masa yang akan datang. Semoga buku ini dapat memberikan manfaat nyata bagi pengembangan Pendidikan IPA di Indonesia dan menjadi bagian dari upaya kolektif untuk meneguhkan pendidikan sebagai kekuatan transformasi menuju masa depan yang berkelanjutan.

Bandung, Mei 2026

Tim Penulis

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## Daftar Pustaka

- Aeschbach, V. M.-J., Schwichow, M., & Rieß, W. (2025). Effectiveness of climate change education: A meta-analysis. *Frontiers in Education*, *10*, Article 1563816. <https://doi.org/10.3389/educ.2025.1563816>
- Ásványi, K., & Gedeon, E. (2025). Enhancing sustainability consciousness in higher education: Short- and long-term impacts of a project-based learning approach. *The International Journal of Management Education*, *23*(3), Article 101235. <https://doi.org/10.1016/j.ijme.2025.101235>
- Bianchi, G., Pisiotis, U., & Cabrera Giraldez, M. (2022). *GreenComp: The European sustainability competence framework*. Publications Office of the European Union. <https://doi.org/10.2760/13286>
- Chan, J. (2025). Future-oriented science learning and its effects on students' emotions, futures literacy and agency in the Anthropocene. *Research in Science Education*, *55*, 899–919. <https://doi.org/10.1007/s11165-024-10213-1>
- Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*, Article 101586. doi:10.1016/j.ijer.2020.101586
- Hijazi, R. A., Hijazi, A. A., & Jones, V. (2025). Climate literacy for students in higher education: A case study from the University of the West of England (UWE), Bristol, in the United Kingdom. *International Journal of Sustainability in Higher Education*, *26*(9), 188–206. <https://doi.org/10.1108/IJSHE-07-2024-0455>
- Holst, J. (2023). Towards coherence on sustainability in education: A systematic review of *Whole Institution Approaches*. *Sustainability Science*, *18*, 1015–1030. <https://doi.org/10.1007/s11625-022-01226-8>
- Intergovernmental Panel on Climate Change. (2022). Annex III: Scenarios and modelling methods. In *Climate change 2022*:

*Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Intergovernmental Panel on Climate Change. [https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC\\_AR6\\_WGIII\\_Annex-III.pdf](https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Annex-III.pdf)

- Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*. IPCC. <https://doi.org/10.59327/IPCC/AR6-9789291691647>
- Kosow, H., & Gaßner, R. (2008). *Methods of future and scenario analysis: Overview, assessment, and selection criteria* (Studies, No. 39). German Development Institute. [https://www.die-gdi.de/uploads/media/Studies\\_39.pdf](https://www.die-gdi.de/uploads/media/Studies_39.pdf)
- Kranz, J., Breitenmoser, P., Laherto, A., Krug, A., Schwichow, M., & Tasquier, G. (2025). Science education for collective agency in the climate crisis: A social identity approach. *Research in Science Education*, 55, 1149–1168. <https://doi.org/10.1007/s11165-025-10282-w>
- Laherto, A., Levrini, O., & Erduran, S. (2023). Editorial: Future-oriented science education for agency and sustainable development. *Frontiers in Education*, 8, Article 1155507. <https://doi.org/10.3389/educ.2023.1155507>
- Laherto, A., Rasa, T., Miani, L., Levrini, O., & Erduran, S. (2023b). Future-oriented science education building sustainability competences: An approach to the European GreenComp framework. In X. Fazio (Ed.), *Science curriculum for the Anthropocene, volume 2* (pp. 83–105). Palgrave Macmillan. [https://doi.org/10.1007/978-3-031-37391-6\\_5](https://doi.org/10.1007/978-3-031-37391-6_5)
- Matos, S., Arroz, A. M., Martins, B., Amorim, I. R., & Gabriel, R. (2024). Backcasting for youths: Hypothetical and critical thinking in the context of sustainable development education. *Sustainability*, 16(24), Article 11088. <https://doi.org/10.3390/su162411088>
- OECD. (2019a). *OECD learning compass 2030*. OECD Future of Education and Skills 2030 Concept Note. OECD.

- OECD. (2019b). *Student agency for 2030*. OECD Future of Education and Skills 2030 Concept Note.
- OECD. (2026). *Strategic foresight*. Retrieved March 21, 2026, from <https://www.oecd.org/en/about/programmes/strategic-foresight.html>
- Strachan, A., & Markwick, A. (2025). Using a scoping review to inform a planetary-conscious pedagogical approach to primary science education. *Research in Science Education*, 55, 817–871. doi:10.1007/s11165-025-10280-y
- Tang, K. (2024). Climate change education in Indonesia's formal education: A policy analysis. *npj Climate Action*, 3, Article 57. doi:10.1038/s44168-024-00143-z
- Tang, K. H. D. (2022). A model of behavioral climate change education for higher educational institutions. *Environmental Advances*, 9, Article 100305. doi:10.1016/j.envadv.2022.100305
- Tytler, R. W., Monroe, M. C., Eames, C., & White, P. J. (2025). Expanding the scope of science education to engage with Anthropocene challenges. *Research in Science Education*, 55(4), 1129–1147. <https://doi.org/10.1007/s11165-025-10276-8>
- UN SDG:Learn. (2026). *UNESCO cross-cutting and specialized SDG competencies*. Retrieved March 21, 2026, from <https://www.unsdglearn.org/unesco-cross-cutting-and-specialized-sdg-competencies/>
- UNESCO, & MECCE. (2024). *Education and climate change: Learning to act for people and planet*. UNESCO. <https://doi.org/10.54676/GVXA4765>
- UNESCO. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO. <https://unesdoc.unesco.org/ark:/48223/pf0000247444>
- UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. UNESCO. doi:10.54675/ASRB4722

- UNESCO. (2024). *Greening curriculum guidance: Teaching and learning for climate action*. UNESCO. <https://doi.org/10.54675/AOOZ1758>
- UNESCO. (2025). *Greening Education Partnership: Getting every learner climate-ready*. UNESCO.
- UNESCO. (2026). *Education for sustainable development*. UNESCO. Retrieved March 21, 2026, from UNESCO website.
- UNESCO. (2026). *Futures literacy & foresight*. Retrieved March 21, 2026, from <https://www.unesco.org/en/futures-literacy>
- UNESCO. (2026). *Futures literacy & foresight*. UNESCO. Retrieved March 21, 2026, from <https://www.unesco.org/en/futures-literacy>
- UNESCO. (2026, February 12). *Education for sustainable development: What you need to know*. UNESCO.
- World Meteorological Organization. (2025). *State of the global climate 2024* (WMO-No. 1368). World Meteorological Organization.



## Daftar Pustaka

- Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2025). A Decade of Teacher Training Trends on Education for Sustainable Development (ESD): A Systematic Literature Network Analysis. *EASE Letters*, 4(1), 270-285.
- Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2023). *Penerapan ESD dalam Pembelajaran IPA*. Bandung: UPI Press.
- Eliyawati, Widodo, A., Kaniawati, I., & Fujii, H. (2022). Education for Sustainable Development (ESD in Students' Textbooks. *Journal of Engineering Science and Technology*, 17(Special Issue), 50-57.
- Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2023a). The Development and Validation of an Instrument for Assessing Science Teacher Competency to Teach ESD. *Sustainability*, 15(4), 3276. doi:<https://doi.org/10.3390/su15043276>
- Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2023b). The Effectiveness of Teacher Training on Environmental Education: Challenges and Strategy for Future Training Program. *Jurnal Penelitian Pendidikan IPA*, 9(8), 6056-6066. <https://doi.org/10.29303/jppipa.v9i8.3153>
- Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2023c). *Merancang Program Pelatihan Guru Yang Dapat Mengembangkan Kompetensi Guru IPA Dalam Mengajarkan ESD*. In Proceeding Seminar Nasional IPA. Semarang. UNNES.
- Eliyawati, E., Widodo, A., Kaniawati, I., & Fujii, H. (2025, July). The readiness of science teachers to teach education for sustainable development (ESD). In *AIP Conference Proceedings* (Vol. 3206, No. 1, p. 080008). AIP Publishing LLC.
- UNESCO. (2017). *Education for Sustainable Development Goals: Learning Objectives*: United Nations Educational Scientific and Cultural Organization.
- UNESCO. (2018). *Issues and trends in Education for Sustainable Development Issues and trends in Education*. Paris, France: UNESCO Publishing.

- Widodo, A. (2021). *Pembelajaran Ilmu Pengetahuan Alam Dasar-Dasar Untuk Praktik*. Bandung: UPI Press.
- Widodo, A., & Kaniawati, I. (2024). Developing Indonesian Preservice Science Teachers' Understanding of Education for Sustainable Development (ESD) Through Integrated Courses. In *Science Education for Sustainable Development in Asia* (pp. 285-300). Singapore: Springer Nature Singapore.

## Daftar Pustaka

- AlAli, R. (2024). Enhancing 21st century skills through integrated STEM education using project-oriented problem-based learning. *Geo Journal of Tourism and Geosites*, 53(2),
- Ansari, Z., & Naseer, S. (2024). Perspective Chapter: Collaborative Learning Benefits and Its Role in Critical Thinking. In *Massive Open Online Courses—Learning Frontiers and Novel Innovations*.
- Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education*, 5(6).
- Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The influence of project-based STEM (PjBL-STEM) applications on the development of 21st century skills. *Journal of Turkish Science Education*, 18(4),
- Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, 112(1),
- Broman, G., Robert, K., Collins, T. J., Basile, G., Baumgartner, R. J., Larsson, T., & Huisingh, D. (2017). Science in support of systematic leadership towards sustainability. *Journal of Cleaner Production*, 140(1).  
<https://doi.org/10.1016/j.jclepro.2016.09.085>
- Coletti, A., McGloin, R., Embacher-Martin, K., Hamlin, E., & Turner, M. (2023). Examining Oral Communication Skills in Communication Training Programs for STEM Professionals: A Systematic Quantitative Literature Review. *Science Communication*, 45(6),
- Efgivia, M. G., Rinanda, R. A., Hidayat, A., Maulana, I., & Budiarto, A. (2021). *Analysis of constructivism learning theory*. 208–212.

- Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing Students' Creativity through STEM Project-Based Learning. *Journal of Science Learning*, 2(2),
- Hdom, H. A. (2019). Examining carbon dioxide emissions, fossil & renewable electricity generation and economic growth: Evidence from a panel of South American countries. *Renewable Energy*, 139, 186-197 PY-2019 ER-.
- Ilwandri, I., Rahman, A., Santosa, T. A., Zulkifli, Z., Suharyat, Y., & Suhaimi, S. (2023). The Effect of Problem Based Learning-STEM on Students' 21st Century Skills in Indonesia: A Meta-Analysis. *LITERACY: International Scientific Journals of Social, Education, Humanities*, 2(1),
- Iskandar, Sastradika, D., Jumadi, Pujianto, & Defrianti, D. (2020). *Development of Creative Thinking Skills through STEM-Based Instruction in Senior High School Student*. 1567, 042043.
- Jones, M. W., Peters, G. P., Gasser, T., Andrew, R. M., Schwingshackl, C., Gütschow, J., Houghton, R. A., Friedlingstein, P., Pongratz, J., & Le Quéré, C. (2024). National Contributions to Climate Change Due to Historical Emissions of Carbon Dioxide, Methane and Nitrous Oxide [Dataset]. In *Scientific Data*. Zenodo. <https://doi.org/10.5281/zenodo.14054503>
- Mentari, W., Abdurrahman, & Jalmo, T. (2019). The Effectiveness of STEM Integrated Handouts to Improve Students' Creative Thinking Skills in Biotechnology Material. *Dinamika Jurnal Ilmiah Pendidikan Dasar*, 11(2),
- Nurramadhani, A., Riandi, R., Permanasari, A., & Suwarma, I. R. (2023). STEM Learning: The Way to Construct Undergraduate Students' Oral Communications Skills in Science Learning. *IJIS Edu: Indonesian Journal of Integrated Science Education*, 5(2),
- Roy, R., Potter, S., & Yarrow, K. (2008). Designing low carbon higher education systems: Environmental impacts of campus and distance learning systems. *International Journal of*

*Sustainability in Higher Education*, 9(2), Article 2.  
<https://doi.org/10.1108/14676370810856280>

- Saribas, D., Kucuk, Z. D., & Ertepinar, H. (2017). Implementation of an environmental education course to improve pre-service elementary teachers' environmental literacy and self-efficacy beliefs. *International Research in Geographical and Environmental Education*, 26(4).  
<https://doi.org/10.1080/10382046.2017.1330035>
- Sherman, D., Parupudi, T., Mentzer, N., Chesley, A., Laux, D., & Baniya, S. (2020). Oral Communication in an integrated STEM and humanities first-year experience. *Journal of Technology Education*, 32(1),
- Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, 6(39),
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., & Struyf, A. (2018). Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education. *European Journal of STEM Education*, 3(1),
- Wahyuni, S., Yani, A., Rosana, D., Wilujeng, I., & Nurohman, S. (2024). Improving Students' Critical Thinking Skills Through The Use Of Pbl-Base Google Sites Learning Media And Review Students' Collaboration Skills. *Journal of Social Research*, 3(10),
- Wang, H. (2012). A New Era of Science Education: Science Teachers' Perceptions and Classroom Practices of Science, Technology, Engineering, and Mathematics (STEM) Integration [Doctoral dissertation]. In *Unpublished*.
- Widodo, A. (2004). *Constructivist Oriented Lessons, the Learning Environment and the Teaching Sequences*. Peter Lang.
- Widya, Rifandi, R., & Rahmi, Y. L. (2019). *STEM education to fulfil the 21st century demand: A literature review*. 1317, 1–7.

Zajda, J., & Zajda, J. (2021). Constructivist learning theory and creating effective learning environments. In *Globalisation and Education Reforms: Creating Effective Learning Environments* (pp. 35–50). Springer.

## Daftar Pustaka

- Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*, 29(7), 1645-1660
- Abbasy, M. B., & Quesada, E. V. (2017). Predictable influence of IoT (Internet of Things) in the higher education. *International Journal of Information and Education Technology*, 7(12), 914-920.
- Abdel-Basset, M., Manogaran, G., Mohamed, M., & Rushdy, E. (2019). Internet of things in smart education environment: Supportive framework in the decision-making process. *Concurrency and Computation: Practice and Experience*, 31(10), e4515.
- Bagheri, M., & Movahed, S. H. (2016, November). The effect of the Internet of Things (IoT) on education business model. In *2016 12th international conference on signal-image technology & internet-based systems (SITIS)* (pp. 435-441). IEEE.
- Saadé, R. G., Zhang, J., Wang, X., Liu, H., & Guan, H. (2023). Challenges and opportunities in the internet of intelligence of things in higher education—Towards bridging theory and practice. *IoT*, 4(3), 430-465.
- Rochintaniawati, D., Susilawati, A., Kustiawan, I., Hasanah, L., Irawan, D., Juhanda, A., & Putri, S. D. (2024). Tren Penelitian dan Dampak Adanya Internet of Things terhadap Peningkatan Kualitas Pendidikan IPA dalam Upaya Melaksanakan Sustainable Development Goals (SDGs): Analisis Bibliometrik. *Pedagogia: Jurnal Ilmiah Pendidikan*, 16(2), 109-115. <https://doi.org/10.55215/pedagogia.v16i2.20>
- Lone, A. N., Mustajab, S., & Alam, M. (2023). A comprehensive study on cybersecurity challenges and opportunities in the IoT world. *Security and Privacy*, 6(6), e318.
- Hanum, G. K., Irwin, A., Sari, R. N., Ardi, A., & Lismaryanti, L. (2024). Integration of Internet of Things (IoT) Technology in the Management of Educational Facilities and Infrastructure. *al-fikrah: Jurnal Manajemen Pendidikan*, 12(1), 189-201.

- Ferri, F., Grifoni, P., & Guzzo, T. (2020). Online learning and emergency remote teaching: Opportunities and challenges in emergency situations. *Societies*, 10(4), 86.  
<https://doi.org/10.22460/pej.v7i1.3687>
- Maple, C. (2017). Security and privacy in the internet of things. *Journal of cyber policy*, 2(2), 155-184.
- Lee, I., & Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Business horizons*, 58(4), 431-440.
- Liston, M., Morrin, A. M., Furlong, T., & Griffin, L. (2022, August). Integrating data science and the internet of things into science, technology, engineering, arts, and mathematics education through the use of new and emerging technologies. In *Frontiers in education* (Vol. 7, p. 757866). Frontiers Media SA.
- Gendreau Chakarov, A., Bidy, Q., Hennessy Elliott, C., & Recker, M. (2021). The data sensor hub (DaSH): A physical computing system to support middle school inquiry science instruction. *Sensors*, 21(18), 6243.
- Odeh, S., Abu Shanab, S., & Anabtawi, M. (2015). Augmented Reality Internet Labs versus its Traditional and Virtual Equivalence. *International Journal of Emerging Technologies in Learning*, 10(3). 4-9.
- Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, 47(4), 474-496.
- Khattak, K. S., & Khan, Z. H. (2024). Evaluation and challenges of IoT simulators for intelligent transportation system applications. *Science, Engineering and Technology*, 4(1), 94-111.
- Salman, M. Y., & Hasar, H. (2023). Review on environmental aspects in smart city concept: Water, waste, air pollution and transportation smart applications using IoT techniques. *Sustainable Cities and Society*, 94, 104567.

- Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E. H. M. (2019). Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk. *IEEE access*, 7, 129551-129583.
- Qiao, W., & Fu, J. (2023). Challenges of engineering education in digital intelligence era. *Journal of Educational Technology Development and Exchange (JETDE)*, 16(2), 145-159.
- Ashford, N. A. (2004). Major challenges to engineering education for sustainable development: what has to change to make it creative, effective, and acceptable to the established disciplines?. *International Journal of Sustainability in Higher Education*, 5(3), 239-250
- Susilawati, A. (2025). Pelatihan STEM learning berbasis internet of things (STEM-IoT) pada tema hemat energi untuk meningkatkan. Disertasi.
- Ang, L. M., Seng, K. P., & Wachowicz, M. (2022). Embedded intelligence and the data-driven future of application-specific Internet of Things for smart environments. *International Journal of Distributed Sensor Networks*, 18(6), 15501329221102371.
- Meylani, R. (2024). Transforming Education with the Internet of Things: A Journey into Smarter Learning Environments. *International Journal of Research in Education and Science*, 10(1), 161-178.
- Rochintaniawati, D., Susilawati, A., Kustiawan, I., & Hasanah, L. (2025). Design of lesson plans for Internet of Things products in science learning by teachers to improve the quality of education. *SciEnggJ*, 18, 120-127.
- Ganesan, S., Lean, C. P., Chen, L., Yuan, K. F., Kiat, N. P., & Khan, M. R. B. (2024). IoT-enabled smart weather stations: innovations, challenges, and future directions. *Malaysian Journal of Science and Advanced Technology*, 180-190.
- Ghasemi, R., Mohaghar, A., & Dehghanian, M. M. (2025). Advancing Intelligent Supply Chain Management in the Industry 4.0 Era: A Meta-Synthesis Analysis. *Industrial Management Journal*, 17(2), 117-148.
- Mondragón-Ruiz, G., Tenorio-Trigoso, A., Castillo-Cara, M., Caminero, B., & Carrión, C. (2021). An experimental study of

- fog and cloud computing in CEP-based Real-Time IoT applications. *Journal of Cloud Computing*, 10(1), 32.
- Abo-Khalil, A. G. (2024). Integrating sustainability into higher education challenges and opportunities for universities worldwide. *Heliyon*, 10(9).
- Aydınlı, A., Mavi, A., Kütükçü, E., Kırımlı, E. E., Alış, D., Akın, A., & Altıntaş, L. (2024). Awareness and level of digital literacy among students receiving health-based education. *BMC Medical Education*, 24(1), 38.
- Ortiz-Martínez, E., Marín-Hernández, S., & Santos-Jaén, J. M. (2023). Sustainability, corporate social responsibility, non-financial reporting and company performance: Relationships and mediating effects in Spanish small and medium sized enterprises. *Sustainable Production and Consumption*, 35, 349-364.
- ElZein, Z. (2025). Renewable Energy in Architecture and Urbanism: Integrated Sustainable Development Approach in Architecture Education. *Engineering Research Journal*, 184(3), 225-241.
- Zhang, D., & Chen, L. (2023). A BP neural network-assisted smart decision method for education quality. *IEEE Access*, 11, 74569-74578.
- Yarritu, I., Idoiaga Mondragon, N., Axpe Saez, I., & Arriaga, C. (2024). The representation of sustainability among university teachers: knowing the present to change the future. *International Journal of Sustainability in Higher Education*, 25(2), 319-337.
- Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal. *Sustainability*, 9(10), 1889.
- Semerikov, S. (2024). educational dimension of sustainable development: analytical review. *Continuing Professional Education: Theory and Practice*, 81(4), 7-30.
- Sangrá, A., Raffaghelli, J. E., & Guitert-Catasús, M. (2019). Learning ecologies through a lens: Ontological, methodological and applicative issues. A systematic review of

- the literature. *British journal of educational technology*, 50(4), 1619-1638.
- Tariq, R., Casillas-Muñoz, F., Hassan, S., & Ramírez-Montoya, M. (2024). Synergy of internet of things and education: Cyber-physical systems contributing towards remote laboratories, improved learning, and school management. *Journal of Social Studies Education Research*, 15(2), 305-352.
- Badshah, A., Ghani, A., Daud, A., Jalal, A., Bilal, M., & Crowcroft, J. (2023). Towards smart education through internet of things: A survey. *ACM Computing Surveys*, 56(2), 1-33.