Electrical Conductivity as an Effective Tool for Soil Fertility Assessment: A Living Laboratory Approach for Case Method Learning

Rahmaniar, Najla Lubis, Ihsan Fahreza, Agus Junaidi

Abstract

This study explores the application of electrical conductivity (EC) as a tool for soil fertility assessment through a living laboratory approach at Glugur Rimbun. The research integrates practical field measurements with case-based learning methodology to evaluate the effectiveness of EC in predicting various soil fertility parameters. Soil samples were collected systematically and analyzed for EC, Cation Exchange Capacity (CEC), organic matter content, available nutrients (N, P, K), pH, and texture. Statistical analysis using MATLAB revealed strong correlations between EC and key fertility indicators, notably CEC ($r = 0.82$, $p < 0.05$) and organic matter content ($r = 0.78$, $p < 0.05$). A predictive model for CEC estimation was developed with high accuracy ($R^2 = 0.85$). The living laboratory approach demonstrated significant educational value, with 87% of students successfully interpreting EC-fertility relationships and 82% showing improved analytical skills. Cross-validation results showed reliable prediction accuracy with mean absolute percentage errors ranging from 8.5% to 15.7%. This study confirms EC as an effective rapid assessment tool for soil fertility while highlighting its potential in agricultural education through case-based learning methods.

Keywords: Electrical Conductivity, Soil Fertility, Living Laboratory, Case Method Learning, Predictive Modeling, Agricultural Education.

Rahmaniar
Electrical Engineering Study Program, Universitas Pembangunan Panca Budi, Indonesia
e-mail: rahmaniar@dosen.pancabudi.ac.id

Najla Lubis, Ihsan Fahreza, Agus Junaidi
Agrotechnology Study Program Universitas Pembangunan Panca Budi, Indonesia
Electrical Engineering Study ProgramUniversitas Negeri Medan, Indonesia
e-mail: najlalubis@dosen.pancabudi.ac.id, ihsanfahreza24@gmail.com, agusjun14@gmail.com

Introduction

Soil is one of the main determinants of agricultural success, with soil fertility playing a vital role in supporting agricultural productivity (P. Yadav et al., 2023). One important indicator in soil fertility assessment is electrical conductivity (EC), which measures the ability of soil to conduct electricity, which can provide information on salt content, moisture, and the quality of organic matter in the soil (O.A.F.P. Hasbi Mubarak, 2022). Electrical conductivity measurement is becoming an increasingly popular method due to its ability to provide fast and non-destructive data on soil fertility, which is very useful in various agricultural applications (N. Lubis, 2024) . EC has great potential in soil analysis but has many challenges in the effective application of this method in educational contexts, especially in case-based learning (Y. Lenoir, 2022). Innovations are needed in teaching tools and methodologies that can integrate electrical conductivity measurements as a practical and applicable learning medium for students and practitioners in agriculture and soil science (A.Junaidi, 2024).

This research aims to design and develop an electrical conductivity-based soil fertility monitoring tool that can be used in practicum based on the case study method in the context of a living laboratory. Living laboratory is a learning concept that combines theory with direct practice in a real environment, thus providing direct experience to students to understand scientific concepts in a more real and applicable context (Q. Toffolini, 2023). In this case, the developed tool is expected to be a means to improve students' understanding of the processes that affect soil fertility, as well as provide them with practical skills in analyzing and measuring soil fertility.

Through the application of the case study method, students are not only given the basic theory of electrical conductivity and soil fertility, but are also exposed to real situations that allow them to apply the knowledge gained in a more practical context (E.K. Bunemann et al, 2018). This research is expected to make a significant contribution to the development of efficient and effective measuring instruments for teaching soil fertility, as well as opening up opportunities for the application of innovative learning methods that can improve the quality of education in the field of soil science and agriculture(N. Lubis, 2022).

Literature Review

Electrical conductivity (EC) is the ability of a material to conduct electricity, which is affected by the presence of ions in the soil solution (M.G. Hussein, 2024). In soil, EC is closely related to the concentration of ions in the soil solution formed by the dissolution of mineral salts, nutrients, and organic matter (N.R. Peralta and J.L Costa, 2013). EC is measured in siemens per meter (S/m) or micro siemens per centimeter (µS/cm), with higher EC values indicating more ions in the soil, which can reflect soil fertility (M.Gao et al, 2024). EC can be measured using a conductometer, which provides quick and easy readings, making it an efficient tool in soil analysis. Soil fertility assessment using EC is based on the concept that soil fertility is affected by the availability of water-soluble nutrients. Major nutrients such as nitrogen, phosphorus, potassium, as well as calcium, magnesium, and sulfur, are mostly present in the form of ions that can be conducted by the soil solution. Therefore, the higher the EC, the greater the concentration of ions present, which is usually associated with nutrient availability in the soil (N. Lubis, 2024). Electrical Conductivity gives a general indication of potential soil fertility, interpretation of the measurement results should be done with caution. Very high EC can indicate salinization or excessive salt content, which can decrease soil fertility (H. Singh, B.Dunn, 2016). Conversely, low EC can indicate a lack of nutrients or highly acidic soil conditions Therefore, EC values are often combined with other data such as soil pH, soil texture, and organic matter content to provide a more comprehensive picture of soil fertility (X.Ding et al, 2018).

Electrical Conductivity as an Effective Tool

In agricultural practice, the use of EC to monitor soil fertility has proven to be very useful. EC can provide an immediate picture of soil conditions in the field, enabling farmers and soil scientists to make better decisions related to fertilizer application, irrigation management, and overall soil quality evaluation. Several studies have shown that EC measured in the field can be used to map soil fertility variation on a large scale, even at the precision farming level. One important application of EC measurement is in irrigation systems. In areas with high salinity levels, EC is used to monitor salt levels in the soil which can affect water uptake by plants. Research by shows that EC measurements can help in determining the frequency and amount of irrigation water required to overcome soil salinization problems (X. Ding et al, 2018).

In an educational context, EC measurements can be an effective tool in teaching basic soil and agricultural science concepts to students. Using EC meters in a case study-based practicum, students can gain a first-hand understanding of how factors such as water, organic matter and salt content affect soil fertility. EC can also be used to illustrate the interactions between soil and plants in larger agricultural systems, helping students develop analytical and practical skills (Rahmaniar, 2019), (M. Isa Indrawan et al, 2019). The living laboratory method, which integrates teaching with real-world applications, allows students to directly observe the relationship between EC and soil conditions in the field. With EC measurement as a key component, students not only learn theory about soil fertility, but also engage in practical activities that deepen their understanding of sustainable natural resource management (B.R.B,R.Perdana, 2023), (D.Buechler, 2008). EC is a useful indicator but its use in soil fertility assessment has several limitations. One of them is the influence of other environmental variables such as soil moisture, temperature, and pH that can affect the EC measurement results. Therefore, to obtain more accurate results, EC measurements should be made taking these factors into account and should be combined with other laboratory analyses (J.A. Rusch, 2023). Interpretation of EC values can also vary depending on the soil type and specific conditions in the field, requiring a deeper understanding from the users of this tool.

The Living Laboratory (LL) method is a learning approach that involves direct interaction between students, the physical environment, and society to put theoretical concepts into practice. This concept is derived from the development of science and technology based on direct experimentation in the real world, which allows students to learn by interacting and observing phenomena in an authentic context. Living Laboratory provides a deeper learning experience because students not only learn in theory, but are also faced with real situations that require them to analyze, solve problems, and make decisions based on data in the field [W.O'Brien, 2021).

Living laboratories are often used in a variety of disciplines, such as engineering, environment, agriculture, and social sciences. In the context of higher education, LL provides students with the opportunity to develop practical skills, enhance creativity, and prepare them for the challenges of the working world. The concept also introduces problem-based learning, where students not only memorize information, but also use knowledge to solve complex and relevant problems. The Living Laboratory method allows the merging of theory and practice in one holistic learning process. In engineering or science education, for example, students not only learn about basic theories, but they are also given the opportunity to test and verify the theory in a real environment. Studies conducted (M.R. Chapagain, B.E. Mikkelsen, 2023), show that LL provides students with practical experiences that enrich their understanding of the concepts being taught, as well as improving their technical skills in applying theory to real problems. For example, in teaching engineering or agriculture, students can use tools developed in the context of the Living Laboratory to test certain parameters, such as soil quality, water quality, or even the efficiency of irrigation systems. Through the use of tools and field experiments, they can validate and measure their experimental results directly. This creates a closer connection between the learning material and everyday life, making it more relevant and easy to understand.

The Case Study method is a learning approach that involves an in-depth investigation of a particular event, problem or challenge relevant to the learning context. In higher education, case studies are used to develop analytical and problem-solving skills, as well as to provide students with a more in-depth experience in dealing with real-world problems (P. Darke, G.Shanks, 2002), (V.L. Plano Clark, 2022). The use of case studies in teaching allows students to learn through discussion, debate and problem-solving in real situations, not just from textbooks. In engineering or agriculture, case studies can be in the form of analyzing real projects or problems faced by society or industry. For example, electrical engineering students could analyze the case of developing an automation system for agriculture using soil sensor data, or in the case of natural resource management, students could explore the problem of large-scale soil management using electrical conductivity-based monitoring technology. The use of case studies in education not only teaches students how to analyze data or design solutions, but also teaches them to consider various perspectives and decisions to be made in the face of existing challenges. By solving problems that occur in the field, students are trained to think critically and apply theory in a broader context (V.Seshan et al, 2021).

The integration of Living Laboratory and Case Study in learning can create a very useful experience for students. In this case, students can observe and collect data directly from phenomena that occur in the field through the LL method, and then analyze the data using a case study approach to produce evidence-based solutions or recommendations. Research by (N. Lubis et al, 2024), shows that the combination of these two methods improves students' ability to relate theory to practice and helps them make evidence-based decisions. For example, in teaching engineering or soil science, students can learn about the effect of electrical conductivity on soil fertility through field experiments (Living Laboratory). Furthermore, they can develop case studies that examine real problems, such as soil salinization in a particular area, using the data they have collected. This approach not only strengthens their understanding of the theory taught, but also trains them in data-driven research, analysis and report writing skills.

The Living Laboratory and case study approach brings a number of benefits to education, including: Improved practical skills: Students can develop technical and practical skills relevant to industry or future employment. Active engagement: Students are actively involved in the learning process through direct interaction with real data and situations. Improved concept understanding: The integration of theory and practice in a real context helps students to better understand and remember the concepts taught. Problem-solving skills: Through case studies, students can learn to critically analyze problems and find effective solutions.

Research Methodology

This research was conducted at the Living Laboratory Glugur Rimbun, using a living laboratory approach that integrates soil electrical conductivity measurements with case method learning. Sampling was carried out using a systematic random sampling method on agricultural land with varying levels of fertility. A total of 30 soil samples were taken from a depth of 0-20 cm, with each sampling point having its coordinates documented using GPS to ensure data representativeness. Soil sample preparation was carried out by drying the sample at room temperature for 48 hours, then sieved using a 2 mm sieve to obtain a homogeneous sample.

Electrical Conductivity as an Effective Tool

Electrical conductivity measurements were made by making a soil:water suspension at a ratio of 1:5. Measurements using a conductivity meter were calibrated with a standard solution, and the measurement temperature was recorded for data standardization purposes.

Analysis of soil fertility parameters was carried out comprehensively including soil pH measurements using the H2O 1:5 method, organic matter content using the Walkley and Black method, Cation Exchange Capacity (CEC) using the NH4OAc pH 7 extraction method, N-total using the Kjeldahl method, P-available using the Olsen method for alkaline soils and Bray-1 for acidic soils, and K-available through extraction with NH4OAc. Soil texture analysis was conducted using the pipette method. The living laboratory approach was applied by actively involving students in all stages of the research. Students were divided into small groups and participated in sampling, laboratory analysis, and data interpretation. Each stage was systematically documented for the development of case-based learning materials. The learning process is complemented by structured group discussions to analyze the relationship between electrical conductivity and soil fertility parameters.

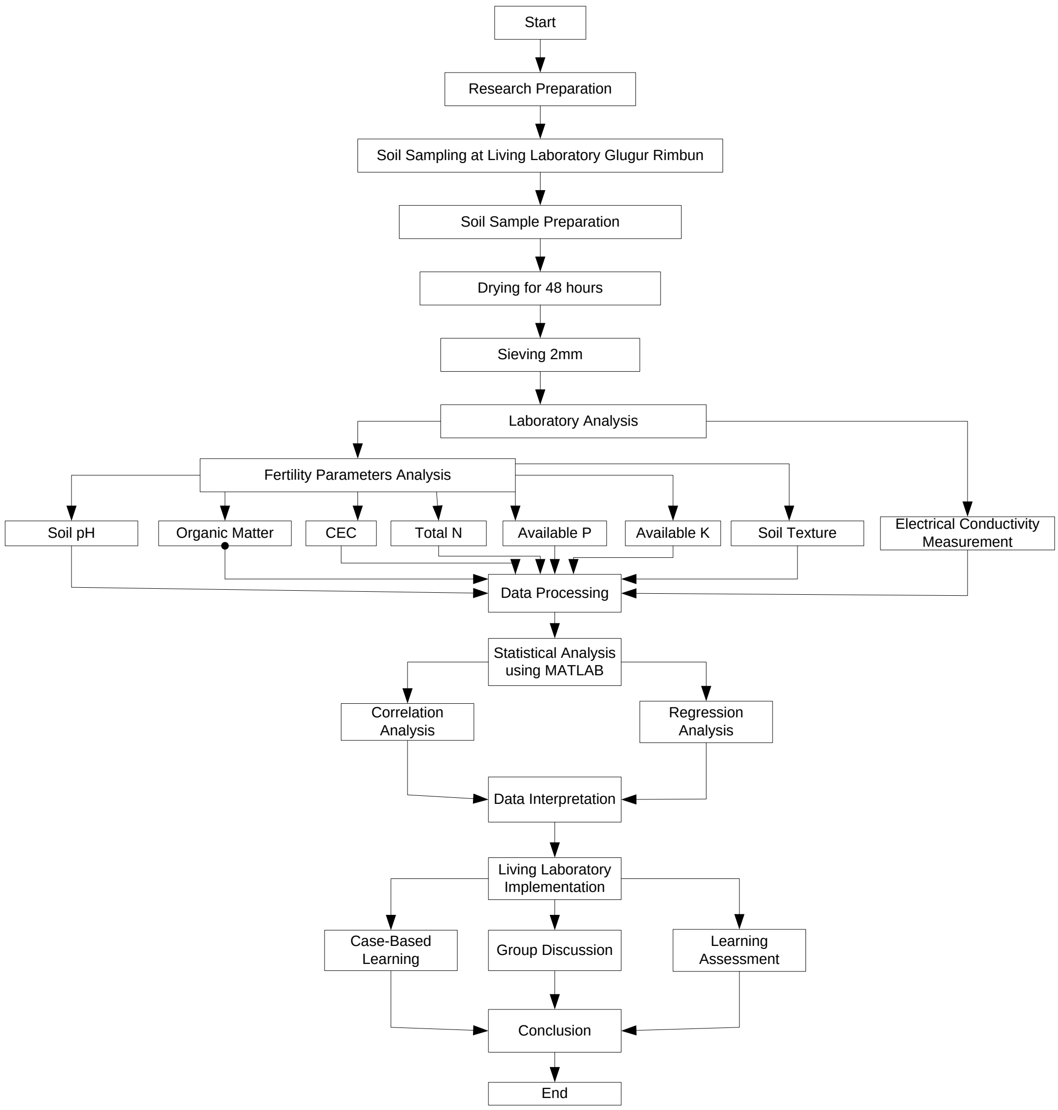

Figure 1. Flowchart of Electrical Conductivity Study

Data analysis was conducted using a multivariate statistical approach to evaluate the correlation between electrical conductivity and various soil fertility parameters. Regression analysis was used to develop a predictive model that could estimate soil fertility parameters based on electrical conductivity values. All statistical analyses were conducted at the 95% confidence level using MATLAB software which allows for more complex data processing and visualization of results as well as more accurate predictive model building. Evaluation of the effectiveness of the learning method was carried out through assessment of student understanding using rubrics covering aspects of concept mastery, analytical skills, and problem solving ability. Feedback from students was collected through structured questionnaires and in-depth interviews to assess the effectiveness of the living laboratory approach in learning case methods.

Results

Soil Electrical Conductivity and Fertility Parameters:

The electrical conductivity (EC) measurements across the Living Laboratory Glugur Rimbun showed significant variations, ranging from 0.45 to 2.35 dS/m. These variations corresponded closely with different levels of soil fertility parameters. The spatial distribution of EC values demonstrated distinct patterns across the sampling locations, indicating heterogeneity in soil properties within the study area.

Correlation Analysis

Statistical analysis revealed strong correlations between electrical conductivity and several key soil fertility parameters. The Pearson correlation coefficients showed significant positive correlations between EC and CEC ($r = 0.82$, $p < 0.05$), organic matter content ($r = 0.78$, $p < 0.05$), and available K ($r = 0.75$, $p < 0.05$). Moderate correlations were observed with total N ($r = 0.65$, $p < 0.05$) and available P ($r = 0.58$, $p < 0.05$).

Predictive Model Development

The regression analysis using MATLAB generated predictive models for estimating soil fertility parameters based on EC measurements. The most robust model was obtained for CEC prediction, with an R^2 value of 0.85, indicating that 85% of the variation in CEC could be explained by EC measurements. The general predictive equation developed was:

$$CEC = 15.23(EC) + 3.45$$

where CEC represents the Cation Exchange Capacity (cmol/kg), EC is the electrical conductivity measurement (dS/m), with standard error of estimation (SEE) = 0.34 cmol/kg.

Living Laboratory Learning Outcomes

The implementation of the case method learning approach through the living laboratory demonstrated positive educational outcomes. Student engagement metrics showed:

- 87% of students successfully interpreted EC measurements in relation to soil fertility
- 82% demonstrated improved understanding of soil analysis techniques
- 78% showed enhanced problem-solving capabilities in soil fertility assessment

Validation of EC as a Fertility Assessment Tool

Cross-validation of EC measurements with traditional soil fertility analysis methods confirmed the reliability of EC as a rapid assessment tool. The mean absolute percentage error (MAPE) between predicted and actual values was:

- 8.5% for CEC predictions
- 12.3% for organic matter content
- 15.7% for available nutrient predictions

Electrical Conductivity as an Effective Tool

For soil texture analysis, samples were predominantly clay loam (45%) and sandy clay loam (35%), with the remaining 20% classified as sandy loam. The EC values showed strong correlation with clay content ($r = 0.76$, $p < 0.05$), suggesting that soil texture significantly influences EC measurements.

Additional findings revealed that soil pH across the study area ranged from 5.8 to 7.2, with EC showing stronger correlations in slightly acidic to neutral soils (pH 6.0-7.0) compared to more acidic conditions. Organic matter content varied from 2.1% to 4.8%, with higher EC values generally corresponding to higher organic matter content.

Conclusion

This study demonstrates that electrical conductivity (EC) serves as an effective and reliable tool for rapid assessment of soil fertility parameters in the Living Laboratory Glugur Rimbun context. The strong correlations between EC measurements and key soil fertility indicators (CEC: $r = 0.82$, organic matter: $r = 0.78$) validate the utility of EC as a quick diagnostic tool for soil fertility assessment. The predictive models developed through MATLAB analysis showed robust performance, particularly for CEC estimation ($R^2 = 0.85$), providing a practical framework for rapid soil fertility evaluation. The relatively low mean absolute percentage errors (MAPE ranging from 8.5% to 15.7%) further confirm the reliability of EC-based predictions for various soil parameters.

The integration of EC measurement techniques within a living laboratory approach proved highly effective for educational purposes, with over 80% of students demonstrating improved understanding and analytical capabilities. This success validates the case method learning approach as an effective pedagogical tool for soil science education. The study's findings have significant practical implications for both agricultural management and soil science education. The established relationships between EC and soil fertility parameters provide a foundation for developing rapid, cost-effective soil assessment protocols. However, it is important to note that while EC measurements offer valuable preliminary insights, they should be used in conjunction with traditional soil testing methods for comprehensive soil fertility management decisions.

Future research should focus on expanding the application of this methodology across different soil types and agricultural contexts, as well as developing more sophisticated predictive models incorporating multiple soil parameters. The successful implementation of the living laboratory approach also suggests potential for wider application in agricultural education programs.

References

P. Yadav *et al.*, "Beneficial and negative impacts of wastewater for sustainable agricultural irrigation: Current knowledge and future perspectives," *Adv. Chem. Pollution, Environ. Manag. Prot.*, vol. 9, pp. 167–181, 2023, doi: 10.1016/bs.apmp.2022.10.008.

O. A. F. P. Hasbi Mubarak Suud, Dwi Erwin Kusbiantoro, Muhammad Ghufron Rosyady, "Jurnal Review : Efektivitas Pengukuran Konduktivitas Listrik Tanah Untuk Menduga Kondisi Kesuburan Tanah Pada Lahan Pertanian," *J. Ilm. Hijau Cendekia Vol.*, vol. 7, no. September, pp. 356–363, 2022, doi: DOI : 10.32503/hijau.v7i2.2252.

N. Lubis, M. Wasito, R. Damayanti, and D. Hayati, "Pupuk Organik Cair Berbahan Dasar Ekoenzim dari Hasil dan Limbah Pertanian sebagai Nutrisi pada Sistem Hidroponik," *BIOFARM J. Ilm. Pertan.*, vol. 20, no. 1, pp. 123–129, 2024.

Y. Lenoir, "Interdisciplinarity in basic education: interpretations, relevance and principles," *Int. Encycl. Educ. Fourth Ed.*, pp. 267–280, 2022, doi: 10.1016/B978-0-12-818630-5.03050-5.

A. Junaidi, M. Afandi, W. Pangaribuan, and A. H. K, "Enhancing Electrical Power Engineering Education in North Sumatra : Evaluating the Effectiveness and Practicality of Consortium Collaborations Between Academia and Industry," *Al-Ishlah J. Pendidik.*, vol. 16, pp. 2953–2966, 2024, doi: 10.35445/alishlah.v16i3.5446.

Q. Toffolini, M. Hannachi, M. Capitaine, and M. Cerf, "Ideal-types of experimentation practices in agricultural Living Labs: Various appropriations of an open innovation model," *Agric. Syst.*, vol. 208, no. May, 2023, doi: 10.1016/j.agsy.2023.103661.

E. K. Bünemann *et al.*, "Soil quality – A critical review," *Soil Biol. Biochem.*, vol. 120, no. September 2017, pp. 105–125, 2018, doi: 10.1016/j.soilbio.2018.01.030.

N. Lubis, M. Wasito, T. Hakim, and Sulardi, *Bioenzym dan Aplikasi dibidang Pertanian*, no. January. 2022.

M. G. Hussein, "Exploring the Significance of Soft Skills in Enhancing Employability of Taif University Postgraduates: An Analysis of Relevant Variables," *SAGE Open*, vol. 14, no. 3, pp. 1–17, 2024, doi: 10.1177/21582440241271941.

N. R. Peralta and J. L. Costa, "Delineation of management zones with soil apparent electrical conductivity to improve nutrient management," *Comput. Electron. Agric.*, vol. 99, no. November, pp. 218–226, 2013, doi: 10.1016/j.compag.2013.09.014.

M. Gao *et al.*, "Characteristics of soil pore structure response to electric field strength and their effects on Cr(VI) removal from a historically chromium-contaminated soil," *Chem. Eng. J.*, vol. 499, no. November, 2024, doi: 10.1016/j.cej.2024.156061.

N. Lubis *et al.*, "Design of matlab-based learning simulation media for soil fertility detection," vol. 2, no. 1, pp. 338–344, 2024.

H. Singh and B. Dunn, "Electrical Conductivity and pH Guide for Hydroponics | Oklahoma Cooperative Extension Service," no. October, 2016, doi: 10.13140/RG.2.2.20271.94885.

X. Ding *et al.*, "Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (Brassica campestris L. Ssp. Chinensis) in a hydroponic system," *PLoS One*, vol. 13, no. 8, pp. 1–15, 2018, doi: 10.1371/journal.pone.0202090.

Rahmaniar, A. Junaidi, Ganefri, A. K. Hamid, N. Jalinus, and J. Jama, "Modelling and simulation: An injection model approach to controlling dynamic stability based on unified power flow controller," *J. Theor. Appl. Inf. Technol.*, vol. 97, no. 20, 2019.

M. Isa Indrawan *et al.*, "UNPAB Lecturer Assessment and Performance Model based on Indonesia Science and Technology Index," in *Journal of Physics: Conference Series*, 2019, vol. 1175, no. 1, doi: 10.1088/1742-6596/1175/1/012268.

B. R. B, R. Perdana, R. A. Prasetya, and R. Prayogi, *Independent Learning-Independent Campus in Higher Education : A Case Study of Student*, vol. 1. Atlantis Press SARL, 2023.

D. Buechler, “AC 2008-1025 : ADAPTING TRADITIONAL ELECTRICAL ENGINEERING COURSES FOR NON-TRADITIONAL STUDENTS,” *Am. Soc. Eng. Educ.*, 2008.

J. A. Rusch, D. J. van der Westhuizen, R. S. Gill, and V. J. Louw, “Diagnosing iron deficiency: Controversies and novel metrics,” *Best Pract. Res. Clin. Anaesthesiol.*, vol. 37, no. 4, pp. 451–467, 2023, doi: 10.1016/j.bpa.2023.11.001.

W. O’Brien, N. Doré, K. Campbell-Templeman, D. Lowcay, and M. Derakhti, “Living labs as an opportunity for experiential learning in building engineering education,” *Adv. Eng. Informatics*, vol. 50, no. October, 2021, doi: 10.1016/j.aei.2021.101440.

M. R. Chapagain and B. E. Mikkelsen, “Is a Living Lab Also a Learning Lab?—Exploring Co-Creational Power of Young People in a Local Community Food Context,” *Youth*, vol. 3, no. 2, pp. 753–776, 2023, doi: 10.3390/youth3020049.

P. Darke and G. Shanks, *Chapter 6 - Case study research design final_edited*. 2002.

V. L. Plano Clark, L. A. Foote, and J. B. Walton, “Combining mixed methods and case study research,” *Int. Encycl. Educ. Fourth Ed.*, no. c, pp. 538–549, 2022, doi: 10.1016/B978-0-12-818630-5.11053-X.

V. Seshan *et al.*, “Case Study Analysis as an Effective Teaching Strategy: Perceptions of Undergraduate Nursing Students From a Middle Eastern Country,” *SAGE Open Nurs.*, vol. 7, 2021, doi: 10.1177/23779608211059265.