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Effectiveness of Learning Model Based on Sustainable Development for Indonesian Prospective Electrical Engineering Educators

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Abstract
Sustainable development has become crucial in various fields, including electrical engineering education. This study proposes a learning model incorporating sustainable development principles to better prepare prospective electrical engineering teachers in Indonesia. The model emphasizes interdisciplinary learning outcomes, cognitive mapping of sustainability concepts, and the integration of environmental ethics into the curriculum. The development of the model uses the ADDIE model and involves participants consisting of several potential users and experts. The investigation results show that the developed model is quite effective based on the criteria according to the N-Gain coefficient obtained.

Keywords: Electrical Engineering Education, Sustainable Development, Interdisciplinary Learning, Environmental Ethics

1. Introduction

In light of pressing environmental challenges, future educators in electrical engineering must acquire the necessary knowledge, skills, and attitudes to weave sustainable development principles into their teaching methods (Yue & Ji, 2021). The training of electrical engineers is crucial for developing professionals skilled in creating and implementing sustainable practices and innovations. This study introduces a pedagogical framework to equip future electrical engineering instructors with the knowledge and skills to integrate sustainability into their teaching and professional activities (Gelles et al., 2021). The need for sustainable solutions is more pressing than ever, and engineers play a crucial role in addressing these challenges. However, traditional engineering education often fails to prepare graduates with the interdisciplinary skills to tackle complex environmental, economic, and social issues. Many educational institutions now integrate interdisciplinary approaches into their engineering programs to bridge this gap. It combines knowledge from various fields, such as environmental science, economics, and social sciences, to develop holistic solutions. For example, some programs focus on sustainable infrastructure

development, where students learn to design and manage projects that consider environmental impact, social equity, and economic viability (Songer & Recalde, 2021).

Moreover, there is a growing emphasis on incorporating real-world problems into the curriculum, encouraging students to work on projects that address global challenges like climate change, resource scarcity, and urbanization. This hands-on experience helps students develop critical thinking and problem-solving skills to create sustainable solutions (Jumrodah et al., 2019).

By fostering an interdisciplinary mindset, engineering education can better equip graduates to meet the demands of our rapidly changing world and contribute to a more sustainable future (Waters, 2022). Consequently, a paradigm shift in engineering curricula is necessary to cultivate future professionals capable of leading the charge toward sustainable development. Awareness of the pressing need for sustainable practices and innovations has been growing, and the sustainability debate has evolved from whether changes are necessary to what kind of changes are needed and how they can be carried out. Engineers are now considered key players in devising and implementing sustainable solutions, yet they often find themselves ill-prepared for this responsibility (Crofton, 2000; Zoghi et al., 2015). This study proposes a comprehensive learning model that empowers aspiring electrical engineering educators to integrate sustainable development principles into their teaching and research seamlessly. The need for a shift in engineering education is further underscored by the global challenges outlined in the United Nations Sustainable Development Goals (SDGs), which call for developing a technical workforce capable of designing and continuously improving sustainable processes and products.

The proposed learning model for prospective electrical engineering teachers is grounded in the principles of sustainable development and aims to equip these future educators with the necessary competencies to integrate sustainability across their instructional practices, research endeavors, and broader engagement with the community.

Sustainability is becoming a pivotal focus in engineering as the world faces multifaceted environmental, economic, and social challenges that require innovative and interdisciplinary solutions. Engineers are considered key players in addressing these sustainability challenges. Yet, it is increasingly acknowledged that existing engineering education curricula do not sufficiently equip students with the essential knowledge, skills, and attitudes to confront these critical issues in their professional futures (Thürer et al., 2018).

The proposed learning model addresses gaps by establishing a holistic, competency-based framework encompassing knowledge, skills, and attitudes. The knowledge aspect ensures that future electrical engineering educators thoroughly comprehend the scientific concepts, technological progress, and systemic interconnections essential to sustainable development. The skills aspect fosters critical thinking, problem-solving, teamwork, and communication skills vital for effectively applying sustainable practices in educational and professional contexts. Building on this base, the attitudinal aspect of the model strives to develop a sustainability mindset marked by responsibility, environmental stewardship, and a dedication to ongoing learning and enhancement (Redman & Wiek, 2021). This learning model's execution is designed as a comprehensive strategy that combines classroom instruction, practical experiential learning, and cooperative project-driven tasks.

Current research indicates that although engineering educators understand the significance of sustainability education, there is an inconsistency in the breadth and methods applied (Dhinakaran et al., 2020). Therefore, creating an all-encompassing educational model that thoroughly acquaints students with the various facets of sustainability issues, equipping them to make knowledgeable choices, and promoting sustainable practices is crucial. Sustainable learning acknowledges that education must provide learners with pertinent knowledge and hands-on skills for their personal and professional application. Incorporating sustainable learning methods into electrical engineering curricula can foster the growth of essential critical thinking, problem-solving, and decision-making abilities needed to tackle the intricate issues of sustainable development.

By implementing the proposed learning model, prospective electrical engineering teachers will be equipped with the necessary competencies to effectively integrate sustainability into their teaching and professional practice,

ultimately contributing to the development of a new generation of electrical engineers who are prepared to address the pressing environmental, economic, and social challenges of the 21st century (Karjanto, 2023). Through the comprehensive integration of sustainability-focused knowledge, skills, and attitudes, this learning model aims to cultivate a cadre of electrical engineering educators equipped to nurture a new generation of professionals capable of spearheading sustainable solutions for a more resilient and equitable future.

The demand for sustainable solutions intensifies as the world confronts urgent environmental, economic, and social challenges. Electrical engineers are in a prime position to lead the development of these solutions by addressing the involved complexities (Mishra, 2019). Yet, many engineering graduates feel unprepared to fulfill the requirements of sustainable development. The sustainability discourse has matured, recognizing the interplay between environmental, economic, and social elements. To equip future electrical engineers for sustainability, they must acquire the essential knowledge, critical thinking, and decision-making skills to devise sustainable solutions for these intricate problems. Creating a comprehensive educational framework for prospective electrical engineering educators grounded in sustainable development principles is crucial. It will cultivate a new generation of educators who can motivate their students to innovate and contribute to a more sustainable future.

In line with that, the guiding research question for this study is: How can we design a learning model that effectively prepares future electrical engineering educators to weave sustainable development principles into their teaching and professional practice? How effective is this model in enabling preservice electrical engineering teachers to attain the competencies necessary for fostering sustainability in their education and professional roles? This paper introduces a research-informed learning model to prepare future electrical engineering educators with the knowledge, skills, and attitudes necessary to seamlessly integrate sustainable development principles into their teaching and professional practice. The learning model is underpinned by four key principles: 1) Comprehensive sustainable development knowledge: Ensuring that electrical engineering students possess a robust understanding of the scientific, technological, and systemic aspects of sustainable development, including environmental, economic, and social dimensions. 2) Sustainability-focused skills development: Cultivating critical thinking, problem-solving, teamwork, and communication skills essential for applying sustainable practices in educational and professional contexts. 3) Sustainability mindset and attitudes: Fostering a sustainability-oriented mindset marked by responsibility, environmental stewardship, and a commitment to ongoing learning and improvement. 4) Integrated learning and application: Combining classroom instruction, practical, experiential learning, and cooperative project-driven tasks to enable the seamless integration of sustainability principles into teaching and professional practice.

1.1 Electrical Engineering Educator Competencies

An electrical engineering educator's role in preparing students to tackle the complex challenges of sustainable development is vital. Research indicates that these educators need a thorough understanding of sustainability principles, which include environmental, economic, and social aspects, to incorporate them successfully into their teaching and professional practice (Yue & Ji, 2021).

Beyond knowledge, engineering educators must also be equipped with the necessary skills to apply sustainability concepts in real-world contexts, such as critical thinking, problem-solving, teamwork, and communication (Cebrián et al., 2020). Developing a sustainability-oriented mindset and positive attitude is equally important. It fosters a sense of responsibility, environmental stewardship, and a commitment to continuous learning and improvement. A comprehensive learning model is essential to equip future electrical engineering educators with the necessary knowledge, skills, and attitudes. This model should integrate classroom instruction, practical and experiential learning, and cooperative, project-based activities to seamlessly incorporate sustainability principles into teaching and professional practice incorporate sustainability principles into teaching and professional practice (Ben-Eliyahu, 2021).

Classroom instruction must prioritize a comprehensive understanding of sustainable development's scientific, technological, and systemic aspects, encompassing its environmental, economic, and social dimensions. Integrating practical and experiential learning opportunities, such as case studies, simulations, and field

experiences, is imperative to equip students with critical thinking, problem-solving, and application skills crucial for sustainable engineering (Powers et al., 2021). Engaging engineering students in cooperative, project-driven tasks emphasizing teamwork, communication, and sustainability principles can significantly nurture a sustainability-oriented mindset and foster positive attitudes. This hands-on approach enhances their technical skills and instills a sense of responsibility toward sustainable practices. Additionally, these tasks enable the development of teamwork and communication skills while reinforcing the integration of sustainability principles into actual practice.

Ultimately, the learning model should empower future electrical engineering educators to become agents of change, capable of inspiring their students to innovate and contribute to a more sustainable future. The importance of sustainability education is becoming more evident in engineering curricula, with a growing emphasis on sustainability competencies for engineering graduates (Wilson, 2019). However, the methods to integrate sustainability into engineering education vary and often lack uniformity. Some approaches focus on analytical methods like life-cycle assessments, while others aim for system transformation through management and innovation. This diversity in methods highlights the need for a more standardized approach to embed sustainability in engineering education effectively. This learning model is designed to develop a comprehensive set of competencies for aspiring electrical engineering educators, equipping them to effectively incorporate sustainability into their teaching and professional activities. Anchoring this learning model to sustainable development principles is crucial to ensure that future educators in electrical engineering have the requisite knowledge, skills, and attitudes to foster sustainable practices in their teaching and professional endeavors (Mukhtar et al., 2020).

Sustainable development education has gained prominence in various disciplines, including engineering, to equip learners with the necessary knowledge, skills, and mindsets to address complex sustainability challenges. As highlighted in the literature, integrating sustainability into engineering education requires a multifaceted approach that addresses curricular and pedagogical aspects (Powers et al., 2021). Educators must understand the interconnectedness between environmental, economic, and social dimensions of sustainability (Qu et al., 2020). Furthermore, developing critical thinking, problem-solving, and collaborative skills is essential for engineers to navigate the intricate challenges of sustainable development (Chandu & Kancharla, 2012).

Importantly, research suggests that a sustainability-oriented mindset, marked by a sense of responsibility, environmental stewardship, and a commitment to lifelong learning, is crucial in preparing engineers for the evolving sustainability landscape (Thürer et al., 2018). By cultivating these attitudes, future electrical engineering educators can role-model and instill sustainability-minded behaviors in their students, empowering them to become agents of change in their professional pursuits.

The learning model proposed in this study aims to seamlessly integrate sustainability principles into the education of prospective electrical engineering teachers, equipping them with the necessary competencies to effectively teach and model sustainable practices in their classrooms and professional work. Sustainable development requires a multifaceted approach considering the interconnected environmental, economic, and social dimensions. To that end, the proposed learning model emphasizes the development of four key competency areas: 1) Sustainability Knowledge, 2) Systems Thinking, 3) Critical Thinking and Decision-Making, and 4) Pedagogical Strategies for Sustainability Education (Yue & Ji, 2021). Sustainability Knowledge: Prospective electrical engineering teachers must possess a deep understanding of the core principles and concepts of sustainable development, including environmental protection, resource efficiency, renewable energy, and social equity. This knowledge base will enable them to make informed decisions and develop innovative solutions to address sustainability challenges within their teaching and professional practice (Guo et al., 2020). Systems Thinking: Sustainability issues are inherently complex, requiring a holistic perspective considering the interconnections and interdependencies between environmental, economic, and social systems. Cultivating systems thinking skills in prospective electrical engineering teachers will empower them to analyze and address sustainability challenges from a multidimensional viewpoint, fostering more comprehensive and integrated solutions (Thürer et al., 2018). Critical Thinking and Decision-Making: Addressing sustainability challenges requires navigating ambiguity, conflicting priorities, and complex trade-offs. Developing critical thinking and decision-making skills will equip prospective electrical engineering teachers to analyze information, evaluate alternatives, and make well-informed decisions that

prioritize sustainable outcomes (Nurdiansyah et al., 2019). Pedagogical Strategies for Sustainability Education: Effective integration of sustainability into electrical engineering education necessitates adopting innovative pedagogical approaches that engage students and foster active learning. Prospective teachers must be equipped with a repertoire of teaching strategies, such as case-based learning, project-based learning, and collaborative problem-solving, to effectively deliver sustainability-focused content and cultivate sustainable mindsets and behaviors in their students (Gómez et al., 2019).

1.2 Learning Model Based on Sustainable Development

This educational model aims to develop a wide array of skills in future electrical engineering educators, preparing them to seamlessly integrate sustainability principles into their teaching methods and professional behavior. The model includes four interrelated areas of competence: Sustainability Knowledge, Systems Thinking, Critical Thinking and Decision-Making, and Pedagogical Strategies for Sustainability Education (Yue & Ji, 2021).

Sustainability Knowledge: Aspiring electrical engineering instructors need a thorough grasp of fundamental principles and concepts related to sustainable development, such as environmental conservation, resource efficiency, renewable energy, and social fairness. This foundation will allow them to make educated choices and devise creative approaches to overcome sustainability obstacles in their educational and professional activities.

Systems Thinking: The complexity of sustainability issues demands a comprehensive approach that acknowledges the connections and dependencies among environmental, economic, and social systems. By fostering systems thinking abilities in future electrical engineering educators, they will be better equipped to analyze and tackle sustainability challenges from a multifaceted perspective, leading to more holistic and integrated solutions.

Critical Thinking and Decision-Making: Confronting sustainability challenges involves uncertainty, competing interests, and intricate compromises. Enhancing these educators' critical thinking and decision-making abilities will prepare them to scrutinize data, weigh options, and make informed choices that favor sustainable results.

Pedagogical Strategies for Sustainability Education: Successfully incorporating sustainability into electrical engineering education requires innovative teaching methods that captivate students and promote participatory learning. Prospective teachers must be equipped with a repertoire of pedagogical approaches, such as case-based learning, project-based learning, and collaborative problem-solving, to effectively deliver sustainability-focused content and cultivate sustainable mindsets and behaviors in their students (Parry & Metzger, 2023; Yue & Ji, 2021; Wilson, 2019).

The proposed learning model aims to equip prospective electrical engineering teachers with the necessary competencies to integrate sustainability principles into their teaching and professional practice. This holistic approach, encompassing knowledge, skills, and pedagogical strategies, will empower these educators to model sustainable behaviors, inspire their students, and drive meaningful change toward a more sustainable future in the electrical engineering field. Furthermore, the model's emphasis on experiential learning and reflective practice aligns with best practices in teacher education. Providing preservice teachers with opportunities to apply their knowledge and skills in real-world contexts while engaging in critical self-reflection is crucial for developing their ability to design and implement sustainability-focused curricula and teaching strategies.

2. Method

The proposed learning model for prospective electrical engineering teachers was developed through a comprehensive review of the existing sustainability education literature, focusing on the intersection of engineering education and sustainable development. The model's four key competency areas were identified by analyzing the common themes and recommendations across the selected sources. The source discussions highlight the need for a multifaceted approach to sustainability education, encompassing knowledge, skills, and pedagogical strategies that enable future electrical engineering educators to effectively integrate sustainability principles into

their teaching and professional practice. The proposed learning model represents a holistic framework that aims to equip prospective electrical engineering teachers with the necessary competencies to integrate sustainability into their teaching and professional behavior.

This learning model is a blueprint for curriculum development and teacher preparation programs, guiding the critical knowledge, skills, and pedagogical approaches required to cultivate sustainability-focused electrical engineering educators. The proposed learning model for prospective electrical engineering teachers represents a comprehensive and innovative approach to preparing these educators for the challenges of the 21st century. By equipping them with a robust understanding of sustainability, the ability to think systemically, and a repertoire of effective teaching strategies, this model empowers future electrical engineering educators to play a crucial role in promoting sustainable development within the field of electrical engineering. Figure 1 illustrates the proposed learning model for prospective electrical engineering teachers, highlighting its three interrelated components: Foundational Knowledge, Experiential Learning, and Reflective Practice.

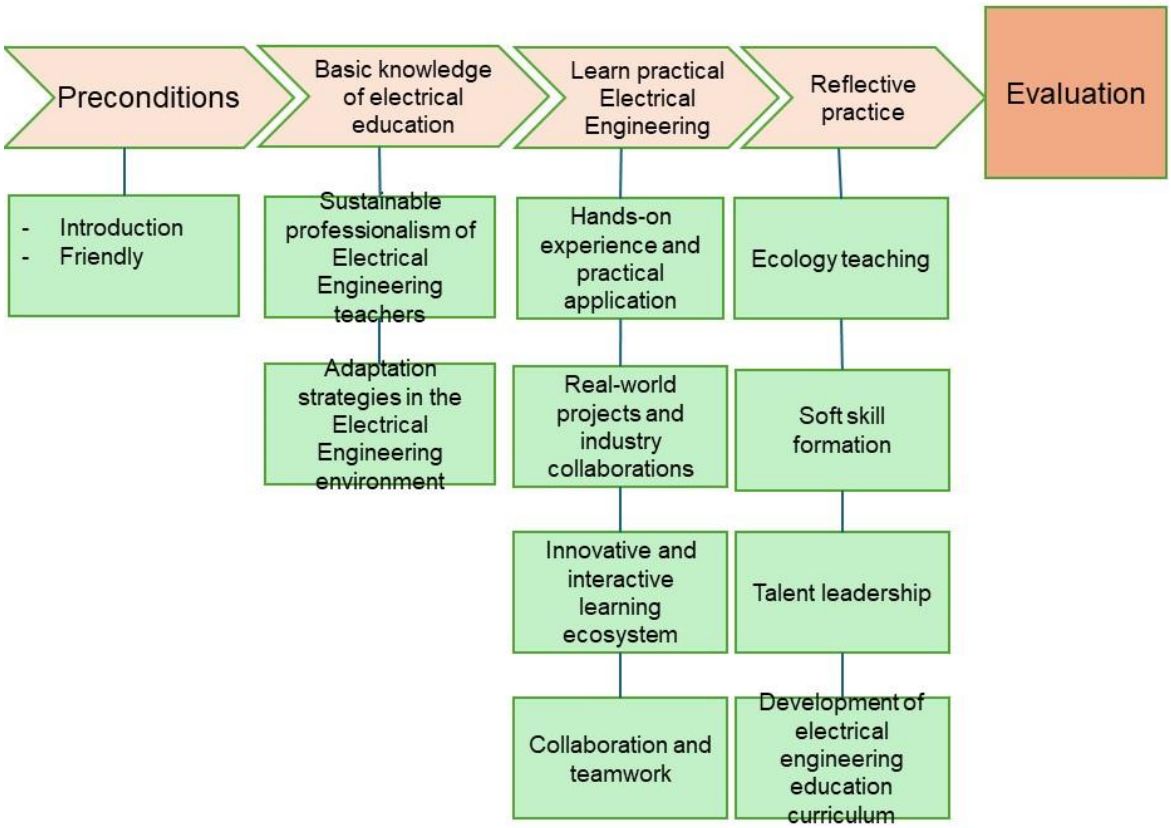

Figure 1: Learning Model for Prospective Electrical Engineering Teachers Based on Sustainable Development

The foundational knowledge component aims to provide prospective teachers with a thorough understanding of sustainable development's core principles and concepts, encompassing environmental, economic, and social aspects.

Experiential Learning: The experiential learning component emphasizes applying sustainability principles in real-world contexts. It enables preservice teachers to develop critical thinking, decision-making, and systems thinking abilities and fosters their ability to design and implement effective sustainability-focused pedagogical strategies.
Reflective Practice: This component encourages ongoing self-evaluation and critical examination of sustainability education beliefs, assumptions, and approaches. It helps cultivate a deep and nuanced understanding of the complexities and challenges of integrating sustainability into electrical engineering education and practice. The proposed learning model is designed for integration within preservice teacher preparation programs in electrical engineering. Its purpose is to equip future educators to incorporate sustainability into their teaching practices and

professional activities. The development model for aspiring electrical engineering educators outlines a comprehensive strategy to provide them with the necessary knowledge, skills, and mindsets to serve as catalysts for progress in advancing sustainable development.

2.1 Learning model examination

Implementing a comprehensive assessment plan is crucial for evaluating the effectiveness of the proposed learning model. This assessment should engage multiple stakeholders, such as preservice teachers, faculty members, and sustainability experts, to guarantee a thorough and equitable evaluation. The assessment plan should encompass formative and summative evaluations to monitor student progress and the overall impact of the learning model.

Formative assessments, such as reflective journals, classroom observations, and project-based evaluations, can provide valuable insights into the preservice teachers' development of sustainability-focused knowledge, skills, and pedagogical approaches.

Summative assessments, including capstone projects, comprehensive exams, and post-program surveys, can measure the learning model's long-term outcomes, such as the preservice teachers' ability to design and implement sustainability-infused curricula, their commitment to sustainability principles, and their impact on their future students' learning and environmental awareness.

The analyzed data identified areas for improvement and informed ongoing refinement of the learning model. Continuous improvement and adaptation are critical to ensuring the model remains relevant and effective in preparing electrical engineering teacher candidates for the evolving sustainability challenges in the field.

Data collection methods include (1) Pre and post-program assessments to measure the development of sustainable competencies among preservice teachers, (2) Classroom observations to evaluate the implementation of sustainability-focused pedagogical strategies, (3) Focus group discussions and interviews with preservice teachers, faculty, and industry partners were used to gather qualitative feedback on the model's impact and areas for improvement of student learning outcomes, such as project-based assignments, reflective journals, and sustainability-focused course projects.

Evaluation findings are used to refine and improve the learning model, ensuring it remains relevant and effective in preparing prospective electrical engineering teachers to integrate sustainability into their teaching and professional practice. Periodic review and refinement of the learning model based on assessment findings ensure its continued relevance and effectiveness in preparing prospective electrical engineering educators to meet sustainable development challenges.

2.2 Data Analysis

Assessment data is collected and analyzed to understand the model's success in achieving its goals. Quantitative data from pre- and post-program assessments can measure ongoing skill improvements among preservice teachers. Qualitative data from classroom observations, focus groups, and interviews can provide insight into the model's impact on teaching methods, implementation of sustainability principles, and preservice teachers' views and experiences. The analysis should reveal strengths and areas for improvement in the instructional model. The results can then inform improvements to the model, ensuring it meets the changing needs of future electrical engineering educators and the sustainability challenges they will face in their profession.

3. Results and Discussion

Analysis of the data collected during the assessment process revealed several key findings. Among them are significant increases in prospective teachers' knowledge and attitudes regarding sustainability, indicating the effectiveness of the fundamental knowledge component of the learning model (N-Gain = .71). The experiential

learning component plays a critical role in developing the critical thinking, problem-solving, and decision-making skills of prospective teachers so that they can apply sustainability principles in practical, real-world contexts. The reflective practice component was instrumental in fostering a deeper understanding of the complexities and challenges of integrating sustainability into electrical engineering education and practice, as evidenced by the preservice teachers' more nuanced perspectives and increased self-awareness. The learning model's evaluation showed that it could provide future electrical engineering educators with the essential knowledge, skills, and attitudes needed to integrate sustainability into their teaching and professional activities effectively. The foundational knowledge component ensures that preservice teachers comprehensively understand sustainable development. In contrast, the experiential learning component enables them to apply this knowledge in practical scenarios, honing their critical thinking and problem-solving abilities. The reflective practice component is precious in cultivating a nuanced perspective on the complexities and challenges associated with sustainability education, empowering preservice teachers to navigate these issues with confidence and adaptability.

The assessment process has also highlighted areas for further refinement and improvement, such as strengthening the connections between the model's components and enhancing the integration of sustainability across the preservice teacher preparation curriculum. The proposed learning model for prospective electrical engineering teachers holds significant promise in equipping future educators with the necessary competencies to effectively incorporate sustainable development principles into their teaching and professional practice. Ongoing refinement and implementation of the model within preservice teacher preparation programs can contribute to developing a new generation of electrical engineering educators who are well-equipped to advance sustainable development within the field. It aligns with the United Nations Sustainable Development Goals 4 and 6 and holds strong potential for a positive impact on the local and global community (Santos et al., 2013; Breslin et al., 2020; Dhinakaran et al., 2020; Karjanto, 2023).

The comprehensive and integrated approach, which includes foundational knowledge, experiential learning, and reflective practice, seems to be a practical framework for equipping future educators to spearhead sustainable development in electrical engineering (Qu et al., 2020). By establishing a solid base in sustainability principles, offering practical application opportunities, and encouraging self-reflection, this educational model prepares preservice teachers to act as change-makers, adept at creating and applying innovative teaching strategies centered on sustainability. The proposed learning model for prospective electrical engineering teachers represents a promising approach to equipping future educators with the necessary knowledge, skills, and attitudes to effectively integrate sustainable development principles into their teaching and professional practice.

Integrating this learning model within preservice teacher preparation programs can catalyze the transformation of electrical engineering education, ensuring that the next generation of educators is well-equipped to address the world's pressing sustainability challenges. This comprehensive learning model for prospective electrical engineering teachers holds immense promise in advancing the integration of sustainability principles within electrical engineering education and practice.

4. Conclusions

The proposed learning model for prospective electrical engineering teachers offers a comprehensive framework to equip future educators with the necessary knowledge, skills, and attitudes to effectively integrate sustainable development principles into their teaching and professional practice. The key components of the model - foundational knowledge, experiential learning, and reflective practice - work in tandem to develop preservice teachers' capabilities in addressing the multifaceted challenges of sustainability within the field of electrical engineering. Evaluation of the learning model through qualitative and quantitative data collection has demonstrated its efficacy in enhancing preservice teachers' understanding and application of sustainability concepts and their ability to navigate the complexities associated with sustainability education. Ongoing refinement and implementation of this learning model within preservice teacher preparation programs can be pivotal in cultivating a new generation of electrical engineering educators well-equipped to spearhead sustainable development integration within the field.

5. Limitation

While the implementation and evaluation of this learning model have yielded promising results, future research and implementation efforts should acknowledge certain limitations. First, the study was conducted within a specific preservice teacher preparation program, and the generalizability of the findings to other contexts may be limited. Additional research is needed to assess the model's effectiveness in diverse educational settings and across preservice teacher populations. Second, the long-term impact of the learning model on the preservice teachers' future teaching practices and their ability to influence sustainable development within the field of electrical engineering remains to be examined. Longitudinal studies tracking the professional trajectories and sustainability-related practices of the preservice teachers who have undergone this learning model would provide valuable insights into its long-term effectiveness.

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