Integration of independent learning and physics innovation in STEAM-based renewable energy education to improve critical thinking skills in the era of Society 5.0 for Sustainable Development Goals (SDGs) 2030

Sri Dwi Indahwati[1*], *Fida* Rachmadiarti[1], *Eko* Hariyono[1], *Binar Kurnia* Prahani[1], *Firmanul Catur* Wibowo[2], *Muhammad Abd Hadi* Bunyamin[3], and *Muhammad* Satriawan[1]

[1]State University of Surabaya, Postgraduate Science Education Program, Jl. Ketintang Cell. No. Kel, Ketintang, Kec. Gayungan, Surabaya, East Java 60231, Indonesia
[2]State University of Jakarta, Physics Education Program, Rawamangun, Kota Jakarta Timur, Daerah Khusus Ibukota Jakarta 13220, Indonesia
[3]Universiti Teknologi Malaysia, School of Education, 81310 UTM Skudai, Johor, Malaysia

Abstract. This study aims to integrate Free Learning and Physics Innovation in STEAM-based Renewable Energy Education to improve critical thinking skills in Era Society 5.0 in order to achieve the 2030 Sustainable Development Goals (SDG). This research uses a literature review method that collects and analyzes related articles. The results showed that integrating Free Learning and Physics Innovation in STEAM-based Renewable Energy Education is an effective approach to improving students' critical thinking skills. Renewable energy education is a relevant and important topic in SDG 2030, and the STEAM approach helps students understand and overcome this challenge. Era Society 5.0 emphasizes technology integration, so the educational approach must constantly be updated and adapted to the times. The results of this literature review can assist educators, policymakers, and researchers in developing educational strategies that align with the times' needs.

1 Introduction

This research aims to integrate the concept of "Freedom of Learning" and physics innovation [1-5] in STEAM-based renewable energy education [6] to improve students' critical thinking skills to support the achievement of Sustainable Development Goals (SDG) 2030 in the Era of Society 5.0 [7, 8]. The main challenge is to combine the flexibility of "Freedom of Learning" with innovative physics so that students not only understand the physics behind renewable energy but can also apply critical thinking to

* Corresponding author: sri.22006@mhs.unesa.ac.id

solve global energy problems [9-12]. It is hoped that the results of this research can help educators and stakeholders overcome educational challenges in this ever-changing era.

Several studies related to integrating the concept of "Freedom of Learning" and physics innovation in STEAM-based renewable energy education and its impact on student's critical thinking skills and the achievement of SDG 2030 in the Era of Society 5.0 have been carried out [13-16]. Febriansari [17] has developed a framework combining the STEAM learning model and design thinking that can be applied to learning renewable energy materials. Meanwhile, Sulisworo [14] examines the use of information and communication technology in STEM-based education as an alternative for adapting students' competencies to work and society, emphasizing the importance of critical thinking skills. Arifuddin [18] has integrated STEM in learning to encourage students to think critically, comprehensively, and innovatively in finding solutions to problems, using Educational Robots as an effective learning tool. In addition, Rahayu [16] developed an E-Student Worksheet integrated with STEAM on acid-base material in digital flip form, which can increase interactivity in learning. These studies provide deeper insight into how the integration of the concept of "Freedom of Learning" and physics innovation can be applied in the context of STEAM-based renewable energy education and its impact on student's critical thinking skills and the achievement of SDG 2030 in the Era of Society 5.0 [19]. This research focuses on integrating Independent Learning and Physics Innovation in STEAM-based Renewable Energy Education to Improve Critical Thinking Skills in the Society 5.0 Era for Sustainable Development Goals (SDG) 2030. To develop an innovative approach to integrating STEAM in renewable energy learning, students can work in teams to design, develop and implement renewable energy solutions. Researchers consider Project-Based Learning (PjBL) with learning designs that focus on real projects relevant to renewable energy [20-24].

This will encourage active engagement, independent exploration, and problem-solving related to developing new concepts or theories that did not exist before. For example, if your research on renewable energy produces a new concept or theory that has never been discussed, this can be considered new in research. The type of research used is literature study or library research, namely collecting data obtained from books, journals or scientific papers related to the research object.

This research aims to design, implement and evaluate an innovative educational model that helps students develop critical thinking skills in facing renewable energy challenges in the Society 5.0 era and contributes to achieving SDG 2030. This article highlights the importance of integrating independent learning, physics innovation, and the STEAM approach to renewable energy education. Through this approach, students can better understand the challenges and opportunities of renewable energy and are able to create creative solutions for a sustainable future [25, 26]. Thus, this article provides insight into how integrating these three elements can improve students' critical thinking skills in understanding and overcoming renewable energy problems and contribute to achieving sustainable development goals in the Society 5.0 era, especially related to renewable energy and SDG 2030.

2 Methods

This research examines the integration of independent learning and physics innovation in renewable energy education using the STEAM approach to improve critical thinking skills in the era of Society 5.0 for Sustainable Development Goals (SDG) 2030 [27]. This research is a type of qualitative research using a library study method with an art education concept approach. In qualitative research, the main focus is on an in-depth understanding of the phenomenon or topic being studied through the interpretation of the data and the meaning contained therein [28-30]. The concept approach to art education adds a dimension of creativity and the application of art approaches in teaching and learning. Data sources in this research include various journals, articles, books, and other references relevant to the research topic, especially those related to renewable energy education, independent learning, physics innovation, and the STEAM approach.

This literature review aims to present a comprehensive summary of previous research related to a particular topic [31, 32]. The aim is to inform what is already known about the topic and identify what knowledge is still lacking. Literature reviews can also provide a rational basis for research that has been conducted and inspire further research ideas [33]. In this research, we will use a literature review as the main approach to understand this topic more deeply.

Literature study involves collecting data from various sources such as journals, books, documents, the internet, and libraries. The method includes collecting library materials, reading, recording relevant information, and managing these materials for writing purposes [34]. This method allows researchers to access various sources to support understanding and analysis of research topics.

This research uses a descriptive qualitative research method, allowing researchers to describe and analyze existing phenomena in detail. Data is obtained from various sources to ensure the diversity and accuracy of the information required. The data collection technique used is literature study or library research, with Google Scholar as the main search platform for finding scientific sources. This research aims to understand the integration of Independent Learning and Physics Innovation in STEAM-based Renewable Energy Education and improve students' critical thinking skills in facing renewable energy challenges in the Society 5.0 era in order to achieve SDG 2030.

3 Results

Based on initial search results on Google Scholar with the keywords, namely "Integration, Independent Learning, Physics Innovation, Renewable Energy Education, STEAM, Critical Thinking Skills, Society 5.0 Era, SDG 2030," researchers found 784 relevant article titles. However, not all of these articles have themes that match the research objectives, and some articles are duplicates. Then, researchers carried out further searches on Google Scholar by limiting the search to only the title (in title) using the same keywords. As a result, 563 articles were found that met the research objectives. Meanwhile, 221 articles that did not match the research objectives and duplicates were excluded from the study.

Of the 563 articles found, researchers screened them to ascertain whether the articles had complete manuscripts. 530 articles were excluded because they were not available in full text or paid versions. Finally, the remaining 33 articles are available in full-text

versions. Furthermore, of the 33 articles, screening was carried out again based on the research criteria, and 26 articles were excluded because they did not meet the criteria. Finally, the researcher found seven journals with similar research themes/contents. Research articles that best fit the research objectives are selected from the seven journals based on the most appropriate criteria. This is shown in the research flowchart in Figure 1.

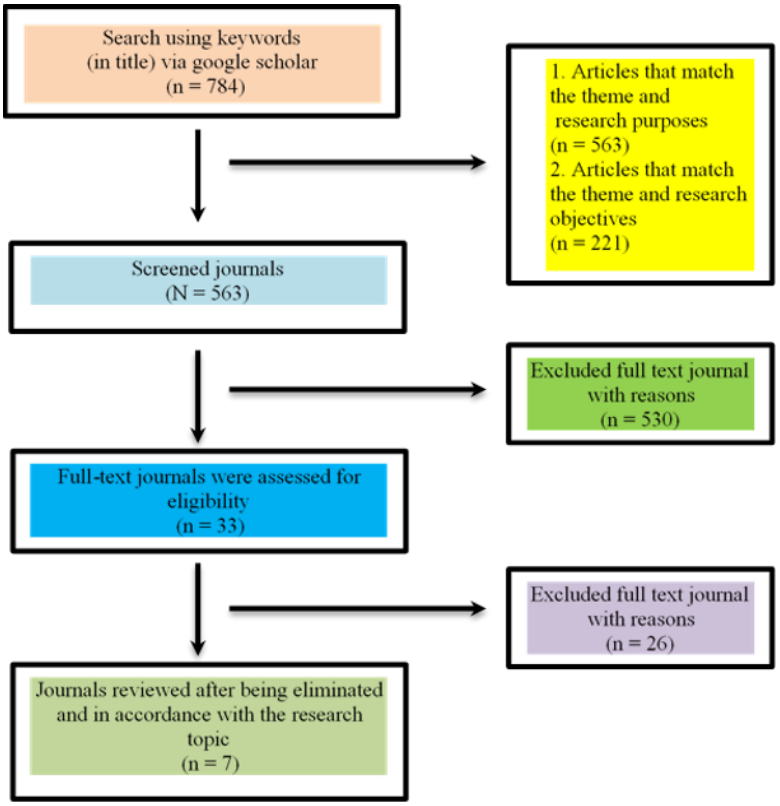

Fig. 1. Research flow chart.

The results of this research will provide valuable insight into the benefits and potential of integrating independent learning, physics innovation, and the STEAM approach in renewable energy education. Apart from that, it is also hoped that this research can provide practical recommendations for developing curriculum and learning methods that are more effective in improving students' critical thinking skills in the Society 5.0 era in order to achieve the 2030 Sustainable Development Goals (SDG) related to renewable energy. With a deeper understanding of how integrating these approaches can support sustainable development, educators and policymakers can play an active role in creating a highly competitive generation that is innovative in facing future renewable energy challenges [35]. In addition, this research can also contribute to a global understanding of the importance of renewable energy education in achieving SDG 2030 and creating a sustainable world for future generations.

No	Authors	Finding
1	Cahyorini Wulandani, Meida Afina Putri, Rahmalia Indah Pratiwi, Komareeyah Sulong (2022) [36]	Every industrial revolution has an impact that will give birth to change. Education is one of the fields that has an impact in every revolutionary era. To be able to produce students who are appropriate to the times, the curriculum and learning activities must always innovate and change to suit current developments. STEAM-Project Based Learning or project-based STEAM can be used to develop early childhood skills in the era of Industrial Revolution 5.0 by combining elements of science, technology, engineering, art and mathematics as well as applying strategies consisting of reflection, discovery, application and communication in implementing Learning Activities
2	Atiaturrahmaniah Atiaturrahmaniah, Ida Bagus Putu Aryana, I Wayan Suastra (2022) [37]	The STEAM (Science, Technology, Engineering, Mathematics) model can be applied to students in schools basic because it can improve critical thinking skills, collaboration, communication skills and able to analyze all forms of information that has been obtained, thus forming students with character and students are also able to increase their interest in scientific literacy in looking for various comparisons existing facts and realities so that they can find solutions to the problems they find.
3	Yose Indarta, Nizwardi Jalinus, Waskito, et al., (2022) [38]	The era of society 5.0 requires society to be able to solve various problems or dynamics social by utilizing technology such as the Internet of Things (IoT), Artificial Intelligence (AI), technology robots, even big data.
4	Andrea Lesková, Zuzana Uličná, Hedviga Tkáčová, Klodiana Leka, Daniel Alvarez Mateo (2023) [39]	It is necessary to guide the child from early childhood to build values, critical thinking, but also own self-esteem and empathy. Since the foundations for a child's education are laid in the family, it is precisely family education that can (un)prepare the child for entering the world of digital media and its optimal functioning in it.
5	Agus Sugiarto, Rahmat Mulyono (2022) [40]	The role of teachers in implementing STEM learning is very important. Teachers who have optimal knowledge and experience in preparing STEM learning will provide optimal learning experiences for students. However, many teachers face challenges in implementing STEM learning. Therefore, support from education stakeholders is very necessary to develop STEM learning and prepare the young generation to face challenges in the era of Society 5.0.
6	Lia Amelia Megawati, Budi Arief (2021) [41]	Education has an important role in creating the young generation as Agents of Change and Agents of Producers who can create real change. Good quality education is needed to support an Indonesian society that is productive, competitive, and able to compete at the international level in the 21st century. The young generation, as agents of innovation, must be able to make important contributions to implementing the concept of sustainable development or SDGs. Independent Learning Campus (MBKM) is relevant to

No	Authors	Finding
		21st-century skills and SDGs. However, its implementation at the study program level is still not optimal. Lack of socialization of MBKM policies, guidelines and operational procedures means that student participation in the MBKM program scheme is still low. It is necessary to increase online and offline socialization at the study program level so that all students can feel the benefits of this program.
7	Iim Halimatul Mu'minah (2021) [42]	The STEAM approach in 21st-century learning is key in preparing for the Society 5.0 era. With a focus on science, technology, engineering, arts, and mathematics, students are developed in critical, creative, and logical thinking as well as solving everyday problems. They are also capable of producing innovative products and designs. In the era of Society 5.0 which is full of change, the STEAM approach helps students be ready as future innovators.

4 Discussion

This research highlights the important potential of integrating independent learning, Physics Innovation, and the STEAM Approach in renewable energy education. The implications of this research can be used as a basis for developing curriculum and learning methods that are more effective in improving students' critical thinking skills in the Society 5.0 era in order to achieve the 2030 Sustainable Development Goals (SDG) related to renewable energy [36, 38, 41]. In addition, this research can also contribute to global understanding of the importance of renewable energy education in achieving SDG 2030 and creating a sustainable world for future generations. Apart from that, the results of this research can also provide benefits for educators and educational practitioners in designing teaching strategies that are more innovative and relevant to future renewable energy challenges. By understanding the importance of integrating independent learning, Physics Innovation, and the STEAM Approach, educators can adopt more interactive and fun learning methods to encourage active student involvement [35, 37]. The results of this research can also have an impact on developing human resources who are more competent and competitive in the field of renewable energy. Students involved in learning based on integrating independent learning, Physics Innovation, and the STEAM Approach will have strong critical thinking skills, the ability to innovate, and a deep understanding of renewable energy. This will prepare them to contribute to advancing renewable energy technologies, confronting climate change, and achieving the 2030 SDG sustainable development goals [41]. However, this research also has some limitations. The main limitation is using the literature study method as the only data source. Although literature studies provide valuable insights into the integration of Free Learning, Physics Innovation, and the STEAM Approach in renewable energy education, the data obtained from the literature may be limited and do not include experience and views from the field [42]. Therefore, to produce more comprehensive and representative findings, further research may involve other research methods, such as field research or interviews with experts and practitioners in renewable energy education.

5 Conclusion

Integrating Independent Learning, Physics Innovation, and the STEAM Approach in Renewable Energy Education has great potential to improve students' critical thinking skills in the Society 5.0 era to achieve the 2030 Sustainable Development Goals (SDG) related to renewable energy. Results from seven relevant articles consistently show that this approach is effective. By combining these approaches in renewable energy learning, students experience more meaningful and active learning, conducting experiments, integrating scientific disciplines, and applying their knowledge in authentic contexts. This increases their understanding of renewable energy and develops critical thinking skills essential in the Society 5.0 era. This integration also supports the achievement of SDG 2030 regarding renewable energy, equipping students to become agents of change in sustainable development. This approach is not just about academic learning but also preparing young people to play an active role in creating a sustainable future. To improve STEAM-based renewable energy education and students' critical thinking skills in the Society 5.0 era towards SDG 2030, independent learning, Physics Innovation, and the STEAM Approach must be integrated into the curriculum. Teachers need to receive adequate training, educational facilities must be improved, and cooperation with the renewable energy industry needs to be increased. Student assessments should focus on critical thinking skills, technology can be used as a supporting tool, and students should be encouraged to develop innovative projects. Environmental awareness also needs to be promoted. By following these suggestions, renewable energy education can more effectively prepare young people to achieve sustainable development goals.

References

1. Y. E. Ika, A. F. Laka, P. N. Supardi, D. Rendo, D. N. Birhi, 2022 Optika J. Pendidik. Fis. **6** 158.
2. F. Alatas, Implementasi dan Problematika Merdeka Belajar: Tantangan dan Peluang Penerapan Merdeka Belajar Kampus Merdeka (Akademia Pustaka, Tulungagung, 2021)
3. A, Purwanto, D. H. Putri, D. Hamdani, J. Kumparan Fis. **4**, 25 (2021)
4. I. Susanto, R. Daya, J. Darma Agung **30**, 59 (2022)
5. Z. F. Rozi, R. N. Sasongko, Bioedusains J. Pendidik. Biol. Sains **5**, 410 (2022)
6. S. Suwardi, Paedagogy J. Ilmu Pendidik. Psikol. **1**, 40 (2021)
7. S. H. Olsen, E. Zusman, M. Hengesbaugh, N. Amanuma, S. Onoda, Governing the Sustainable Development Goals in the Covid-19 Era: Bringing Back Hierarchic Styles of Governance? (Asian Development Bank Institute, Tokyo, 2021).
8. M. D. Tavares, G. M. Azevedo, Adv. Tour. Technol. Syst. **208**, 49 (2021)
9. R. Rosmiati, L. Liliasari, B. Tjasyono, et al., Reflective Practice 21, 4 (2020)
10. A. Amran, I. Jasin, M. Perkasa, et al., Journal of Physics: Conference Series **1521**, 4 (2020)
11. S. Sutarno, D. H. Putri, E. Risdianto, et al., Journal of Physics: Conference Series **1731**, 1 (2021)
12. A. A. Sihombing, S. Anugrahsari, N. Parlina, Y. S. Kusumastuti, Asian Journal of

University Education **17**, 4 (2021)
13. N. Khoiri, S. Ristanto, A. F. Kurniawan, Jurnal Pendidikan IPA Indonesia **12**, 2 (2023)
14. H. Retnowati, S. Subanti, International Online Journal of Education and Teaching **7**, 1 (2020)
15. H. Galindo-Dominguez, Educational Technology & Society **24**, 3 (2021)
16. M. I. Simeon, M. A. Samsudin, N. Yakob, International Journal of Technology and Design Education **32** (2020)
17. D. Febriansari, S. Sarwanto, S. J. Yamtinah, Inov. Pembelajaran **8**, 1 (2022)
18. R. Arifudin, A. Setiawan, Z. Abidin, D. A. Efrilianda, J. Jumanto, Abdimasku J. Pengabdi. Masy. **5**, 2 (2022)
19. M. L. Bernacki, L. Vosicka, J. C. Utz, C. B. Warren, Journal of Educational Psychology **113**, 6 (2021)
20. E. C. Miller, S. Severance, J. Krajcik, Journal of Science Teacher Education, **32**, 7 (2021)
21. N. Jalinus, S. Syahril, R. A. Nabawi, Journal of Technical Education and Training **11**, 1 (2019)
22. M. Baran, M. Baran, F. Karakoyun, A. Maskan, Journal of Turkish Science Education **18**, 4 (2021)
23. D. Triana, Y. U Anggraito, S. Ridlo, Journal of Innovative Science Education, **9**, 2 (2020)
24. M. Muhibbuddin, N. Yustina, S. Safrida, Ijaedu-International E-Journal of Advances In Education **6**, 16 (2020)
25. M. Maulidia, P. Dargusch, P. Ashworth, F. Ardiansyah, Renewable and Sustainable Energy Reviews **101** (2019)
26. A. Rahman, P. Dargusch, D. Wadley, Renewable and Sustainable Energy Reviews **144** (2021)
27. D. Demina, T. Rexy, A. Danyl, Journal International Inspire Education Technology **1**, 2 (2022)
28. F. Y. Sebele-Mpofu, Cogent Social Sciences **6**, 1 (2020).
29. N. A. Stahl, J. R. King, Journal of Developmental Education **44**, 1 (2020)
30. N. Harahap, Penelitian Kualitatif (Wal Ashri Publishing, Medan, 2020)
31. C. Vindrola-Padros, G. A. Johnson, Qualitative health research **30**, 10 (2020)
32. A. Mehrad, M. H. T. Zangeneh, International Journal For Research In Educational Studies **5**, 7 (2019)
33. A. S. Denney, R. Tewksbury, J. Crim. Justice Educ. **24** (2013)
34. M. Abdar, et al., Information fusion **76** (2021)
35. U. A. Izzati, B. S. Bachri, M. Sahid, D. E. Indriani, Journal for the Education of Gifted Young Scientists **7**, 3 (2019)
36. C. Wulandani, M. A. Putri, R. I. Pratiwi, K. Sulong, Indonesian Journal of Early Childhood Educational Research (IJECER) **1**, 1 (2022)
37. A. Atiaturrahmaniah, I. Bagus, P. Aryana, I. W. Suastra, JPGI (Jurnal Penelitian Guru Indonesia) **7**, 2 (2022)
38. Y. Indarta, N. Jalinus, W. Waskito, A. D. Samala, A. R. Riyanda, N. H. Adi, Edukatif: Jurnal Ilmu Pendidikan **4**, 2 (2022)

39. A. Lesková, Z. Uličná, H. Tkáčová, K. Leka, D. A. Mateo, Journal of Education Culture and Society **14**, 2 (2023)
40. A. Sugiarto, R. Mulyono, Didaktik: Jurnal Ilmiah PGSD STKIP Subang **8**, 2 (2022)
41. L. A. Megawati, B. Arief, *Relevansi antara Merdeka Belajar Kampus Merdeka dengan Keterampilan Abad 21 dan SDGs*. In Prosiding Seminar Nasional Merdeka Belajar Kampus Merdeka (MBKM), Bogor: Portal Prosiding MBKM Universitas Pakuan (2021)
42. I. H. Mu'minah, *Studi Literatur: Pembelajaran Abad-21 Melalui Pendekatan Steam (Science, Technology, Engineering, Art, and Mathematics) Dalam Menyongsong Era Society 5.0*. In Prosiding Seminar Nasional Pendidikan (2021, October)