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Advancing Green Pedagogical Competence Through Circular Economy-Integrated Project-Based Learning: Evidence from Prospective Vocational Teacher

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ABSTRACT

The transition to a green economy requires vocational teacher education institutions to prepare prospective teachers with sustainability-oriented pedagogical competence. Integrating sustainability principles into teacher education, however, remains difficult, particularly in developing Green Pedagogical Competence (GPC) among prospective vocational teachers. This study tests the effectiveness of a Circular Economy-Integrated Project-Based Learning (CE-PjBL) model in improving the GPC of Electrical Engineering Education students. It uses a quantitative, one-group pretest-posttest design with 39 students enrolled in the Learning Planning course. Data were collected with a GPC instrument covering six dimensions, namely Green Pedagogical Awareness, Green Instructional Design, Sustainable Resource Management, Green Teaching Implementation, Green Assessment Literacy, and Reflective Green Pedagogical Transformation, and analyzed using Normalized Gain (N-Gain) to measure the size of the competency change after the intervention. The average GPC score rose from 63.59 in the pretest to 90.47 in the posttest, yielding an N-Gain of 0.738, in the high category. Among the six dimensions, Green Teaching Implementation recorded the highest increase and Green Assessment Literacy the lowest, though both remained in the high category. These results suggest that CE-PjBL can build sustainability-oriented pedagogical competence through authentic learning experiences that embed Circular Economy principles in project-based activities, and point to its potential as an instructional approach for preparing vocational teachers able to support the implementation of Education for Sustainable Development and sustainability-oriented learning in vocational education.

Keywords: Circular Economy, Project-Based Learning, Green Pedagogical Competence, Vocational Teacher Education, Sustainable Education, Prospective Teachers

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INTRODUCTION

Climate change, environmental degradation, and the growing strain on natural resources have pushed many countries to build sustainability principles into their education systems. Education prepares the knowledge, skills, values, and behavior that sustainable development requires (Mukhuty et al., 2022). Vocational education carries particular weight here, since it trains the workers who will carry industrial and economic sectors through the

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shift toward a green economy (Hamid et al., 2024). Vocational teacher education has followed the same shift: preparing prospective teachers no longer means pedagogical and subject-matter mastery alone, but also the competence to weave sustainability principles into the learning process itself. We call this Green Pedagogical Competence (GPC): a teacher's capacity to design, implement, evaluate, and reflect on instruction oriented toward environmental sustainability. Mastering GPC matters because teachers act as agents of change, shaping the awareness, attitudes, and sustainable behavior of their students. UNESCO frames this directly, calling for educators equipped with the knowledge, skills, values, and behaviors that a transition toward a more sustainable society demands (Yang, 2026).

Even so, integrating sustainability into vocational education still runs into real obstacles (Muaddab, 2024; Suharno et al., 2025). Educators often have only a partial grasp of sustainability concepts, green skills remain loosely woven into the curriculum, learning strategies stay short on context, and ties to the needs of the green industry stay weak, each one a barrier to building students' sustainability competence (Lenziardi et al., 2025). What this points to is a need for learning innovations that connect sustainability to authentic, contextual learning experiences. Circular Economy (CE) is one approach drawing growing attention in sustainability education: it offers a paradigm built on waste reduction, resource efficiency, material reuse, and sustainable economic value creation (Keramitsoglou et al., 2023; Otasowie et al., 2025). Several recent studies suggest that higher education institutions play a strategic role in building Circular Economy competencies through relevant curricula and learning experiences, though integrating the Circular Economy into education still calls for a pedagogical approach able to link these concepts to real-world practice and workplace problem-solving (Trevisan et al., 2025).

Project-Based Learning (PjBL) carries particular weight in higher education for building sustainability competence. Working on real-world projects pushes students to think critically, collaborate, solve problems, and generate solutions to environmental and social issues (Birdman et al., 2022). Recent work on project-based approaches and hands-on experience reports gains in students' sustainability competence, systems thinking, collaboration, and environmental responsibility. Folding Circular Economy principles into project-based learning sharpens this further: it gives students authentic situations in which to apply sustainability concepts, which makes the learning carry more weight.

Interest in weaving sustainability and circular economy principles into vocational education keeps growing, yet building sustainability-oriented pedagogical competence among prospective vocational teachers still has far to go (Hamid et al., 2024). Research on the circular economy in vocational education and training lays important groundwork here, showing how circular economy principles can enter curricula, instruction, and workforce competence development (Lewis, 2025). What is missing is a clearer account of how these principles translate into instructional models that build Green Pedagogical Competence (GPC) specifically for prospective vocational teachers. These teachers need more than a grasp of sustainability concepts; they need the ability to design, implement, assess, and reflect on instruction that carries sustainability principles into a vocational context. Project-Based Learning has, in vocational education, already proven effective at building green-skills and green-energy-literacy competencies (Lozjanin et al., 2025), but most of that work looks at secondary school

students or vocational students in general. Studies that examine GPC specifically among prospective vocational teachers, through Circular Economy principles folded into Project-Based Learning, remain scarce. This gap points to the need for an instructional model that explicitly joins Circular Economy principles with project activities to build environmentally oriented pedagogical competence in prospective vocational teachers.

Addressing these issues, this study implements a Circular Economy-Integrated Project-Based Learning model with prospective vocational teachers and tests its effect on their Green Pedagogical Competence. Comparing pretest and posttest results gives empirical evidence of what the model contributes to strengthening sustainable pedagogical competence. Beyond that evidence, the findings aim to inform the theory of sustainability pedagogy in vocational education and to offer an alternative instructional model for preparing prospective teachers able to support the transformation toward sustainable development.

METHODS OF RESEARCH

This study uses a one-group pretest-posttest design (Abdi et al., 2025) to track change in students' Green Pedagogical Competence (GPC) before and after the Circular Economy-Integrated Project-Based Learning (CE-PjBL) model. Students completed a pretest at the start of the course to establish baseline GPC scores, went through the CE-PjBL activities, and completed the same instrument as a posttest at the end of the course. This allowed GPC scores to be compared at two points within the same group, though without a control or comparison group the design cannot isolate how much of the change came from CE-PjBL specifically.

A one-group pretest-posttest design carries several threats to internal validity worth noting here. History: events or experiences during the study period, apart from CE-PjBL itself, may have shaped students' competence. Maturation: students' knowledge and skills can change naturally over time regardless of instruction. Testing effect: taking the pretest can itself shape how students respond to the same instrument on the posttest. Regression to the mean: score changes can appear simply because participants started from extreme initial scores. Each of these is a standard concern in one-group designs without a comparison group (Anderson-Cook, 2005).

Changes in GPC scores were read by comparing pretest and posttest results and calculating the normalized gain (N-Gain). We treat that change as what followed participation in CE-PjBL, not as proof that the instructional model alone caused it. No inferential statistical test was run, so the analysis does not speak to the statistical significance of the pretest-posttest difference. Settling how much CE-PjBL itself contributes to GPC development would need further research with a control or comparison group, appropriate inferential analysis, and performance-based assessment.

The research design can be illustrated as follows:

$$O_1 \rightarrow X \rightarrow O_2$$

Information:
O_1= Pretest Green Pedagogical Competence
X= Implementation of Circular Economy-Integrated Project-Based Learning
O_2= Posttest Green Pedagogical Competence

The research began with the administration of a pretest to assess all students' Green Pedagogical Competence. The Circular Economy-Integrated Project-Based Learning (CE-PjBL) model was then implemented in the Instructional Planning course, engaging students in project activities that incorporated circular economy principles into instructional design. Upon completing their projects, students presented their results and reflected on their work. Following the completion of all learning activities, a posttest was administered to reassess their Green Pedagogical Competence. The pretest and posttest data were subsequently analyzed to determine the extent of improvement in students' competence.

The study drew on students from the Electrical Engineering Education Study Program taking the Instructional Planning course in the 2025/2026 even semester, 39 in total. Because every student enrolled in the course took part in the CE-PjBL model as it ran, the sample followed a total sampling technique (Hazari, 2023; Raifman et al., 2022).

The Green Pedagogical Competence (GPC) instrument was developed to assess the sustainability-oriented pedagogical competence of prospective vocational teachers (Dsilva et al., 2023; Heriani et al., 2026; Jeronen & Jeronen, 2026; Mukhuty et al., 2022; Susanto et al., 2026; Wu et al., 2026). The assessment scale encompasses six main dimensions. Green Pedagogical Awareness examines teachers' awareness of sustainability issues and the importance of incorporating environmental education into instruction. Building on this awareness, Green Instructional Design assesses their ability to develop instruction that integrates sustainability and circular economy principles. Sustainable Resource Management addresses the effective, efficient, and environmentally responsible management of instructional resources, while Green Teaching Implementation focuses on conducting instruction that promotes sustainable behaviors and practices. To evaluate competence in assessing learning outcomes, Green Assessment Literacy examines teachers' ability to design and implement assessments that measure students' attainment of sustainability competencies. Finally, Reflective Green Pedagogical Transformation addresses their capacity to reflect on and continuously improve sustainability-based instructional practices.

The GPC instrument was administered as both pretest and posttest to capture change in students' Green Pedagogical Competence after the CE-PjBL instruction. It took the form of a questionnaire on a five-point Likert scale, from 1 (strongly disagree) to 5 (strongly agree) (Imansari et al., 2022).

Cronbach's alpha was used to check the internal reliability of the GPC instrument and returned a value of 0.82, indicating good internal consistency among its items, enough to say the questionnaire items are consistent for measuring the GPC construct. Internal reliability alone, however, cannot establish the instrument's validity, nor does it guarantee that self-reported scores reflect the teaching competence students actually demonstrate.

Normalized Gain (N-Gain) was used to read the level of improvement in students' Green

Pedagogical Competence after the CE-PjBL instruction. N-Gain measures instructional effectiveness as the difference between pretest and posttest scores relative to the maximum possible improvement students could achieve (Triyono et al., 2024).

The N-Gain calculation is performed using the formula:

$$g = \frac{Posttest - Pretest}{100 - Pretest}$$

where:
g = N-Gain value
Posttest = score after instruction
Pretest = score before instruction
100 = maximum score

The N-Gain values were classified using the categories Hake proposed (Larasati et al., 2026; Pambudi et al., 2026; Satriani & Prasojo, 2024), yaitu:

Table 1 N-Gain Category

N-Gain value	Category
G < 0.30	Low
0.30 ≤ g <0.70	Medium
G ≥ 0.70	High

This classification is widely used in educational research to evaluate the effectiveness of an instructional intervention. Here, it shows how far students' Green Pedagogical Competence moved after the Circular Economy-Integrated Project-Based Learning model: the higher the N-Gain, the more effective the model was at building GPC in prospective vocational teachers.

Data analysis compared mean pretest and posttest GPC scores and calculated the normalized gain (N-Gain) value to describe how students' scores changed after Circular Economy-Integrated Project-Based Learning (CE-PjBL). N-Gain shows the size of that improvement relative to the maximum possible gain; because no inferential statistical test was run, the analysis does not speak to whether the pretest-posttest difference is statistically significant.

RESULTS AND DISCUSSION

This section reports how the Circular Economy-Integrated Project-Based Learning (CE-PjBL) model affected the Green Pedagogical Competence (GPC) of students in the Electrical Engineering Education Study Program's Instructional Planning course, measured before and after the intervention with a GPC instrument spanning six dimensions of competence.

Improvement in Green Pedagogical Competence

Green Pedagogical Competence scores rose after students took part in CE-PjBL instruction: the mean pretest score of 63.59 climbed to 90.47 in the posttest, and the Normalized Gain (N-Gain) came out to 0.738, in the high category.

Table 2 Pretest, Posttest, and N-Gain Results for Green Pedagogical Competence

Variable	Pretest	Posttest	N-Gain	Category
Green Pedagogical Competence	63,59	90,47	0,738	High

The details for each dimension of green pedagogical competence are presented in Table 3 below.

Table 3. Average per Dimension

No.	Dimensions of Green Pedagogical Competence	Average Pre-test Score	Average Post-test Score	N-Gain
1	Green Pedagogical Awareness	64,36	91,03	0,75
2	Green Instructional Design	63,46	89,62	0,72
3	Sustainable Resource Management	63,33	89,62	0,72
4	Green Teaching Implementation	63,46	92,05	0,78
5	Green Assessment Literacy	63,46	89,49	0,71
6	Reflective Green Pedagogical Transformation	63,46	91,03	0,75
	Overall Average	63,59	90,47	0,738

These results point to a real gain in students' Green Pedagogical Competence under the CE-PjBL model. An N-Gain in the high category means most of the competency gaps students carried into the course closed after they took part in project-based learning built around circular economy principles.

Improvement in Each Dimension of Green Pedagogical Competence

Scores rose across all six dimensions of Green Pedagogical Competence (GPC) once the Circular Economy-Integrated Project-Based Learning (CE-PjBL) model was in place, with an overall N-Gain of 0.738, in the high category. The gain was not confined to sustainability awareness; it reached students' perceived ability to design, implement, assess, and reflect on sustainability-oriented learning as well. Green Pedagogical Awareness rose along with students' awareness of environmental issues and the role education plays in sustainable development. In Green Instructional Design, students scored higher on designing learning activities around sustainability and circular economy principles, including formulating learning objectives, developing project activities, and choosing strategies that encourage responsible resource use.

Sustainable Resource Management moved in step with students' growing ability to select and use learning resources efficiently while weighing sustainability. Green Teaching Implementation climbed as students applied strategies that invite active participation, collaboration, problem-solving, and environmentally aware decision-making. Green Assessment Literacy grew as students learned to build assessments that cover sustainability-related attitudes, skills, and behavior, not only subject-matter understanding. Reflective Green Pedagogical Transformation rose along with students' capacity to reflect on their own practice and spot room for continuous improvement grounded in sustainability principles.

Green Teaching Implementation posted the highest N-Gain of the six dimensions (0.78); Green Assessment Literacy posted the lowest (0.71). One plausible reason sits in what project-based learning asks of students: identifying sustainability problems, developing

project solutions, working with peers, managing resources, and presenting outcomes, all of which give fairly direct practice at sustainability-oriented teaching. Green Assessment Literacy asks for something more specialized, namely formulating sustainability-oriented assessment indicators, building instruments and rubrics, choosing appropriate evidence of learning, and judging outcomes against criteria, skills that likely need more explicit instruction and structured practice to develop. These remain plausible readings of the pattern rather than mechanisms the data test directly, and the N-Gain values themselves do not establish that the dimensions differ from one another at a statistically significant level.

Taken together, folding circular economy principles into project-based learning appears to give prospective vocational teachers a learning context that can move several dimensions of GPC at once. It also suggests where a future round of CE-PjBL could place more weight, such as on assessment-related work including rubric development, tighter alignment between learning objectives and assessment criteria, and evaluating project outcomes against sustainability indicators. That said, a one-group pretest-posttest design without a comparison group cannot attribute the gains exclusively to CE-PjBL; what the data show is change in GPC scores following participation in the model, and settling how much of that change the model itself caused would need comparison groups and performance-based assessment in future work.

Green Pedagogical Awareness

Green Pedagogical Awareness rose alongside students' awareness of sustainability issues and the part education plays in moving toward a more sustainable society. CE-PjBL does not leave sustainability as theory: it puts students in front of real problems involving resource use, waste, energy efficiency, and the environmental footprint of human activity (Gannar & Kilani, 2025).

Project-based learning ties academic concepts to real situations, which deepens how students understand the relationship between education and sustainable development (Omelianenko & Artyukhova, 2024). Awareness of environmental challenges sits underneath this: it is what environmentally responsible values, attitudes, and behavior are built on.

Circular economy education adds another layer: it asks students to see how production, consumption, and resource management connect as a system (Keramitsoglou et al., 2023; Renfors, 2024). That systemic view feeds directly into students' growing sense of why sustainability principles belong in educational practice.

Green Instructional Design

Green Instructional Design moved because students got better at folding sustainability principles into learning objectives, materials, methods, media, and assessment. CE-PjBL asks for this directly: the model requires students to design projects that explicitly build on circular economy principles, such as waste reduction, material reuse, resource efficiency, and product sustainability (Otasowie et al., 2025).

Along the way, students did more than arrange learning tools: they weighed the environmental consequences of each pedagogical decision they made. That mirrors what circular economy education asks for in general, a holistic integration of sustainability into curriculum and instruction rather than sustainability bolted on as an afterthought.

Project-Based Learning's demand that students design solutions to authentic problems also plays into this gain (Gannar & Kilani, 2025). Asked to build sustainability-oriented, project-based learning designs, students end up applying pedagogical knowledge in a more contextual way than conventional instruction asks of them.

Sustainable Resource Management

Sustainable Resource Management grew with students' ability to manage learning resources effectively, efficiently, and in an environmentally sound way. That tracks what circular economy thinking asks for at its core: optimizing resource use through reducing, reusing, recycling, repairing, and regenerating (Dsilva et al., 2023; Kougias et al., 2023).

During the project, students had to weigh more sustainable materials, media, technologies, and learning resources. That pushed them toward a resource-efficiency mindset, something lesson planning had rarely asked of them before.

Research on circular economy education backs this up: engagement in project-based activities and hands-on experience can build resource management skills, systems thinking, and sustainable decision-making (Mozumder & Schneider, 2026). That hands-on experience is what makes sustainability concrete for students, something to act on at every stage of learning rather than only a concept held in theory.

Green Teaching Implementation

Green Teaching Implementation rose as students grew readier to deliver instruction that fosters sustainable behavior in their own future learners. CE-PjBL puts students in the driver's seat throughout, through problem exploration, collaboration, investigation, solution design, and presenting project outcomes, and that active role plausibly explains the gain (Lozjanin et al., 2025).

Through this experience, students saw concrete examples of how active learning builds environmental awareness and social responsibility in learners. That authentic experience makes the point better than a lecture could: it shows students teaching strategies that instill sustainability values more effectively than lecturer-centered approaches (Barry et al., 2022).

Project-Based Learning contributes to sustainability competence in a broader sense too, by pulling cognitive, affective, and behavioral learning together at once (Omelianenko & Artyukhova, 2024). Working on projects tied to environmental issues gives students practice at the problem-solving and decision-making that sustainable learning calls for.

Green Assessment Literacy

Green Assessment Literacy grew as students came to see that assessment needs to measure more than academic achievement; it needs to capture sustainability competencies too. CE-PjBL built that understanding directly, since the model required students to develop project success indicators, assessment rubrics, reflection instruments, and learning outcome evaluations aligned with sustainability goals.

That work shifted how students saw assessment: an integral part of learning, not only a tool for assigning grades. Sustainability education asks assessment to measure critical thinking, collaboration, problem-solving, environmental responsibility, and reflective ability. The assessment-literacy literature backs this route to competence, since teachers develop

assessment skill by designing and using authentic instruments tied to learning objectives (Meijer et al., 2023). Designing project-based assessments inside CE-PjBL gave students exactly that kind of practice, which is why Green Assessment Literacy moved.

Reflective Green Pedagogical Transformation

The clearest conceptual shift shows up in Reflective Green Pedagogical Transformation: students' ability to reflect on their learning experience and turn that reflection into more sustainable pedagogical practice.

Continuous reflection, during and after a project, is a defining feature of Project-Based Learning. CE-PjBL asks for more than a finished product: students also evaluate environmental impact, weigh how well their solutions worked, and consider what to improve next time. That reflective habit builds toward transformative learning, and it shifts how students see their own future role as teachers in sustainable development.

Research on experiential learning and circular economy education points to something similar: learning experiences built on critical reflection can grow transformational capacities such as self-awareness, critical reflection, resilience, empathy, and responsible action, all essential to sustainability competence (Menon & Suresh, 2022; Tutore et al., 2026). That fits what the Reflective Green Pedagogical Transformation gain suggests: students did not only pick up new knowledge, they shifted how they think and act as prospective vocational teachers oriented toward sustainability.

Across all six dimensions, integrating Circular Economy principles with Project-Based Learning gave students a learning experience that built Green Pedagogical Competence on several fronts at once. The CE-PjBL model did more than deepen students' understanding of sustainability; it strengthened their capacity to design, implement, evaluate, and reflect on learning that moves vocational education toward sustainability.

Research Limitations

This study offers one picture of how students' Green Pedagogical Competence (GPC) changed under Circular Economy-Integrated Project-Based Learning (CE-PjBL) instruction, and that picture comes with real limits. The single-group pretest-posttest design, without a comparison group, means the observed score changes reflect participants' status before and after instruction based only on what they reported about their own competence. The analysis itself stayed descriptive, comparing mean pretest and posttest scores and calculating the normalized gain (N-Gain) to show the pattern and size of GPC improvement, nothing more. A self-report questionnaire also captures perception rather than directly observed practice. Future research could move past these limits by adding a comparison group, pairing questionnaires with observation of actual teaching practice, and evaluating the instructional materials students produce, together giving a fuller picture of how prospective vocational teachers build GPC through sustainability-oriented instruction.

CONCLUSIONS

This study shows that implementing Circular Economy-Integrated Project-Based Learning (CE-PjBL) goes together with a rise in the Green Pedagogical Competence (GPC) of prospective vocational teacher students: the average GPC score climbed from 63.59 at pretest

to 90.47 at posttest, for an N-Gain of 0.738. This is empirical evidence of change in GPC scores following participation in project-based learning built on circular economy principles, and it points to what CE-PjBL could offer for building sustainability-oriented pedagogical competence more broadly. Reading these results still calls for care, given the study's design characteristics, namely a single-group pretest-posttest design run in one course at one institution, without a comparison group, and reliance on self-report questionnaires that speak to students' perceptions rather than observed competence. Future research should test this model in different vocational education contexts, add a comparison group, and pair questionnaires with observation of teaching practice and assessment of the learning products students create. Such efforts are expected to enrich the empirical evidence regarding CE-PjBL's contribution to GPC development and support the implementation of sustainability-oriented learning in the education of prospective vocational teachers.

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The authors declare that they used ChatGPT for improving grammar and language fluency. Despite using AI, the authors affirm that they are the sole authors of this article and are fully responsible for its content, as outlined in the COPE recommendations.

PARTICIPANT CONSENT

Participants received an explanation of the purpose, procedures, potential risks and benefits of the research, as well as their right to withdraw at any time without consequence. Written consent was obtained from all participants

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

N.I. contributed to the conceptualization of the research idea, development of the Circular Economy-Integrated Project-Based Learning (CE-PjBL) model, research methodology, data analysis, and preparation of the original draft. D. contributed to academic supervision, strengthening the theoretical foundations of vocational education and education for sustainability, and reviewing the manuscript's content. I.H. contributed to the methodological review, interpretation of research findings, and refinement of the discussion. S. contributed to strengthening the vocational education perspective, reviewing the instructional model, and editing the manuscript. A.R.F. contributed to research implementation, collection and organization of pretest and posttest data, and documentation of the learning activities. Z.A. contributed to data processing, N-Gain calculation, and presentation of the analytical results.

A.A.M.P. contributed to the literature review, documentation of the learning implementation, and manuscript review. P.A. contributed to reference organization, research documentation, and final manuscript proofreading. All authors declare that they have read and approved the final version of the manuscript. The total contribution percentages for the conceptualization, research implementation, analysis, writing, and editing of the manuscript are as follows: N.I. (25%), D. (15%), I.H. (15%), S. (15%), A.R.F. (10%), Z.A. (10%), A.A.M.P. (5%), and P.A. (5%), totaling 100%.

REFERENCES

Abdi, M., Beigzadeh, A., Hayat, A. A., Keshavarzi, M. H., & Rezaei, H. (2025). Effectiveness of a short course in communication skills for medical doctors: Evaluation based on a one group pretest posttest design. *Research and Development in Medical Education*, 14(1), 33267–33267. https://doi.org/10.34172/RDME.025.33267

Anderson-Cook, C. M. (2005). Experimental and Quasi-Experimental Designs for Generalized Causal Inference. *Journal of the American Statistical Association*, 100(470), 708–708. https://doi.org/10.1198/JASA.2005.S22

Barry, E. S., Merkebu, J., & Varpio, L. (2022). State-of-the-art literature review methodology: A six-step approach for knowledge synthesis. *Perspectives on Medical Education*, 11(5), 281–288. https://doi.org/10.1007/s40037-022-00725-9

Birdman, J., Wiek, A., & Lang, D. J. (2022). Developing key competencies in sustainability through project-based learning in graduate sustainability programs. *International Journal of Sustainability in Higher Education*, 23(5), 1139–1157. https://doi.org/10.1108/IJSHE-12-2020-0506

Dsilva, J., Zarmukhambetova, S., & Locke, J. (2023). Assessment of building materials in the construction sector: A case study using life cycle assessment approach to achieve the circular economy. *Heliyon*, 9(10). https://doi.org/10.1016/j.heliyon.2023.e20404

Gannar, S., & Kilani, C. (2025). Contextualized Learning and Social Constructivism: Implementing a Project-Based Approach in Information Systems Development Education. *Journal of Science Learning*, 8(1), 15–24. https://doi.org/10.17509/jsl.v8i1.72667

Hamid, N. A., Kamaruzaman, F. M., & Rasul, M. S. (2024). Concept of circular economy in technical and vocational education: a systematic literature review. *International Journal of Evaluation and Research in Education*, 13(4), 2251–2258. https://doi.org/10.11591/ijere.v13i4.28125

Hamid, N. A., Rasul, M. S., & Kamaruzaman, F. M. (2024). Circular Economy and Sustainable Technology in Technical and Vocational Education and Training: A Bibliometric Analysis. *International Journal of Learning, Teaching and Educational Research*, 23(9), 141–160. https://doi.org/10.26803/IJLTER.23.9.8

Hazari, A. (2023). Sampling Types and Methods. *Research Methodology for Allied Health Professionals*, 31–39. https://doi.org/10.1007/978-981-99-8925-6_6

Heriani, D., Simanjuntak, T., Agustinasari, E., & Wang, X. (2026). Sustainability-Oriented English for Specific Purposes Learning in TVET: A Comparative Study of Green Communication Competence between Indonesia and China. *Journal of Education Technology*, 10(1), 130–139. https://doi.org/10.23887/JET.V10I01.105829

Imansari, N., Ardi, P., & Endramawan, P. (2022). Development of Interactive E-Books on Digital Circuits to Improve Technology and Engineering Literacy Skills for Electrical Engineering Education Students. *Jurnal Education And Development*, 10(3), 84–87. https://journal.ipts.ac.id/index.php/ED/article/view/3829

Jeronen, E., & Jeronen, J. (2026). Bibliometric and Content Analysis of Sustainable Education in Biology for Promoting Sustainability at Primary and Secondary Schools and in Teacher Education. *Education Sciences*, 16(2), 201. https://doi.org/10.3390/EDUCSCI16020201

Keramitsoglou, K., Litseselidis, T., & Kardimaki, A. (2023). Raising effective awareness for circular economy and sustainability concepts through students' involvement in a virtual enterprise. *Frontiers in Sustainability*, 4, 1060860. https://doi.org/10.3389/frsus.2023.1060860

Kougias, K., Sardianou, E., & Saiti, A. (2023). Attitudes and Perceptions on Education for Sustainable Development. *Circular Economy and Sustainability*, 3(1), 425–445. https://doi.org/10.1007/s43615-022-00174-w

Larasati, S. D., Herpratiwi, & Caswita. (2026). The Effectiveness of Using Problem Based Learning-Based Student Worksheets to Improve Elementary School Students' Mathematical Problem-Solving Skills. *International Journal of Post Axial: Futuristic Teaching and Learning*, 4(3), 1879–1889. https://doi.org/10.59944/POSTAXIAL.V4I3.1802

Lenziardi, R., Méxas, M. P., Lucas, M., & Sá, P. (2025). Enhancing Teacher Competences in Education for Sustainable Development (ESD): A Value-Oriented Framework. *Journal of Teacher Education for Sustainability*, 27(1), 6–32. https://doi.org/10.2478/jtes-2025-0002

Lewis, P. (2025). Innovation, technician skills, and vocational education and training: connecting innovation systems and vocational education and training. *Journal of Vocational Education and Training*, 77(2), 364–391. https://doi.org/10.1080/13636820.2023.2215749

Lozjanin, A., Chhabra, G., & Mehdian, N. (2025). Exploring green pedagogy for eco-centric praxis-based learning in higher education. *Journal of Applied Learning & Teaching*, 8(S1), 66–79. https://doi.org/10.37074/jalt.2025.8.S1.12

Meijer, K., Baartman, L., Vermeulen, M., & de Bruijn, E. (2023). Teachers' conceptions of assessment literacy. *Teachers and Teaching*, 29(7–8), 695–709. https://doi.org/10.1080/13540602.2023.2190091

Menon, S., & Suresh, M. (2022). Development of assessment framework for environmental sustainability in higher education institutions. *International Journal of Sustainability in Higher Education*, 23(7), 1445–1468. https://doi.org/10.1108/IJSHE-07-2021-0310

Mozumder, M. M. H., & Schneider, P. (2026). Advancing sustainability through the circular economy in small-scale fisheries: A global review of practices, challenges, and policy innovations. *Marine Policy*, 185, 107001. https://doi.org/10.1016/J.MARPOL.2025.107001

Muaddab, H. (2024). Promoting Green Skill and Green Vocational Education for a Circular Economy: A Literature Review. *JOURNAL OF EDUCATION: DEVELOPMENT AND REVIEW (JEDAR)*, 1(1), 8–20. https://pub.ruangrosadi.com/jurnal-ilmiah/index.php/jedar/article/view/2

Mukhuty, S., Upadhyay, A., & Rothwell, H. (2022). Strategic sustainable development of Industry 4.0 through the lens of social responsibility: The role of human resource practices. *Business Strategy and the Environment*, 31(5), 2068–2081. https://doi.org/10.1002/BSE.3008

Omelianenko, O., & Artyukhova, N. (2024). Project-Based Learning: Theoretical Overview And Practical Implications For Local Innovation-Based Development. *Economics & Education*, 9(1), 35–41. https://doi.org/10.30525/2500-946x/2024-1-6

Otasowie, O., Aigbavboa, C. O., & Oke, A. E. (2025). The Principles of Circular Economy. In *Circular Economy Business Model for Construction Organisations*. Springer. https://doi.org/10.1007/978-3-031-88322-4_2

Pambudi, D. A., Mindarta, E. K., Futnawati, K. E., Nugraha, D. S., & Kusmanto, K. (2026). Consistent Individual Learning Gains Following Problem-Based Learning in Automotive Lighting and Signaling Systems: A One-Group Pretest-Posttest Study in Vocational Education. *EDUCARE: Jurnal Pendidikan Dan Kesehatan*, 4(1), 614–637. https://j-edu.org/index.php/edu/article/view/129

Raifman, S., DeVost, M. A., Digitale, J. C., Chen, Y.-H., & Morris, M. D. (2022). Respondent-Driven Sampling: a Sampling Method for Hard-to-Reach Populations and Beyond. *Current Epidemiology Reports*, 9(1), 38–47. https://doi.org/10.1007/S40471-022-00287-8

Renfors, S. M. (2024). Education for the circular economy in higher education: an overview of the current state. *International Journal of Sustainability in Higher Education*, 25(9), 111–127. https://doi.org/10.1108/IJSHE-07-2023-0270

Satriani, R. D., & Prasojo, L. D. (2024). The Effectiveness of Website-Assisted Learning Multimedia to Improve Mathematics Learning Achievement of Elementary School Students. *Journal of Integrated Elementary Education*, 4(2), 120–135. https://doi.org/10.21580/JIEED.V4I2.21523

Suharno, S., Ihsan, F., Himawanto, D. A., Pambudi, N. A., & Rizkiana, R. (2025). Sustainability development in vocational education: a case study in Indonesia. *Higher Education, Skills and Work-Based Learning*, 15(3), 668–689. https://doi.org/10.1108/HESWBL-01-2024-0018

Susanto, A., Fithriyah, N. N., Pujiastuti, A. U., Nuraeni, Z., Ramadhani, W., Alfarisa, F., Rahayu, D. P., Anisah, A., & Tanggu Mara, A. A. P. (2026). A Unified Validation Framework for Assessing Green Skills Implementation from Basic to Vocational Education: A Measurement Invariance Approach. *F1000Research*, 15, 203. https://doi.org/10.12688/f1000research.175658.1

Trevisan, A. H., Boscarato, A., Acerbi, F., Terzi, S., & Sassanelli, C. (2025). Enhancing Circular Economy education and training for the manufacturing sector: A holistic skills framework. *Journal of Environmental Management*, 380, 124982. https://doi.org/10.1016/J.JENVMAN.2025.124982

Triyono, A., Nuary, R. H., Permatasari, N., Yuni, Y., & Wibowo, T. (2024). The Level of Effectiveness of TPS and Conventional Methods Judging from Students' Geometry Learning Results Using the N-Gain Test. *AlphaMath : Journal of Mathematics Education*, 10(1), 142–156. https://doi.org/10.30595/ALPHAMATH.V10I1.21530

Tutore, I., Falcone, P. M., & Chianese, L. (2026). Springing into sustainability: Assessing experiential learning outcomes for circular economy competences. *Journal of Cleaner Production*, 552, 147964. https://doi.org/10.1016/J.JCLEPRO.2026.147964

Wu, D., He, Y., Chen, S., Qin, Z., & Huang, Y. (2026). From national green transition awareness to sustainable development attitudes: Professional responsibility identity as a mediator among polymer materials undergraduates. *Education for Chemical Engineers*, 57, 100516. https://doi.org/10.1016/J.ECE.2026.100516

Yang, S. C. (2026). Modeling the structural interdependence of youth sustainability competencies using UNESCO's key competency framework. *Environmental Education Research*. https://doi.org/10.1080/13504622.2026.2684979