ECOGROW: A LOW-COST SMART GREENHOUSE TEACHING PLATFORM FOR PROJECT-BASED ENGINEERING EDUCATION ALIGNED WITH THE SUSTAINABLE DEVELOPMENT GOALS

ECOGROW: UMA PLATAFORMA DE ENSINO DE ESTUFA INTELIGENTE DE BAIXO CUSTO PARA O ENSINO DE ENGENHARIA BASEADO EM PROJETOS, ALINHADO COM OS OBJETIVOS DE DESENVOLVIMENTO SUSTENTÁVEL

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Abstract
Engineering education increasingly faces a dual requirement: graduates must master embedded sensing, actuation, and basic control, while also developing sustainability-oriented decision-making competencies. This paper presents EcoGrow, a low-cost smart greenhouse teaching platform designed for Education for Sustainable Development (ESD) and project-based learning (PBL) in resource-constrained contexts. EcoGrow integrates an Arduino Mega 2560, a DHT22 temperature–humidity sensor, an I2C LCD, relay-driven actuators (12 V fan, mist pump, and lighting), and a Windows Forms (WinForms) desktop application communicating via serial for real-time monitoring, manual override, threshold configuration, and data logging. Rather than positioning EcoGrow as a novel greenhouse automation product, we frame it as a replicable teaching intervention that makes sustainability operational through measurable trade-offs (e.g., stability vs. duty cycle; humidity recovery vs. water proxy) and transparent control design choices (e.g., hysteresis, minimum on/off time). The paper contributes (i) a replicable hardware–software architecture for hands-on sustainability-oriented engineering education, (ii) a structured PBL module with explicit alignment to SDG 4, SDG 2, SDG 12, and SDG 13, and (iii) an evidence-based evaluation framework combining learning artifacts, rubric-

Resumo
A educação em engenharia enfrenta cada vez mais uma dupla exigência: os graduados devem dominar sensoriamento, atuação e controle básico integrados, ao mesmo tempo em que desenvolvem competências de tomada de decisão orientadas para a sustentabilidade. Este artigo apresenta o EcoGrow, uma plataforma de ensino de estufa inteligente de baixo custo projetada para a Educação para o Desenvolvimento Sustentável (ESD) e aprendizagem baseada em projetos (PBL) em contextos com recursos limitados. O EcoGrow integra um Arduino Mega 2560, um sensor de temperatura e umidade DHT22, um LCD I2C, atuadores acionados por relé (ventilador de 12 V, bomba de névoa e iluminação) e um aplicativo de desktop Windows Forms (WinForms) que se comunica via serial para monitoramento em tempo real, substituição manual, configuração de limite e registro de dados. Em vez de posicionar o EcoGrow como um novo produto de automação de estufas, nós o enquadramos como uma intervenção de ensino replicável que torna a sustentabilidade operacional por meio de compensações mensuráveis (por exemplo, estabilidade versus ciclo de trabalho; recuperação de umidade versus proxy de água) e escolhas de design de controle transparentes (por exemplo, histerese, tempo mínimo de ligar/desligar). O artigo
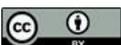
based assessment, and log-derived indicators suitable for publishable reporting. The results from demonstration and classroom deployment show that EcoGrow reliably supports core learning outcomes in embedded systems and control, while enabling explicit sustainability reasoning grounded in data.

Keywords: Education for Sustainable Development. Project-Based Learning. Engineering Education. Smart Greenhouse. Monitoring and Control. Sustainability Education.

contribui com (i) uma arquitetura de hardware-software replicável para o ensino prático de engenharia orientado para a sustentabilidade, (ii) um módulo PBL estruturado com alinhamento explícito com os ODS 4, ODS 2, ODS 12 e ODS 13, e (iii) uma estrutura de avaliação baseada em evidências que combina artefatos de aprendizagem, avaliação baseada em rubricas e indicadores derivados de registros adequados para relatórios publicáveis. Os resultados da demonstração e da implantação em sala de aula mostram que o EcoGrow apoia de forma confiável os principais resultados de aprendizagem em sistemas embarcados e controle, ao mesmo tempo em que permite um raciocínio explícito sobre sustentabilidade baseado em dados.

Palavras-chave: Educação para o Desenvolvimento Sustentável. Aprendizagem Baseada em Projetos. Educação em Engenharia. Estufa Inteligente. Monitoramento e Controle. Educação em Sustentabilidade.

1 INTRODUCTION

Sustainable development is no longer an external constraint to engineering practice; it is increasingly the context in which engineering decisions are judged and implemented. Universities are consequently expected to produce graduates who can design, operate, and evaluate socio-technical systems under resource limitations, environmental uncertainty, and institutional constraints. Education for Sustainable Development (ESD) emphasizes competencies—such as systems thinking, anticipatory competence, normative competence, and strategic competence—that enable learners to act in complex real-world settings (Wiek *et al*., 2011; Rieckmann, 2012). In engineering programs, however, sustainability is often taught as parallel content rather than as a property of everyday technical decisions. Students may learn microcontroller programming or control theory in isolated labs and later discuss sustainability in separate modules, leaving a gap between "how systems work" and "how systems should be designed and operated".

Controlled-environment agriculture provides a natural domain to close this gap. Greenhouse microclimate control involves continuous balancing between competing objectives: maintaining temperature and humidity within acceptable ranges while

minimizing energy and water use. Reviews of greenhouse automation and microclimate modeling highlight that even seemingly simple actuation choices (ventilation, humidification, lighting schedules) can produce nonlinear interactions and oscillatory behavior, requiring careful tuning and performance evaluation (Sethi *et al*., 2013; Shamshiri *et al*., 2018; Achour *et al*., 2021). At the same time, smart farming research demonstrates that monitoring systems derive value only when measurement is translated into accountable decisions with clear trade-offs (Wolfert *et al*., 2017).

Project-based learning (PBL) is widely recognized as a powerful approach for sustainability education in engineering because it requires students to integrate concepts, work within constraints, and produce an artifact that can be tested, iterated, and defended (Guo *et al*., 2020; Sukackè *et al*., 2022). Sustainability-oriented PBL has been shown to benefit from authenticity (a real context with real constraints) and from assessment designs that capture both process and outcomes (Gatti *et al*., 2019; Holgaard *et al*., 2016). Yet many PBL implementations depend on costly infrastructure (industrial controllers, proprietary platforms, cloud services, dedicated labs), which can limit adoption and scalability—especially in institutions that aim to broaden access and equity in engineering education.

This paper presents EcoGrow, a low-cost smart greenhouse teaching platform developed within the context of embedded systems and computer-based monitoring instruction. EcoGrow uses readily available components (Arduino Mega 2560, DHT22 sensor, relay-actuated 12 V fan and mist pump, LCD I2C) and a WinForms desktop interface communicating via serial. The technical architecture is intentionally transparent to support debugging and to encourage students to reason about system behavior rather than treat it as a black box. Importantly, EcoGrow is not proposed as a novel greenhouse automation product; it is proposed as a replicable educational platform for ESD that makes sustainability operational through data, logging, and decision trade-offs. This paper makes three contributions:

(1) A replicable, low-cost smart greenhouse teaching platform (hardware + software + communication protocol) for hands-on engineering education.

(2) A structured PBL module that aligns learning activities with ESD competencies and explicitly maps them to SDG 4 (Quality Education), SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

(3) An evidence-based evaluation framework combining learning artifacts, rubric-based assessment, and log-derived indicators to support credible reporting in Sustainability-oriented education venues (Guo *et al.*, 2020; Wiek *et al.*, 2011).

Paper organization. Section 2 reviews related work on ESD competencies, PBL in engineering education, and greenhouse automation as an authentic sustainability context. Section 3 describes the EcoGrow platform architecture. Section 4 presents the instructional design and SDG/competency mapping. Section 5 describes the research design and evaluation framework. Section 6 reports demonstration and classroom deployment observations and presents how results can be analyzed. Section 7 discusses implications, limitations, and future work. Section 8 concludes.

2 RELATED WORK AND CONCEPTUAL FRAMING

2.1. Education for Sustainable Development competencies

ESD literature increasingly emphasizes competency-based outcomes rather than content coverage. Wiek *et al.* (2011) propose a widely used framework including systems thinking, anticipatory competence, normative competence, strategic competence, and interpersonal competence—often operationalized through authentic tasks, stakeholder reasoning, and reflective assessment. Rieckmann (2012) further argues that future-oriented higher education should cultivate the ability to handle uncertainty, evaluate long-term impacts, and act responsibly. In engineering education, these competencies become meaningful when they are tied to technical decisions: selecting thresholds and hysteresis widths is not just a control design choice; it embodies trade-offs between stability, actuator wear, and resource consumption.

2.2 Project-based learning for sustainability in engineering

Meta-analyses and systematic reviews of PBL in higher education report generally positive effects on content understanding, skills, and engagement, with outcomes influenced by scaffolding quality, authenticity, and assessment (Guo *et al.*, 2020; Sukackė *et al.*, 2022). Sustainability education studies also point to the value of experiential learning and simulation-based activities in helping learners see consequences of

decisions, particularly when performance can be quantified (Gatti *et al*., 2019). In engineering contexts, sustainability-focused PBL can be especially effective when it is integrated into core technical modules rather than isolated "ethics" add-ons (Holgaard *et al*., 2016; Jollands *et al*., 2013).

2.3 Greenhouse automation as an authentic sustainability context

Greenhouse microclimate control has been extensively studied for improving crop performance and stability while addressing energy and water efficiency (Sethi *et al*., 2013). Reviews of greenhouse automation highlight trends toward sensor networks, control loops, and decision support, but also note the need for robust and interpretable control strategies in practical deployments (Shamshiri *et al*., 2018). Recent sustainable greenhouse reviews emphasize integration of technologies to reduce environmental footprint and improve resilience (Achour *et al*., 2021). These insights motivate EcoGrow's design: a transparent system that can be operated, observed, and analyzed by students while discussing sustainability implications.

2.4 Governance, policy, and equity considerations in sustainability education

Sustainability is implemented through institutions, laws, and governance mechanisms, not only through technology. Legal scholarship discussing SDGs highlights their normative value and the challenges of translating goals into enforceable and equitable practices (Pavoni & Piselli, 2016). Higher education's role in sustainable development has also been discussed in terms of rights-based frameworks and equity in access (Melnychenko *et al*., 2025; Nhan, 2025). Including these perspectives strengthens the educational framing: students learn that technical prototypes must align with institutional realities and responsible innovation considerations.

3 THE ECOGROW TEACHING PLATFORM

3.1 Design principles

EcoGrow is designed under four principles:

(1) Low cost and availability: components should be widely accessible and replaceable.

(2) Transparency: the system should be understandable end-to-end (sensor → controller → actuator → monitoring/logs).

(3) Replicability: documentation and modular design should support adoption in other institutions.

(4) Sustainability operationalization: the platform should support quantification of trade-offs (e.g., duty cycle proxies for energy/water) rather than only qualitative discussion.

3.2 Hardware architecture

EcoGrow uses an Arduino Mega 2560 as the central controller due to its multiple I/O pins and robust use in education (El-Abd, 2017; Lee, 2020). Environmental sensing uses a DHT22 sensor for temperature and relative humidity. A 16×2 LCD with I2C interface provides local display for immediate feedback. Actuation is implemented via a relay module switching 12 V loads: (i) a ventilation fan, (ii) a mist pump for humidity increase, and (iii) lighting for demonstration (or for plant growth in small-scale setups). Power is split into regulated 5 V for logic and 12 V for actuators, which supports teaching of electrical safety, grounding, and noise isolation.

Figure 1

EcoGrow system architecture.
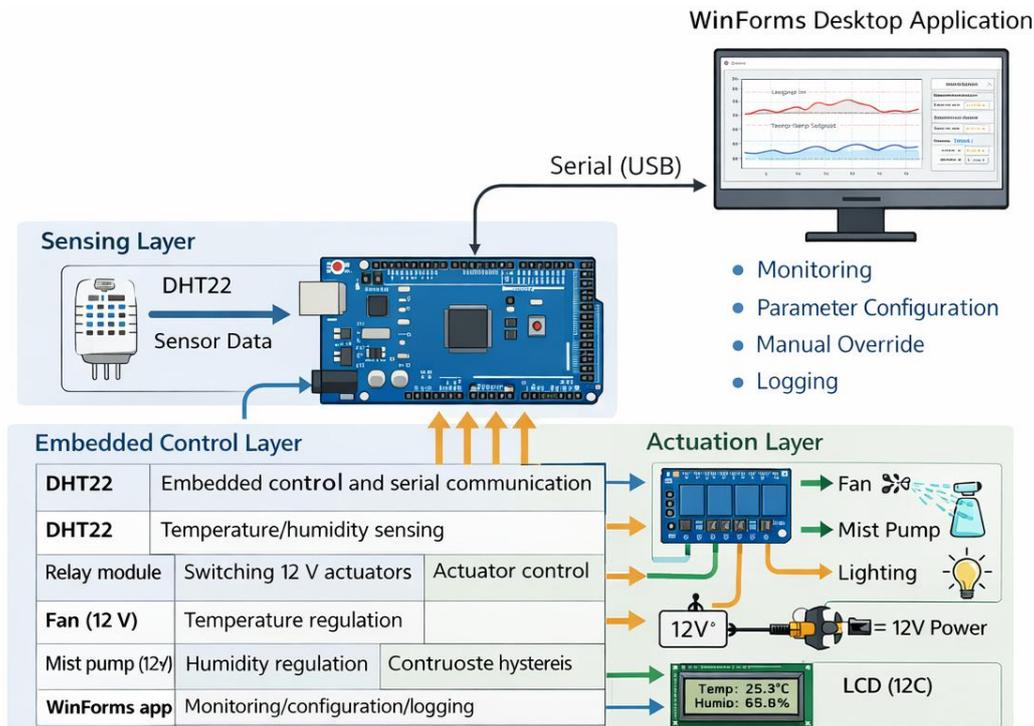
As shown in Fig. 1, the sensing layer (DHT22) feeds the embedded control layer (Arduino Mega 2560), which drives the actuation layer (relay-switched 12 V fan, mist pump, lighting). A local LCD (I2C) provides direct readout. A WinForms desktop application connects via serial for real-time monitoring, parameter configuration, manual override, and logging to files for analysis.

3.3 Software architecture (WinForms + serial monitoring)

The WinForms desktop application provides:

- Live display of temperature and humidity.
- User-defined thresholds and control mode selection (automatic/manual).
- Manual override for actuators to support testing and debugging.
- Logging of sensor readings and actuator states for post-analysis.
- Connection management (COM selection, connection status, and basic error handling).

The software design supports sustainability reasoning by making both "state" and "cost proxies" visible. In practice, students can compute duty cycle of fan and total

runtime of misting as proxies for energy and water consumption, respectively, and compare control strategies.

3.4 Control logic: transparent threshold control with practical safeguards

EcoGrow uses threshold-based control as the baseline because it is pedagogically transparent and widely used for introductory embedded control education (El-Abd, 2017). To avoid common issues (relay chatter and oscillations), the platform can implement two safeguards:

(1) Hysteresis: separate turn-on and turn-off thresholds for temperature and humidity.

(2) Minimum on/off time constraints: a minimum dwell time to protect relays and to reduce rapid switching.

These design choices are excellent ESD teaching moments: a small change in control logic affects system stability, actuator wear, and resource proxies. The platform encourages students to justify these choices using data (logs).

Table 1

EcoGrow core components and educational purpose

Component	Function	Educational purpose
Arduino Mega 2560	Embedded control and serial communication	Microcontroller programming, I/O, debugging
DHT22	Temperature/humidity sensing	Sampling, filtering, calibration, sensor limitations
Relay module	Switching 12 V actuators	Electrical safety, isolation, actuator control
Fan (12 V)	Temperature regulation	Duty cycle analysis, stability vs. consumption
Mist pump (12 V)	Humidity regulation	Water proxy analysis, control hysteresis
LCD 16×2 (I2C)	Local display	Human–machine feedback, I2C basics
WinForms app	Monitoring/configuration/logging	HMI design, serial protocol, data logging

4 INSTRUCTIONAL DESIGN: ESD + PBL INTEGRATION

4.1 Course integration and learning outcomes

EcoGrow is designed for undergraduate modules such as embedded systems, computer-based monitoring, and introductory control. The intervention emphasizes four learning outcomes:

LO1: Implement reliable sensor acquisition and serial communication with robust error handling.

LO2: Design and tune threshold-based control with hysteresis and safeguards, and interpret system behavior from logs.

LO3: Analyze trade-offs between stability and resource proxies using data (duty cycle and runtime).

LO4: Communicate technical decisions transparently, including sustainability reasoning aligned with SDGs.

4.2 SDG alignment and competency mapping EcoGrow links explicitly to SDGs

- SDG 4 (Quality Education): hands-on, competency-based learning outcomes.
- SDG 2 (Zero Hunger): smart agriculture concepts and resilient production.
- SDG 12 (Responsible Consumption and Production): energy/water efficiency trade-offs.
- SDG 13 (Climate Action): adaptation through controlled environments and monitoring.

The competency mapping follows Wiek *et al*. (2011) and Rieckmann (2012): systems thinking is developed through sensor–actuator interactions; anticipatory competence through evaluating control changes over time; normative competence through defining "acceptable" comfort bands; strategic competence through implementing and justifying control strategies under constraints.

Table 2

Mapping EcoGrow activities to ESD competencies and SDGs

Activity	Primary competency	SDG link	Evidence
Sensor calibration and filtering	Systems thinking	SDG 4, 12	Lab notes + stability plots
Design hysteresis bands	Anticipatory competence	SDG 12, 13	Control spec + logs
Compare duty cycles across settings	Strategic competence	SDG 12	Analysis report
Write transparency note (assumptions/limits)	Normative competence	SDG 4	Report section
Reflect on governance/equity constraints	Interpersonal/normative	SDG 4, 10/16 (contextual)	Reflection prompts

4.3. PBL sequence

4.3.1 Week 1: Sensing and communication

Students implement stable sampling, validate sensor ranges, define serial packet format, and build a basic dashboard. They learn that "measurement quality" affects every decision (Sethi *et al*., 2013).

4.3.2 Week 2: Control implementation

Teams implement threshold control, add hysteresis, and evaluate switching behavior. Students observe how hysteresis reduces oscillations and relay stress.

4.3.3 Week 3: Sustainability operationalization

Teams define acceptable comfort bands and quantify duty cycle/runtime as resource proxies, comparing strategies across teams (Holgaard *et al*., 2016).

Week 4: Integration and reporting

Students integrate UI control, manual override, logging, and write a short report defending parameter decisions using data.

5 RESEARCH DESIGN AND EVALUATION FRAMEWORK

5.1 Study type: design-based educational research

EcoGrow is presented as a design-and-deployment educational intervention, suitable for Sustainability education articles that contribute replicable curricula and evidence-informed evaluation designs (Ceulemans *et al*., 2015; Lozano, 2011). The goal is not to claim universal causal effects, but to provide a robust, replicable platform and an evaluation approach that other institutions can adopt and extend.

5.2 Data sources (evidence triangulation)

To avoid relying solely on self-report, EcoGrow encourages triangulated evidence:

(1) Student artifacts: code repository, wiring diagrams, UI design, control specification, and final report.

(2) System logs: timestamped temperature/humidity, actuator states, and mode changes.

(3) Rubric-based performance assessment: reliability, control quality, documentation quality, and sustainability reasoning.

(4) Reflection prompts: short structured reflections on trade-offs and constraints.

This aligns with PBL assessment recommendations that emphasize process and observable outcomes (Guo *et al*., 2020; Sukackė *et al*., 2022).

5.3 Metrics for publishable analysis

EcoGrow supports quantitative indicators without requiring expensive sensors:

• Overshoot frequency: how often temperature/humidity exceed upper bounds.

• Recovery time proxy: time to return into band after a disturbance.

• Actuator duty cycle: fraction of time fan/light is active (energy proxy).

• Misting runtime: total pump activation time (water proxy).

• Switching rate: number of relay transitions (wear/safety relevance).

Table 3

Example log-derived indicators

Indicator	Interpretation	Sustainability link
Duty cycle (fan)	Energy proxy	SDG 12
Misting runtime	Water proxy	SDG 12
Switching rate	Hardware wear and reliability	Responsible operation
Recovery time	Performance under disturbance	SDG 13 (resilience)

6 DEMONSTRATION AND CLASSROOM DEPLOYMENT OBSERVATIONS

6.1 Technical demonstration

In demonstration runs, EcoGrow reliably performed the core functions expected for teaching: (i) real-time sensing and display on LCD and WinForms, (ii) stable serial communication suitable for logging, and (iii) correct actuation of fan and mist pump according to thresholds. The most instructive behavior observed was the difference between "no hysteresis" and "with hysteresis": without hysteresis, systems commonly exhibit rapid switching around thresholds; with hysteresis and minimum on/off constraints, switching stabilizes and actuator chatter reduces. These behaviors are consistent with microclimate control insights that emphasize the role of control logic in preventing oscillatory behavior (Sethi *et al*., 2013; Shamshiri *et al*., 2018).

Figure 2

Smart Greenhouse Teaching Platform.
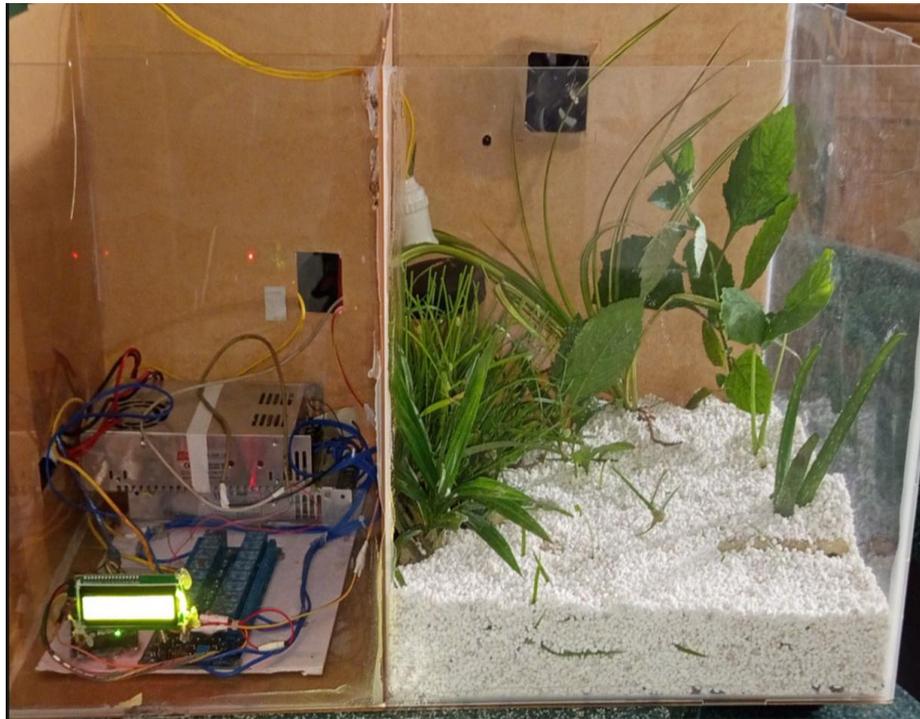
Figure 3

Temperature and humidity control on WinForms.
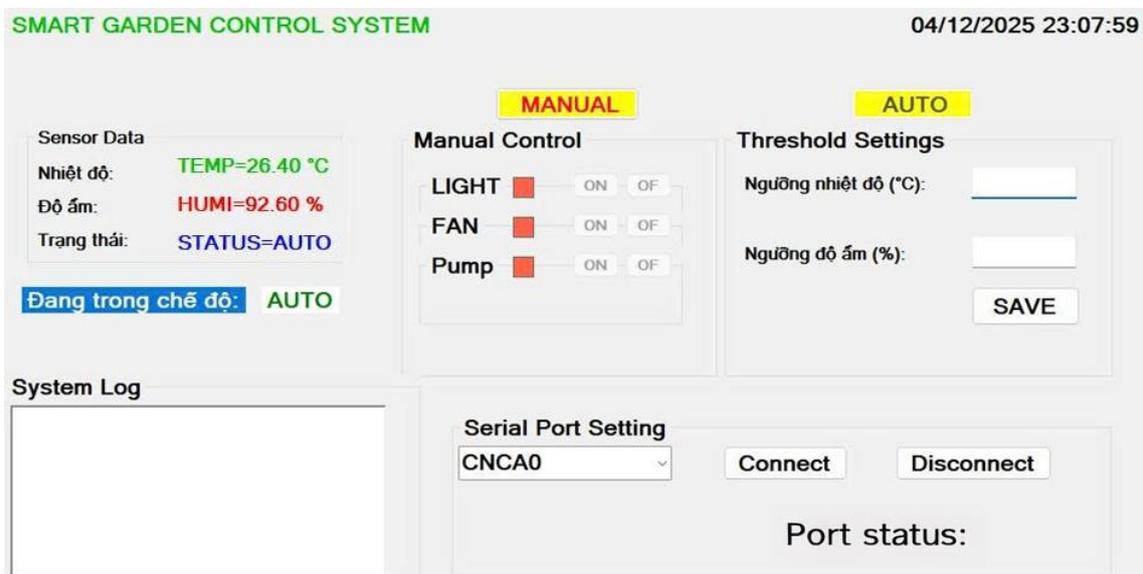
6.2 Learning observations aligned with ESD competencies

EcoGrow supports sustainability learning when students must defend decisions using evidence. Typical learning progressions include:

- Systems thinking: students recognize sensor noise, sampling choices, and actuator latency as system-level phenomena rather than coding errors (Wiek *et al*., 2011).
- Anticipatory competence: students see that thresholds chosen for "fast comfort" may increase duty cycle and switching, raising resource proxies and wear.
- Normative competence: students discuss what "acceptable" comfort means in context (e.g., wider bands reduce consumption but may reduce plant comfort).
- Strategic competence: teams propose control modifications (hysteresis width, dwell times, schedule logic) and compare strategies using log metrics.

These observations align with findings that PBL improves engagement and competence when learners can observe consequences of their choices (Gatti *et al*., 2019) and when tasks are authentic and measurable (Guo *et al*., 2020).

6.3 Governance and equity reflection (Sustainable Development framing)

A short reflection component strengthens the Sustainability scope: students are encouraged to discuss how low-cost designs support equitable access to learning and technology deployment, and how institutional constraints shape what can be implemented. This connects to rights-based and equity-focused higher education perspectives in sustainable development (Melnychenko *et al*., 2025; Nhan, 2025), and to the normative and implementation challenges emphasized in SDG-related legal scholarship (Pavoni & Piselli, 2016).

7 DISCUSSION

7.1 Why EcoGrow fits Sustainability (Education)

EcoGrow aligns with Sustainability education aims in three ways. First, it supports measurable learning outcomes and competency development rather than only "awareness". Second, it embeds sustainability as an operational dimension of technical design: students use logs to quantify resource proxies and stability. Third, it is intentionally designed to be replicable for institutions with limited resources, supporting broader access and equity.

7.2 Pedagogical value of "simple but transparent" control

There is a common misconception that educational platforms must be technologically advanced to be valuable. EcoGrow intentionally uses a transparent baseline controller because it makes causal relationships visible and supports reasoning. This transparency is aligned with recommendations in embedded systems education emphasizing learnability and debugging affordances (El-Abd, 2017; Lee, 2020). Advanced extensions (IoT, predictive control, optimization) can be layered later, but the foundational sustainability reasoning is already achievable with a transparent baseline.

7.3 Relationship to broader smart farming trends

Smart farming increasingly relies on data-driven decision making and system integration (Wolfert *et al.*, 2017). EcoGrow helps students learn that "data" is not only collected but must be validated, interpreted, and used responsibly. This is a critical sustainability lesson: monitoring systems that are not transparent or not auditable can lead to poor decisions or misaligned incentives.

8 LIMITATIONS AND FUTURE WORK

EcoGrow has four main limitations.
(1) Single-sensor scope: DHT22 captures only temperature and humidity; future versions should add soil moisture, CO2, or light intensity for multi-variable control.
(2) Proxy resource metrics: duty cycle and runtime are proxies; future deployments can use power meters and flow sensors for direct resource measurement.
(3) Research rigor: while the evaluation framework supports publishable evidence, stronger claims require cohort-level data collection with ethics-compliant procedures.
(4) Platform modernization: WinForms is pedagogically useful for transparency but can be extended to web/mobile interfaces and IoT connectivity.

Future work can adopt a staged improvement approach consistent with sustainable education interventions: start with transparent baseline control, then add IoT and

analytics, and finally introduce optimization or predictive strategies while preserving interpretability.

9 CONCLUSION

This paper presented EcoGrow, a low-cost smart greenhouse teaching platform for project-based engineering education aligned with ESD competencies and SDGs. EcoGrow combines an Arduino-based sensor–actuator loop with a serial-connected WinForms monitoring and logging interface, enabling students to learn embedded systems and control while making sustainability operational through data and measurable trade-offs. The key educational contribution is not a new automation algorithm, but a replicable instructional platform and evaluation framework that links technical decisions to sustainability objectives. EcoGrow is suitable for resource-constrained institutions seeking practical, evidence-based approaches to integrate sustainability into core engineering curricula.

REFERENCES

Achour, D., Ouammi, A., Zejli, D., & Sayadi, S. (2021). Technological progresses in modern sustainable greenhouses cultivation. Renewable and Sustainable Energy Reviews, 147, 111251. doi:10.1016/j.rser.2021.111251

Annan-Diab, F., & Molinari, C. (2017). Interdisciplinarity: Practical approach to advancing education for sustainability and for the SDGs. The International Journal of Management Education, 15(2), 73–83. doi:10.1016/j.ijme.2017.03.006

Azeiteiro, U. M., Bacelar-Nicolau, P., Caetano, F. J. P., & Caeiro, S. (2015). Education for sustainable development through e-learning in higher education: Experiences from Portugal. Journal of Cleaner Production, 106, 308–319. doi:10.1016/j.jclepro.2014.11.056

Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy, 13(1), 13–26. doi:10.1080/15487733.2017.1394054.

Ceulemans, K., Molderez, I., & Van Liedekerke, L. (2015). Sustainability reporting in higher education: A comprehensive review. Journal of Cleaner Production, 106, 127–143. doi:10.1016/j.jclepro.2014.09.052

El-Abd, M. (2017). A review of embedded systems education in the Arduino age: Lessons learned and future directions. International Journal of Engineering Pedagogy, 7(2), 79–93. doi:10.3991/ijep.v7i2.6845

Gatti, L., Ulrich, M., & Seele, P. (2019). Education for sustainable development through business simulation games: An empirical study. Journal of Cleaner Production, 207, 667–678. doi:10.1016/j.jclepro.2018.09.130

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. International Journal of Educational Research, 102, 101586. doi:10.1016/j.ijer.2020.101586

Holgaard, J. E., Hadgraft, R., Kolmos, A., & Guerra, A. (2016). Strategies for education for sustainable development—Danish and Australian perspectives. Journal of Cleaner Production, 112, 3479–3491. doi:10.1016/j.jclepro.2015.09.063

Jollands, M., & Parthasarathy, R. (2013). Developing engineering students' understanding of sustainability using project based learning. Sustainability, 5(12), 5052-5066. doi:10.3390/su5125052

Kolmos, A., De Graaff, E., & Du, X. (2009). Diversity of PBL–PBL learning principles and models. In Research on PBL practice in engineering education (pp. 9-21). Brill.. doi:10.1163/9789087909321_003

Lee, E. (2020). A meta-analysis of the effects of Arduino-based education in engineering education. European Journal of Educational Research, 9(4), 1503–1512. doi:10.12973/eu-jer.9.4.1503

Lozano, R. (2011). The state of sustainability reporting in universities. International Journal of Sustainability in Higher Education, 12(1), 67–78. doi:10.1108/14676371111098311

Melnychenko, A., et al. (2025). Higher education as a factor to ensure human rights and sustainable development of society. Veredas do Direito, 22(2), e223473. doi:10.18623/rvd.v22.n2.3473

Nhan, N. T. T. (2025). Policies ensuring equity in access to basic and higher education: Lessons from developed countries for Vietnam. Veredas do Direito, 22(5), e223834. doi:10.18623/rvd.v22.n5.3834

Pavoni, R., & Piselli, D. (2016). The Sustainable Development Goals and international environmental law: Normative value and challenges for implementation. Veredas do Direito, 13(26), 13–60. doi:10.18623/rvd.v13i26.865

Rieckmann, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? Futures, 44(2), 127–135. doi:10.1016/j.futures.2011.09.005

Sethi, V. P., Sumathy, K., Lee, C., & Pal, D. S. (2013). Thermal modeling aspects of solar greenhouse microclimate control: A review. Solar Energy, 96, 56–82. doi:10.1016/j.solener.2013.06.034

Shamshiri, R. R., et al. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture.

International Journal of Agricultural and Biological Engineering, 11(1), 1–22. doi:10.25165/j.ijabe.20181101.3210

Sukackė, V., *et al*. (2022). Towards active evidence-based learning in engineering education: A systematic review of PBL/PjBL/CBL. Sustainability, 14(21), 13955. doi:10.3390/su142113955

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. Sustainability Science, 6(2), 203–218. doi:10.1007/s11625-011-0132-6

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big data in smart farming— A review. Agricultural Systems, 153, 69–80. doi:10.1016/j.agsy.2017.01.023

Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: a review of literature. European Journal of Engineering Education, 46(1), 90–115. doi:10.1080/03043797.2020.1718615

Benyezza, H., Bouhedda, M., Rebouh, S., *et al*. (2023). A smart platform based on IoT and sensor networks for monitoring and controlling agricultural environments: A review and synthesis. Internet of Things, 23, 100830. doi:10.1016/j.iot.2023.100830

Wood, B., & Ganago, A. (2018). Using Arduino in engineering education: Motivating students to grow from hobbyist to professional. ASEE Annual Conference Proceedings. doi:10.18260/1-2--31197

Authors' Contribution

All authors contributed equally to the development of this article.

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All datasets relevant to this study's findings are fully available within the article.

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