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Transforming Digital Electronics Education: Integrating Sustainability through Eco−Design, Modularity, and Circular Practices

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***Abstract*—Integrating eco−design principles and open hardware into digital electronics education is crucial to equip future engineers for addressing the environmental issues of the digital era. This research is part of the DEEPCEL (Digital Electronics with Eco-Designed Paradigm in Collaborative Enhanced Learning) ERASMUS+ project. Initially, it explores the knowledge and perceptions of participants through a targeted survey, emphasizing methodologies, the environmental impact of open hardware, and their role in fostering sustainability in digital electronics. The research also explores effective teaching strategies, tools, and platforms that can improve the adoption of eco−transition principles, with the aim of creating guidelines for curriculum modernization focused on sustainability. Participants affirm that open hardware offers transformative potential in improving innovation, accessibility, and eco−conscious practices and community−driven development. This study underscores the need for a collaborative effort between academia, professors, and industry leaders, along with their demands and needs to prioritize and integrate sustainability principles into digital electronics education. However, significant barriers remain, including insufficient training for professors, limited resources, and resistance to changes in traditional pedagogical practices. The findings should be interpreted with caution due to potential limitations in sample representation. Further research will validate the effectiveness of proposed strategies and assess long-term impacts on educational practices.**

***Index Terms*—Eco−design, Modularity, Open hardware, Benchmarking, Reconfigurable electronics, Pedagogical innovation, Survey.**

I. Introduction

Incorporating sustainability into engineering education is no longer optional; it is an urgent responsibility to prepare students for the challenges of the 21st century. Higher education plays a crucial role in equipping students with the skills to incorporate sustainable activities into their careers. The availability of undergraduate programs focused on eco−design or sustainable in many countries of the European Union is limited (2%) [1]. By fostering self−confidence, interdisciplinary collaboration, and innovation, educational institutions enable students to embrace novel practices and drive meaningful changes [2]. Institutions can prepare future engineers to lead innovations aligned with sustainability objectives and address global challenges by promoting concepts related to digital electronics, such as modularity, open hardware, or eco−design. The recently established guidelines will equip students with the skills to tackle real−world challenges, such as improving energy efficiency or contributing to renewable energy initiatives. For example, students engage in activities related to energy use and emphasize recyclable and biodegradable materials, environmentally friendly processes, and recycling, with a general focus on waste reduction and material recovery [3].

Figure 1 illustrates how the curriculum framework, experiential learning, open hardware integration, and interdisciplinary collaboration interrelate, emphasizing the transmission of principles throughout the educational journey. Each element includes aspects such as life cycle analysis, eco−friendly materials, electronic reconfiguration, and integration of cutting−edge tools for modern learning.

The curriculum designed to teach digital electronics should prioritize aspects such as energy consumption, the application of sustainable materials, and principles of eco−friendly design. These priorities are essential for preparing students to address the environmental impacts of electronic systems and develop solutions that align efficiency with environmental challenges. Incorporating case studies and collaborative learning methods aims to improve comprehension and drive innovation [4]–[6]. These active and dynamic learning approaches, which emphasize student participation through hands−on projects

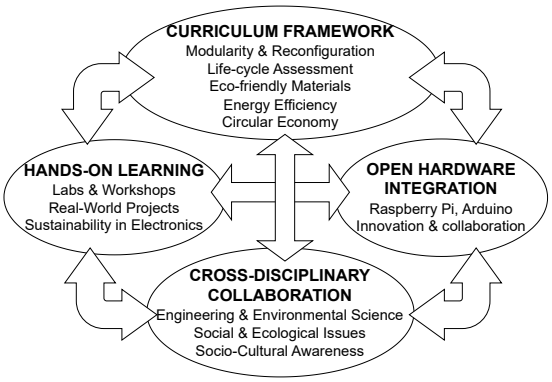

Fig. 1. Relationships between the curriculum framework.

and real−world problem solving, are also empowered to promote sustainable education in digital electronics [7]–[9]. More specifically, participation in case studies and practical scenarios allows students to investigate circular economy models, assess sustainability certifications, and explore environmentally friendly products [10]. A case in point is the recently introduced Master program in eco−inclusive design, which emphasizes interactive workshops and laboratory work to prepare students for innovation in sustainability and social inclusion [11].

The growing trend of incorporating eco−design education into engineering programs is evident, with research recommending its early integration to better equip future professionals [12]. By including novel concepts and activities in digital electronics, students are motivated to embrace creative practices that correspond to global sustainability initiatives [13], [14]. The principles of eco−design propose modular designs for simple upgrades and reuse, adaptable systems to reduce waste, and disassembly strategies to facilitate recycling [15], [16]. For instance, [17] highlights the importance of life−cycle approaches and cross−departmental cooperation to align environmental goals with design and manufacturing processes. In nanotechnology, sustainable design principles are employed to strike a balance between innovation and environmental safety, focusing on the creation of new materials for specific purposes [18]. Additionally, eco−design can be effectively matched with lean design principles to improve efficiency, reduce waste, and reduce environmental impacts across industries [19]. Although the integration of environmental factors throughout the life cycle of a product addresses sustainability issues at each stage, it remains challenging to include and establish comprehensive curricula that adequately prepare students for the complex nature of sustainable electronics design.

The principles of sustainable digital electronics propose modular designs for simple upgrades and reuse, adaptable systems to reduce waste, and disassembly strategies to facilitate recycling. In this context, open hardware has emerged as a revolutionary concept in education, enhancing accessibility, fostering collaboration, and being cost− efficient. The ability of open hardware to expand access to scientific instruments is particularly significant in limited resource settings, since it reduces barriers to conducting scientific research [20]. Platforms like Raspberry Pi [21], Arduino [22], TinyFPGA [23], Alchitry [24], or the Mkr VIDOR 4000 [25] boards exemplify how this approach can reduce costs while integrating new methods and tools, while maintaining educational efficacy [26]. The adaptability and scalability of open source designs allow customization, reducing dependence on proprietary solutions [27]. In addition, open platforms and reconfigurable electronics, such as a programmable system on a chip (SoC), can help students bridge the gap between theoretical knowledge and practical application [28], improving adaptability and skills in electronic system design vital to industry-changing challenges [29], [30]. The emergence of low-cost electronics and the Internet of Things (IoT) has also significantly expanded the opportunities to create new learning experiences. For example, the Arduino MKR board and a LoRaWAN network supported by the IoT network for data transmission [31]. Although open hardware systems face challenges in standardization and maintenance, they remain valuable teaching resources [20]. In summary, Table I illustrates the connections between the fundamental components of this framework and the related work, demonstrating how these concepts support the advancement of sustainable digital electronics education.

To this regard, the DEEPCEL ERASMUS + project, co−funded by the European Union (EU), aims to modernize educational practices by imparting skills in life−cycle assessment, eco−design, and reconfigurable electronics to students, while also offering professor training and curriculum advancements. The main goals of DEEPCEL include: (i) evaluating the educational approaches of the partners; (ii) developing innovative teaching methods; (iii) providing professor training focused on open hardware and modular resources; (iv) incorporating sustainability principles into academic programs; (v) creating eco−design guidelines; and (vi) preparing future educational activities such as life cycle analysis and adaptable electronics. This research paper lays the foundation for integrating sustainability concepts into the education of digital electronics through modularity, circular methodologies, and other approaches. Furthermore, this initiative aims to provide tools for examining how pedagogy can improve sustainability in education while fostering collaboration among European universities. The results will offer tools, training, and guidelines to improve digital electronics education with an emphasis on sustainability and circularity. Incorporating sustainability into education through novel teaching methods, professor training, and novel initiatives empowers students to craft eco−friendly solutions, refine their problem-solving skills, and support a sustainable electronics sector. A key element of this proposal is a survey designed to evaluate existing teaching practices and pinpoint weaknesses. By addressing current educational gaps and applying effective methods, professors can foster a new generation of engineers committed to driving sustainable and responsible innovation.

TABLE I
RELATIONSHIPS BETWEEN THE CURRICULUM FRAMEWORK AND RELATED WORK

Curriculum Framework Element	Description	Main Benefits	References
Life cycle Assessment	Environmental impacts of electronic systems throughout their life cycle.	Identifies environmental key areas and reduces ecological footprint.	[2], [1]
Eco-Friendly Materials	Focuses on using recyclable materials in the design and production of electronics.	Enhances sustainability and reduces waste from non−recyclable materials.	[3], [4]
Energy Efficiency	Addresses strategies to improve energy usage and reduce consumption in digital systems.	Reduces energy costs and promotes environmental conservation.	[1], [7]–[9]
Circular Economy	Promotes activities like reuse, repair, and recycling to minimize waste and enhance sustainability.	Minimizes resource extraction and promotes long−term use of devices.	[9], [10], [15], [16]
Cross-Disciplinary Collaboration	Integrates engineering and environmental sciences to address socio-ecological challenges effectively.	Fosters innovative solutions by leveraging diverse expertise.	[13], [14]
Open Hardware Integration	Encourages the use of platforms for innovation and accessibility.	Promotes cost-effective solutions and democratizes technology development.	[21]–[25]
Modularity, reconfiguration, IoT	Adaptable, interchangeable components, flexible system adjustments, and interconnected devices.	Enhances scalability, ease of maintenance, and adaptability to new technologies.	[28], [29], [30], [31]

The remainder of this paper is organized as follows. Section II describes the proposed activity and the methodology; and Section III details the corresponding results. Finally, this paper ends by drawing some conclusions in Section IV.

II. METHODOLOGY

This study employs a multiphase approach designed to evaluate the current landscape of sustainability in the education of digital electronics. The methodology consists of 4 phases that aim to systematically integrate sustainability principles, modularity, and open hardware into academic programs. The approach emphasizes collaboration among professors, students, researchers, and industry professionals to ensure that the results align with educational objectives and industry demands. Phase 1 will focus on evaluating the current state of sustainability education by surveying stakeholders to identify strengths, weaknesses, and training needs. Phase 2 will introduce new pedagogical methods tailored to improve understanding and application of eco−design and reconfigurable electronics. Phase 3 will involve a targeted training program for professors, equipping them with the skills and resources needed to adopt open hardware and modular teaching tools. Finally, phase 4 will develop forward−looking educational solutions, including innovative platforms and guidelines for curriculum modernization.

Following phase 1, a survey assesses the integration of sustainable design in digital electronics education, identifying the main challenges. It also investigates strategies, tools, and platforms to promote modularity, with the aim of creating guidelines for curriculum modernization focused on sustainability. The activity combines quantitative data from structured questionnaire responses and qualitative insights from open questions. Focusing on engaging key stakeholders involved in digital electronics education to gather diverse perspectives and insights, students are included to assess their awareness of sustainable principles, their perceptions of sustainability, and their learning experiences within the field. Professors also contribute by sharing insights into their teaching methodologies, resource availability, and the challenges they face in integrating sustainability into their curriculum. The researchers provide academic and theoretical perspectives, offering innovative approaches. Finally, industry professionals help bridge the gap between academic practices and industry standards, ensuring that educational outcomes align with practical applications.

Recruitment channels include academic institutions, professional networks, academic conferences, and social media platforms. Personalized invitations are also sent via email and through online platforms linked to the Erasmus+ project. Participation is entirely voluntary, with informed consent obtained before the start of the survey. The study adheres to general data protection regulation guidelines, guaranteeing secure storage and anonymized data handling. Participants have the right to modify or withdraw their responses within six months after the survey. The online survey was created using the EUSurvey platform [32].

Participation involves completing two online surveys, totaling about 20 minutes (see Figure II). Survey A gathers perspectives on the eco−transition in digital electronics education (https://ec.europa.eu/eusurvey/runner/8f2a9abb-ea7b-a8d8-eed3-d581ebded7c2). Survey B takes the form of a quiz to evaluate comprehension related to sustainability and eco−design and responding to a set of open−ended questions (https://ec.europa.eu/eusurvey/runner/3687de3d-e885-5e90-6899-c6523acf4682).

(a) (b)

Fig. 2. Survey (a) and quizz (b) based on eco−design in digital electronics.

The global content is structured into the following sections, as described below.

- Section 1: Demographic and background information (e.g., origin, level of education, area of study or professional field). This section gathers personal information and evaluates their familiarity with the main concepts of the investigation, including eco−design, modularity and open hardware.
- Section 2: Opinions and attitudes. The perspectives of the participants are evaluated through Likert scale [33] questions based on the importance of eco−design in education and multiple choice questions on the benefits of open hardware and modularity.
- Section 3: Challenges and Barriers. This section explores systemic and practical obstacles, such as resource limitations, curriculum integration challenges, and training gaps.
- Section 4: Best Practices and Recommendations. This section is focused on identifying effective teaching tools (e.g., simulation software, prototyping boards). Participants provide insights into teaching strategies such as hands−on projects, real−world case studies, and collaborative learning.

III. Results

The results of this study emphasize the need for educational strategies that align with sustainability by integrating life−cycle assessments, energy−efficient design, and reconfigurable systems into curricula, while also exploring the relationship between sustainability and eco−transition in digital electronics through various perspectives in three key areas. First, opinions underscore the importance of embedding sustainability concepts within curricula, while also addressing barriers and identifying strategies for effective adoption. Second, the results of the quiz provide a quantitative evaluation of the knowledge and understanding of environmental responsibility in the design and production of technology. Third, insights from open questions examine creative and critical perspectives on incorporating open hardware for modularity and circularity, emphasizing its potential to advance more sustainable and responsible electronics development.

A. Perspective on Eco−Transition in Digital Electronics Education.

Table II presents 25 questions on eco−design, modularity's role in sustainability, and integrates circular economy principles in digital electronics education. It evaluates the benefits and challenges of sustainable practice, highlighting the importance of teaching open hardware for eco−friendly electronic design.

20 surveys from students, industry professionals, researchers, and professors at participating universities were analyzed. Although the sample size is relatively small, it remains significant given the survey's specificity, scope, and duration. The number of students and industry professionals participating was significantly lower compared to researchers and academic faculty members (see Figure 3a). Questions about participants' origin and level of studies are optional, resulting in the absence of specific controls for those from non−EU countries or related technical fields. To enhance the preliminary investigation, strategies to distribute the survey across multiple platforms are being implemented to increase the response rate. Based on the initial questions reported, most

No.	Question
A.1	What is your primary role?
A.2	How familiar are you with eco-design in digital electronics?
A.3	How do you perceive the use of open hardware in digital electronics education for fostering sustainability?
A.4	Do you believe the use of open hardware contributes to eco-friendly practices in digital electronics learning?
A.5	Which benefits of open hardware do you consider most impactful for eco-design?
A.6	How familiar are you with the concept of open hardware?
A.7	What are the potential benefits of using open hardware in digital electronics education?
A.8	How do you feel about teaching students to design and use open hardware?
A.9	What challenges do you think educators face when incorporating open hardware into the curriculum?
A.10	Teaching Modularity: How effective do you think teaching modularity in electronic design is for promoting sustainability?
A.11	How important is it to teach modularity in electronic design to foster sustainability?
A.12	What challenges do you consider in teaching modularity?
A.13	In your opinion, what is the most effective way to introduce the concept of modularity in electronic design?
A.14	How important is teaching reconfiguration of digital electronics for achieving eco-design goals?
A.15	Do you find it practical to teach the reconfiguration of digital electronics to achieve different functionalities?
A.16	What skills should be prioritized in teaching reconfiguration of digital electronics?
A.17	How familiar are you with the concept of reconfigurable digital electronics?
A.18	What is the value of teaching the reconfiguration of digital electronics in terms of adaptability and functionality?
A.19	How do you rate the significance of teaching reuse (circular use) of electronic blocks in digital electronics learning?
A.20	In your opinion, what are the best methods for teaching repair and reuse of electronic blocks?
A.21	Do you think the circular use of electronic components should be a mandatory part of digital electronics courses?
A.22	What are the biggest barriers to implementing eco-transition principles in digital electronics learning?
A.23	What is the primary goal of integrating sustainability into electronic systems design?
A.24	Describe an example of an open hardware platform?
A.25	How can open hardware contribute to sustainability in electronics?

TABLE II
QUESTIONS ON OPEN HARDWARE AND SUSTAINABILITY IN DIGITAL ELECTRONICS.

of the participants (84%) were unfamiliar with eco−design concepts but agreed that open hardware promotes sustainability (75%) and supports eco−sustainable practices (100%). A significant focus is denoted on integrating open hardware into education, yet there is widespread unawareness (see Figure 3b-c-d). This integration is valued for its recognized benefits in fostering innovation and sustainability, although concerns about standardization appear.

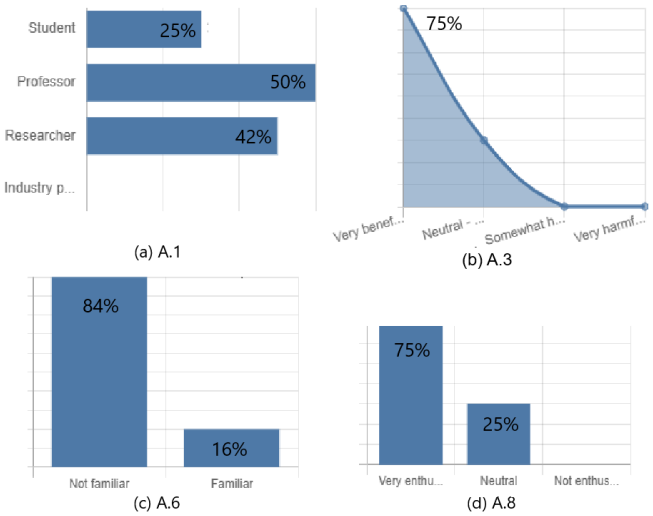

Fig. 3. Survey results for questions based on open hardware in education, covering roles A.1 (a); sustainability impact A.3 (b); familiarity A.6 (c); and teaching enthusiasm A.8 (d). Multiple responses were allowed per question.

Figure 4 summarizes some responses based on open hardware and modularity in digital electronics. 75% of the participants were enthusiastic about teaching students to design and use open hardware, although 67% anticipated difficulties such as resource shortages or technical issues in teaching modularity (see Figure 4a). Open hardware is viewed as essential to ensure compatibility and interoperability, with platforms such as the Arduino microcontroller or FPGA highlighted for their contributions (62.5%). The key advantages of open hardware included community support and collaboration, and flexibility in digital design (75%) (see Figure 4b). Benefits include low cost and accessibility (see Figure 4c), but barriers such as lack of standardization, technical challenges, and resistance to traditional educational practices hinder widespread adoption (58%) (see Figure 4d).

The primary goal of integrating sustainability into digital electronics education is to reduce the environmental impact of the device life−cycle, as highlighted by 72.3% of the participants. The key obstacles are insufficient resources (62.5%) and difficulties in curricular adaptation (50%). Although circular component use is considered crucial for sustainability, only 37.5% support making it mandatory in courses. Participants also recommend strategies such as hands−on projects, starting with simple examples, simulation tools, or real−world case studies (see Figure 5a). Teaching modularity in digital electronics is vital for sustainability, as cited by 99% of

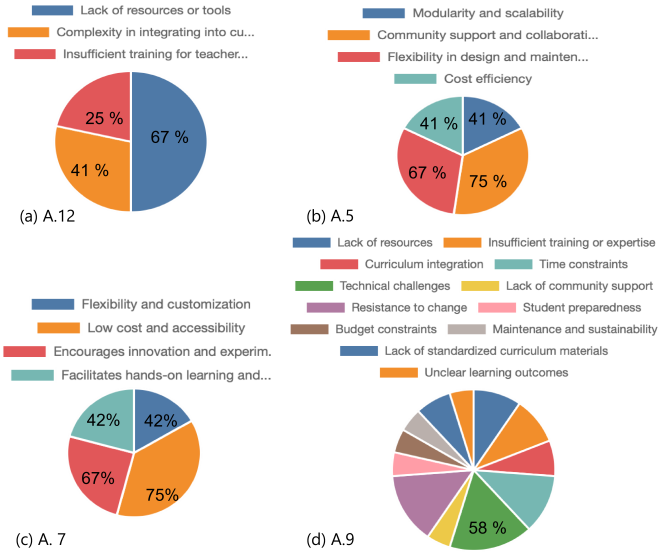

Fig. 4. Survey results for questions on eco−transition in digital electronics learning (A.5, A.7, A.9, A.12). Multiple responses were allowed per question.

the participants to improve the longevity and efficiency of the device (see Figure 5b). Most participants view teaching modularity as effective for sustainability, highlighting goals such as enhancing longevity, resource efficiency, customization, repairability, and reducing environmental impact (see Figure 5c). Energy efficiency supports sustainability by reducing consumption and extending the life−cycle of devices. The key skills needed include mastering hardware description languages (58%) and analyzing the performance of the digital system (25%) (see Figure 5d). Participants also emphasize that energy−efficient designs reduce consumption and impact (75%) and the sharing economy promotes waste reduction by favoring access over ownership (87.5%).

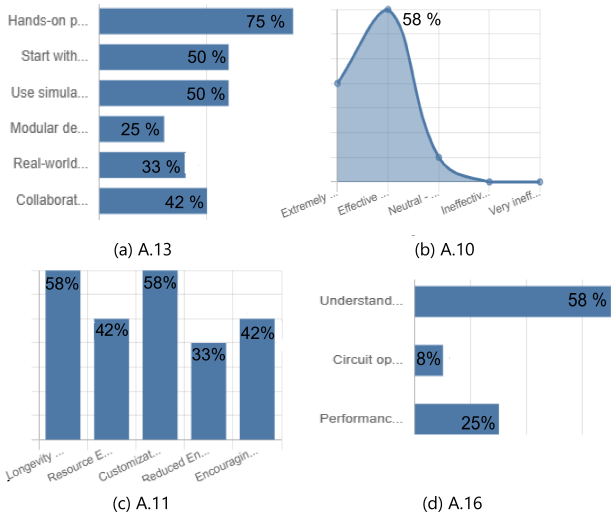

Fig. 5. Survey results for questions on modularity highlighting effectiveness A.13 (a); teaching strategies A.10 (b); importance A.11 (c); and key goals A.16 (d). Multiple responses were allowed per question.

Teaching digital electronics reconfiguration is considered essential for adaptability and eco-design goals by 92% of the participants, with 67% familiar with the concept. Success depends on the background of the students, the experience of the professors, and the integration of the curriculum. Regarding skill prioritization, responses highlight the importance of hardware programming, adaptability, or troubleshooting (see Figure 6).

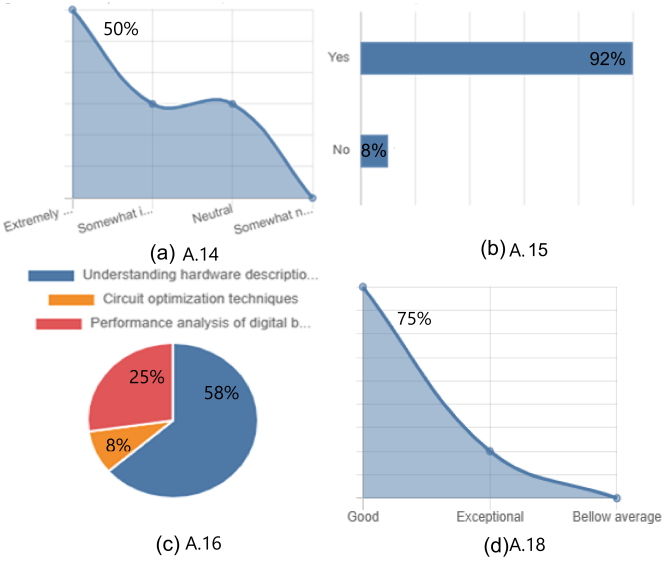

Fig. 6. Survey results for questions on teaching digital electronics reconfiguration and sustainability A.14 (a); importance A.15 (b); key skills A.16 (c); and its role in achieving sustainable and multifunctional designs A.18 (d).

Finally, a circular economy focused on reusing electronic components is the key to sustainability (63.6%). The participants emphasized teaching reuse and repair to mitigate the environmental impact of digital electronics. Furthermore, research identifies the most effective methods for teaching electronic block repair and reuse, with hands-on training, simulation tools, and project-based learning emerging as key approaches. The main challenge in creating eco−friendly products is designing for reusability and modularity (72.3%). Effective teaching involves hands−on repair workshops and circular design case studies (72.7%).

B. Quizz about Sustainability and eco-transition in Digital Electronics

Table III shows 26 questions (B.1 to B.26) designed to assess the level of knowledge of the participants on sustainability and eco−transition in digital electronics. The results reveal the awareness, strengths, and areas of improvement in sustainability, open hardware and modularity, electronic waste, circular economy, and energy efficiency.

The participants demonstrated a strong knowledge of open hardware (72%), open standards in modular electronics (82%) and the sustainability benefits of open hardware (91%). However, only 55% could distinguish between open−source hardware (B.1−B.4, B.15−B.18). Sustainable electronics practices were related to repairability and recyclability by 82%, showing awareness of the impacts of electronic waste. The circular

B#	Question
B.1	What is the primary goal of integrating sustainability into electronic systems design?
B.2	What is open hardware?
B.3	Why are open standards important in the context of modular electronics?
B.4	Which of the following is an example of an open hardware platform?
B.5	How can open hardware contribute to sustainability in electronics?
B.6	Which of the following practices is most closely associated with sustainable electronics?
B.7	In the context of electronic systems, what does the term 'E-waste' refer to?
B.8	Which certification is relevant for assessing the sustainability of electronic products?
B.9	Which process is crucial for enabling the recycling of electronic components at their end of life?
B.10	What is the primary environmental benefit of using recycled materials in the manufacturing of electronic systems?
B.11	In the context of eco-transition in digital electronics, what does the term 'circular economy' refer to?
B.12	Which of the following initiatives is most directly aimed at promoting the eco-transition of digital electronic systems?
B.13	How does implementing energy-efficient design in digital electronics contribute to environmental sustainability?
B.14	Which of the following is a key factor in reducing the environmental impact of electronic products?
B.15	What is modularity in electronic design?
B.16	How does modularity in electronic design help in the learning process for students?
B.17	Which of the following is a benefit of modular design in electronics?
B.18	Which of these is a common application of modular design in digital electronics?
B.19	What is the primary benefit of recycling electronic components in terms of resource conservation?
B.20	How does using recycled materials in digital electronics help the environment?
B.21	Which initiative is known for promoting the use of renewable energy in the production of digital electronics?
B.22	What role does energy efficiency play in environmental sustainability in digital electronic systems?
B.23	Emerging digital technologies can drive transformation into a more sustainable circular economy. Which technology is not typically associated with this transformation?
B.24	What is a key feature of sustainable manufacturing in the digital electronics industry?
B.25	How does the digital sharing economy contribute to eco-transition?
B.26	Addressing the digital divide can contribute to social sustainability. What does the digital divide refer to?

TABLE III
QUIZZ ABOUT SUSTAINABILITY AND ECO-TRANSITION IN DIGITAL ELECTRONICS.

economy and eco−transition principles were understood by 81.82%, focusing on waste reduction, resource efficiency, and device longevity (B.7, B.9, B.19). However, there are knowledge gaps, with 73% recognizing energy efficiency with less understanding of the benefits of recycled materials and the precise classification of recycling (B.5, B.6, B.10-B.14). Participants grasped circular economy principles but showed gaps in understanding recycled materials (B.11, B.12, B.20, B.23). The energy efficiency was recognized by 73% of the participants, suggesting a greater understanding of its sustainability role (B.13, B.22). Participants provided a good knowledge of sustainability certifications but could improve on renewable energy initiatives (B.8, B.21, B.24). Similarly, the concept of addressing the digital electronics divide as part of social sustainability requires more clarity (B.25, B.26).

C. Open−ended questions

The participants shared their experiences and views on tools, platforms, and methodologies in the education of sustainable digital electronics. The discussion ranged from widely used platforms to advanced development and simulation tools. Arduino [34] is popular for its documentation and global use, but its suitability varies by application. It is effective for teaching modular circuit design, as well as Groove Shield and TinyFPGA [35] adding value, despite open−source limits. Other platforms, such as Raspberry Pi [36], and ESP32 [37], accommodate various project requirements. FPGAs, especially RedPitaya [38], TinyFPGA, or MKR Vidor 4000 are considered ideal platforms for teaching reconfigurability. Concerns about energy consumption were noted when including modularity for communication purposes.

In terms of development platforms, Eclipse [39] is a versatile environment with strong debugging tools and version control, suitable for large projects but can be complex for beginners. Python is ideal for prototyping with its simplicity and MicroPython offers an efficient syntax for microcontrollers, but requires careful adaptation due to limited libraries and hardware support. Jupyter [40] supports interactive learning and hardware control, but browser dependence limits its real−time use. The Node-RED drag−and−drop interface excels in IoT and data visualization, but is limited by the JavaScript dependence in advanced programming.

Concerning digital design, LTspice, [41] KiCad [42], and Tinkercad [43] offer strong circuit simulation capabilities. Xilinx Vivado [44] and Intel Quartus Prime [45] are the leading tools for HDL design and offer advanced features for digital design and FPGA programming, supporting complex designs for high−level applications. However, they require deep hardware and software knowledge, and full capabilities are available upon license. Open−source libraries such as Adafruit [46] and SparkFun [47] improve accessibility and innovation with detailed documentation for sensor integration. These simplify design and encourage creativity, but pose a steep learning curve, especially for non−specialist. Both environments require an understanding of low−level details for effective integration, challenging those new to digital electronics and embedded systems. Finally, iFixit provides a comprehensive approach to understanding and practicing the principles of sustainable electronics, combining basic mechanical repair skills with advanced electronic diagnostics.

D. Discussion

Although the sample size of the study is limited, it provides a valuable starting point for understanding eco−design, modularity, or circular practices adoption. The voluntary nature of the survey may introduce self−selection bias, as participants with a prior interest in open hardware or modularity could be overrepresented. Although the study primarily targeted participants from EU−affiliated universities, responses from outside the EU were not strictly controlled. Additionally, variations in the distribution of participants across educational levels and professional backgrounds offer insights but should be interpreted with caution. Despite these limitations, the findings lay the groundwork for further research. Previous studies have also highlighted similar challenges regarding sample representativeness and response bias [48].

The lack of expertise, comprehensive training, and resources makes it challenging to embrace innovative teaching methods centered on sustainability and digital electronics. This issue is further compounded by the lack of structured formalized training programs, leading to professors lacking essential support to modernize their course materials. Similar barriers have been observed in the adoption of sustainable and digital teaching strategies [49]. Institutions can improve their skills in eco−design, modularity, and circular economy through workshops, online courses, and collaborative trainings. Interdisciplinary collaboration between engineering and environmental science departments can support the integration of sustainability into curriculum. Therefore, pilot programs will enable professors to try new teaching methods in low−risk environments, facilitating smoother transitions. Studies have shown that such initiatives can enhance faculty participation and improve educational outcomes [50], [51].

IV. Conclusions

This study highlights the importance of incorporating eco−design, modularity, and circular economy principles into digital electronics education. First, a survey was conducted to evaluate sustainable design, identify challenges, and explore strategies for modularity and curriculum updates, using quantitative data from questionnaires and qualitative insights. Participants included students, professors, researchers, and industry professionals to ensure that education is aligned with practical needs. The participants affirm that open hardware promotes innovation, accessibility, and environmentally friendly practices through community collaboration. Integrating these concepts into curricula helps students design sustainable electronic systems, tackling electronic waste and resource inefficiency. Second, the results of the quiz show a strong understanding of sustainability, but more education is needed about recycling and differentiating open−source from proprietary hardware. Finally, open−ended questions highlight a variety of tools

supporting modularity and reconfigurability in electronics, emphasizing accessible Arduino and Redpitaya FPGAs platforms. The findings highlight awareness of sustainable electronics practices and the importance of integrating technical and practical solutions into education. Challenges such as insufficient resources, limited faculty training, and resistance to new methods require institutional support and professional development. Hands-on learning, interdisciplinary collaborations, and real-world case studies are crucial to improving teaching effectiveness and addressing educational gaps.

Future work will explore scalable approaches to curriculum modernization that emphasize sustainability and adaptability. This includes developing comprehensive frameworks for professor training, creating open−source teaching tools, and fostering industry-academia partnerships to ensure alignment with practical applications. Moreover, the incorporation of advanced technologies such as IoT−enabled devices and reconfigurable digital systems possesses the potential to foster a deeper understanding of eco−design principles.

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