Interweaving Green Electronics and Sustainable Software Development Education in Electrical and Computer Engineering Curricula

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Introduction

The accelerating pace of artificial intelligence and data-intensive computing has its own toll on the environment. Training and operating large language models (LLMs) now require enormous computational resources, as recent studies have shown. The training phase of a single AI model can generate over 625K pounds of CO2 gas—equivalent to almost five times the total emissions produced by an average American car over its lifetime[1]! As AI adoption continues to scale, data centers already account for ~4.4 % of U.S. electricity use (in 2023), and projections indicate that share could triple by 2028[2], which is also the energy equivalent of a country like Argentina or Netherlands[3]. These realities reveal an urgent need to prepare the next generation of engineers to design, deploy, and manage computing systems through a lens of environmental responsibility.

In response to this challenge, we developed three comprehensive educational modules on Green Electronics and Sustainable Software Development designed for three core Electrical and Computer Engineering courses: Microelectronics Circuits, Algorithms for Big Data, and Senior Design. These modules aim to equip future engineers with practical and theoretical tools to reduce technology's environmental impact, and raise their awareness about the sustainability problem, each in their own field.

Procedure and Methods

The educational modules were piloted during Summer and Fall of 2025, targeting students at sophomore, junior, and senior levels. The piloted modules taught sustainable programming practices, environmentally conscious circuit design principles, and capstone project approaches grounded in sustainability, impacting approximately ***85 students*** during these two semesters. The project aims to move sustainability from a peripheral ethical topic to a core technical competency by developing a set of modular learning units that explicitly connect green computing, hardware utilization, and software efficiency to their environmental and societal impacts. Students are exposed to contemporary case studies—from data center cooling optimization to carbon-aware software scheduling—highlighting how computational choices translate directly into energy use.

The following list of topics were curate and implemented in the educational modules offered to the students:

1. Information and Communication Technology (ICT) for Green.
2. Green Electronics and ICT
3. Green Computing and Managing e-Waste
4. Software Carbon-Footprint
5. Efficient Design of Datacenters

The time of this project is in perfect alignment with Pitt's major sustainability plan, that tackles man aspects of sustainability, one of the is "Energy and Emissions", as shown in Fig. 1. The goal is to reduce Green House Gases emissions by 50% by 2030 from the 2008 baseline. While the developed modules discussed many topics, for space limitations, we have only included an example of one of the educational modules developed, depicted in Fig. 2. The top part of the figure shows the life cycle of an ICT service/equipment. In this part, the students learn about the inputs and the outputs of this process, how much energy does it require to manufacture one of these devices, and how they can offset this energy by optimizing the time these devices are used. On the other hand, the lower part of Fig. 2 shows the equation used to calculate the carbon foot-print of a computer program running on a specific machine. Once the students know certain parameters and features of the hardware they are running their code on, they can easily calculate its impact on the environment; and from there, they can easily refine and optimize.

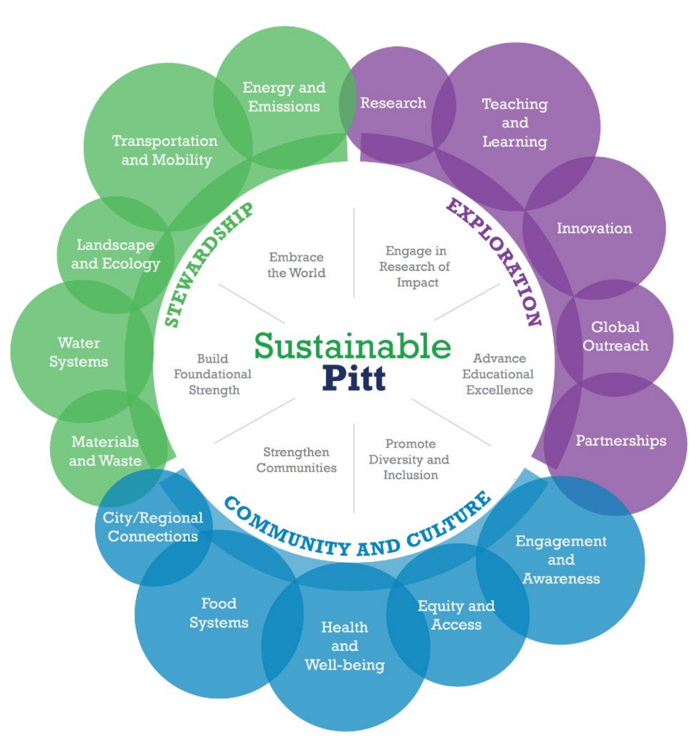
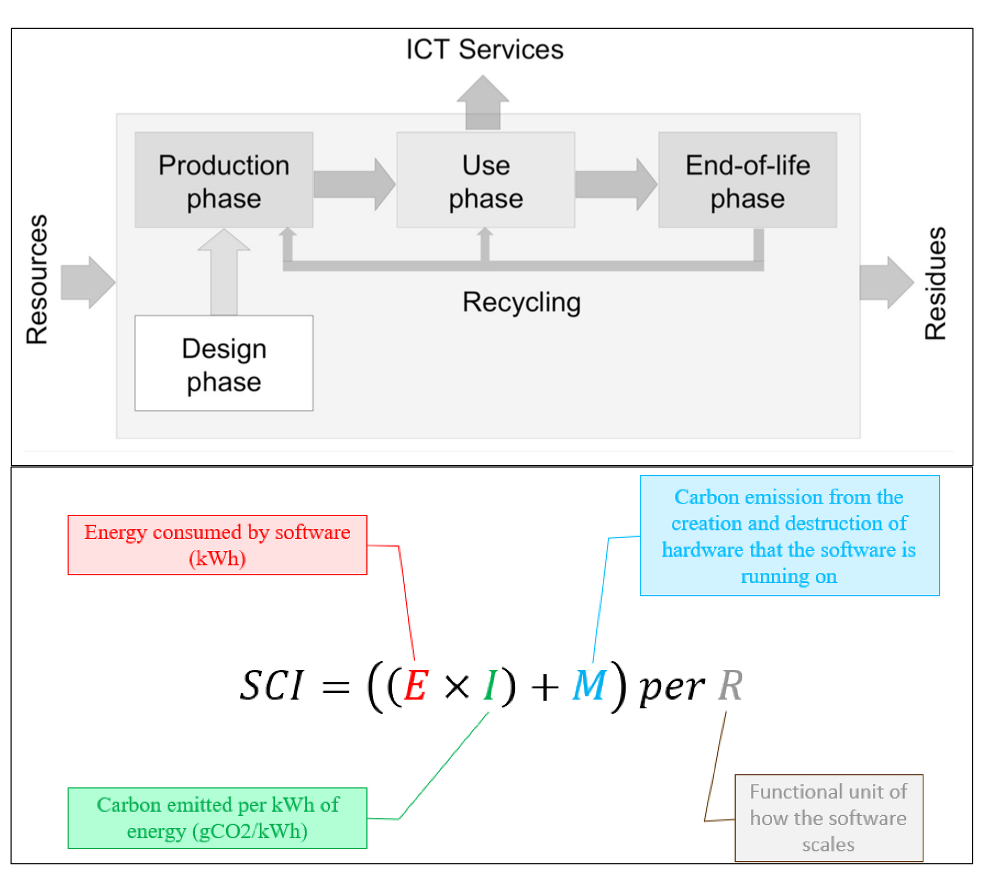


Fig. 1: Pitt Sustainability Plan



$$SCI = ((E \times I) + M) \text{ per } R$$

Fig. 2: Typical ICT Device Life Cycle and the formula for calculating the carbon foot-print of a program.

Evaluation and Impact

The study adopts a mix of evaluation methods to assess both learning outcomes and attitudinal shifts. In the Microelectronics Circuits and Senior Design courses, quantitative evaluation was derived from targeted assignments and performance metrics, directly related to the educational modules proposed. While qualitative data were gathered from Algorithms for Big Data through reflective surveys to gauge the students' eco-consciousness and sustainability-oriented technical reasoning. We were mainly trying to address the following three research questions: 1) How can sustainability-oriented modules be interwoven into deeply technical elective courses without displacing core content, 2) Which evaluation strategies effectively measure changes in students' technical understanding, eco-consciousness, and future intentions, and 3) In what ways did students' perceptions and knowledge of green computing and sustainable software development change as a result of the learning modules?

The total number of students who ere impacted by this pilot study were 85 students, with the following distribution:

- Senior Design (SD): **53 students**
- Algorithms for Big Data (ABD): **22 students**
- Microelectronics Circuits (MC): **10 students**

For the ***ABD course***, most of students were advanced junior/senior students who are about to graduate soon. The newly developed educational modules were offered to the students towards the end of the semester, followed by a post-assessment survey. The survey mainly captures how much the students knew about he discussed sustainability topics before the learned about them in class; and how much the modules changed their view of sustainability. Fig. 3 shows the result of the following question: "*How familiar you were about the different topics discussed in the Green Computing and Sustainable Software Development modules before hearing about them in this course?*" A quick analysis to this result shows that, at best, **only 36%** of the students were at least moderately familiar with "Green Computing and Managing e-waste" topic. That percent drops drastically for other topics, which indicated the gap in knowledge about these topics and how our students needed this education. The results of the following question: "*After going through this module, how interested you are in knowing more about the topics discussed?*" is depicted in Fig. 4, where **at least 86%** of the students were interested in learning about the topics discussed. In fact, **more than 45%** of the students were "*very interested*" in learning about topics like: "Green Computing and Managing e-waste," and "Calculating Software Carbon Intensity of a Program". This result does make sense as it is directly related to the course topics which is how to handle Big Data.

While the survey has more questions to analyze, we will conclude the qualitative analysis with the following question: "*From your own point of view, please rank the following topics by importance:*", with 1 being the most important and 5 being the least important. The results depicted in Fig. 5 shows that most of the students agree on "Efficient Design of Datacenters" being the most important topic, followed by "Green Computing and Managing e-waste", which highlights again that they have developed a sense of eco-consciousness towards the sustainability problem and how it is related to Big Data and Generative AI.

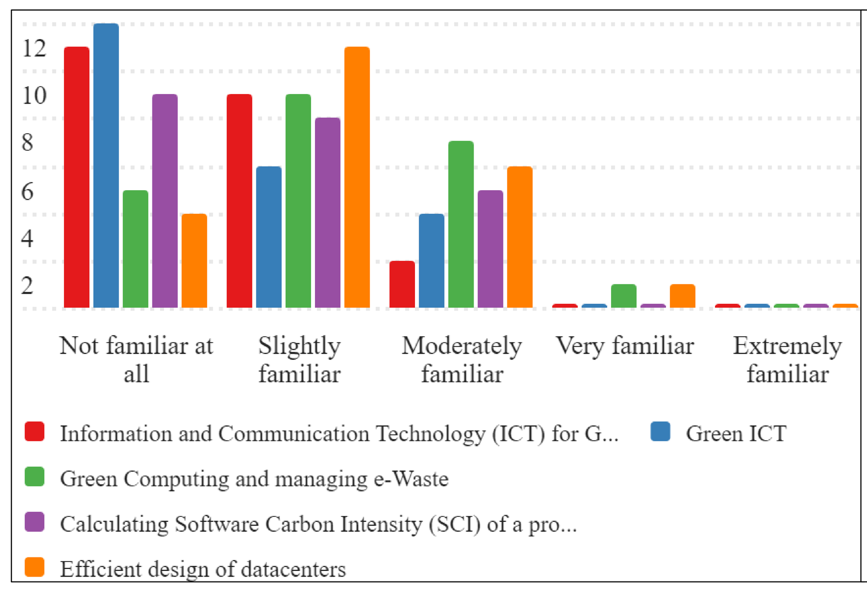


Fig. 3: Students' familiarity with the topics before being introduced in the developed educational modules.

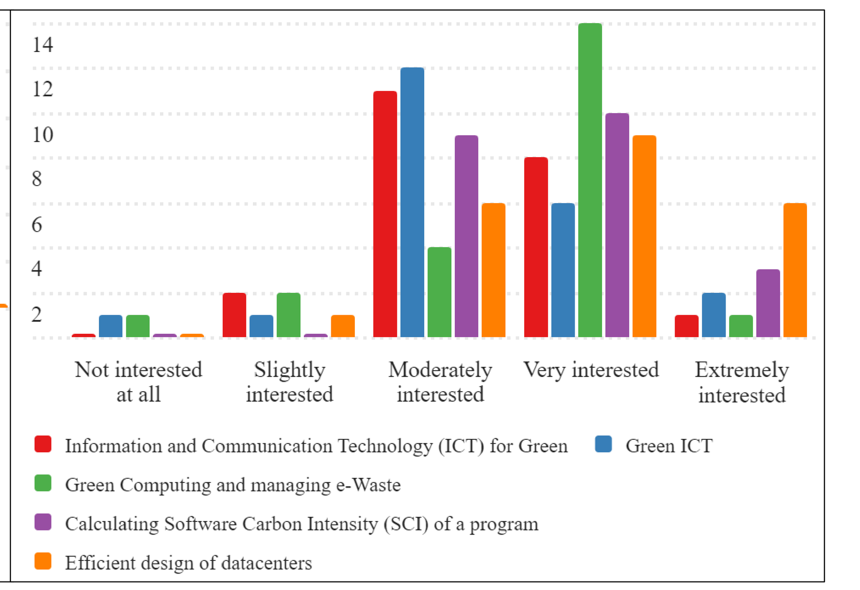


Fig. 4: Students' interest in the topics introduced in the developed educational modules.

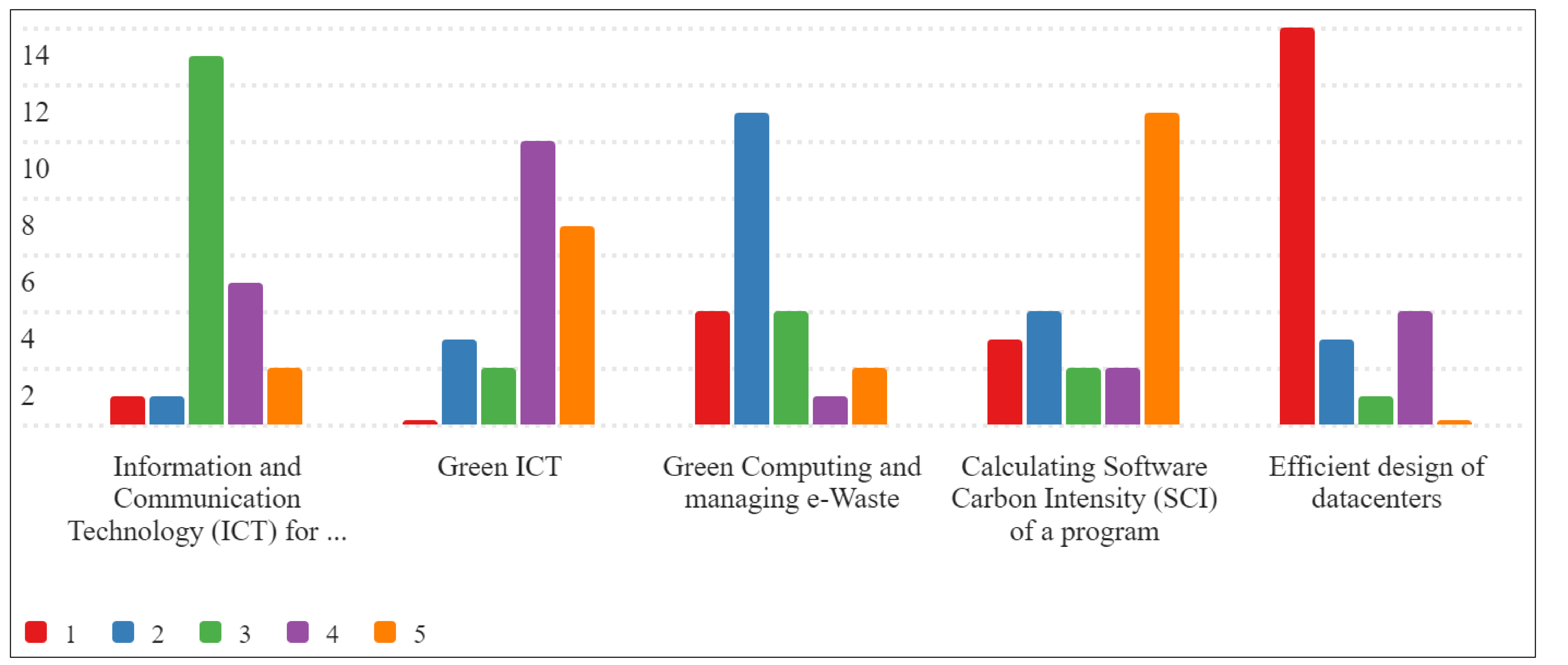


Fig. 5: Students' ranking of the various introduced topics' importance.

For the **SD** and **MC** courses, quantitative data were collected from assignments that were offered post-offering (MC) and pre- and post-offering (SD). A final exam question was used to gauge the students' understanding of basic sustainability consideration in circuit design for the MC course, while a midterm and a final assessments were used to assess the sustainability aspect of the capstone project the student submitted. For the latter, the instructor laid out certain sustainability requirements on all the capstone project that the students design, with such consideration being open-ended enough for the students to innovate. Fig. 6 depicts the analysis of the pre-assessment (a) and post-assessment (b) for 12 teams that were enrolled in the SD course, each team was between 4-5 students. The pre-assessment was for the student proposal of their SD project, which was toward the third of the semester, and the results of this assessment in in Fig. 6(a). As can be seen, all the team have considered all the sustainability requirements in their proposal, with about **42%** of them fully met all these considerations. Fig. 6(b) shows the results of the post-assessment, which was held at the end of the semester when students fully designed and finished their projects. The percentage of the teams that at least met some of the sustainability considerations in their final design dropped down to about 58%, with about 42% of them didn't meet any of the requirements at all. The team working on this study is still analyzing the results and the feedback given by the students to further investigate the reason that hindered them from implementing it.

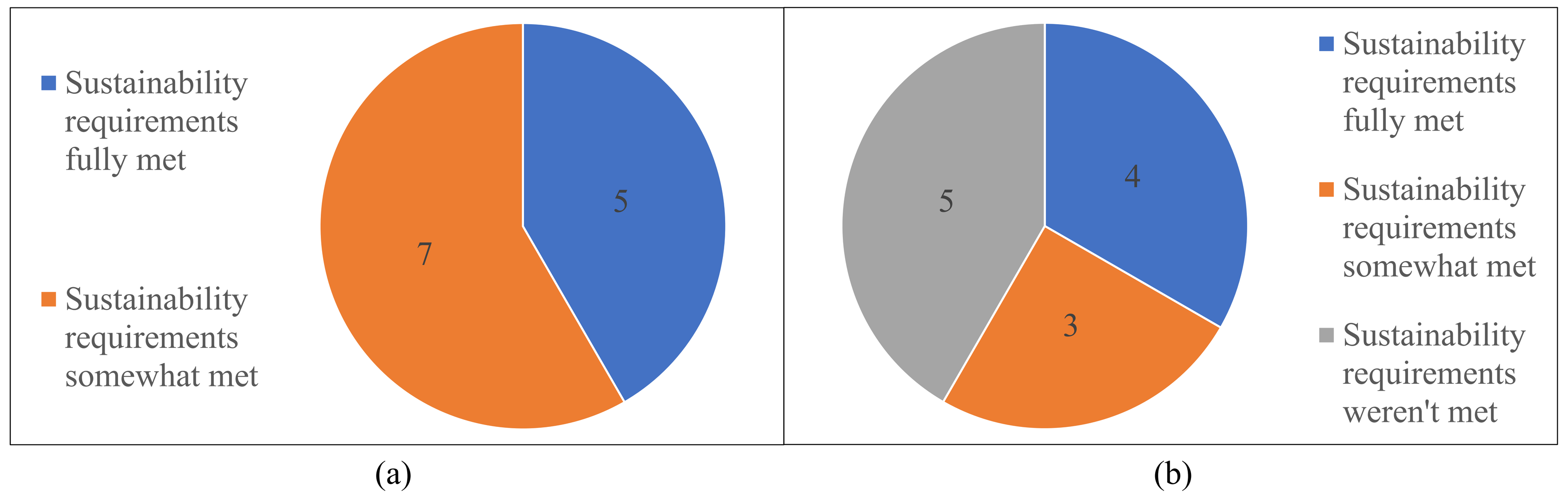


Fig. 6: Pre- and post-assessment of the students' engagement with different sustainability consideration in their final capstone project in the Senior Desing Course..

EOP Framework Integration & Scaling Up

Many learning outcomes from the EOP framework are in perfect alignment with the learning outcomes designed in the developed educational modules under this project. For the sake of the limited space, we are only going to mention few of the core sustainability outcomes that were directly addressed in our modules here. Within the MC course (blue), the modules emphasized the Design, Material Selection, and Environmental Impact Assessment cores, while the ABD modules (red) focused on Environmental Literacy, Social Responsibility, and Design. In SD (black), students were evaluated on Systems Thinking, and Communication and Teamwork.

Since the results of this project were very impactful on the students, the authors plan to permanently offer these modules in the courses mentioned here and seek collaboration with other instructors from different departments to expand the exposure of the students these modules. In addition, the authors will polish the modules and make them publicly available for other instructors to plug-and-play in their courses.

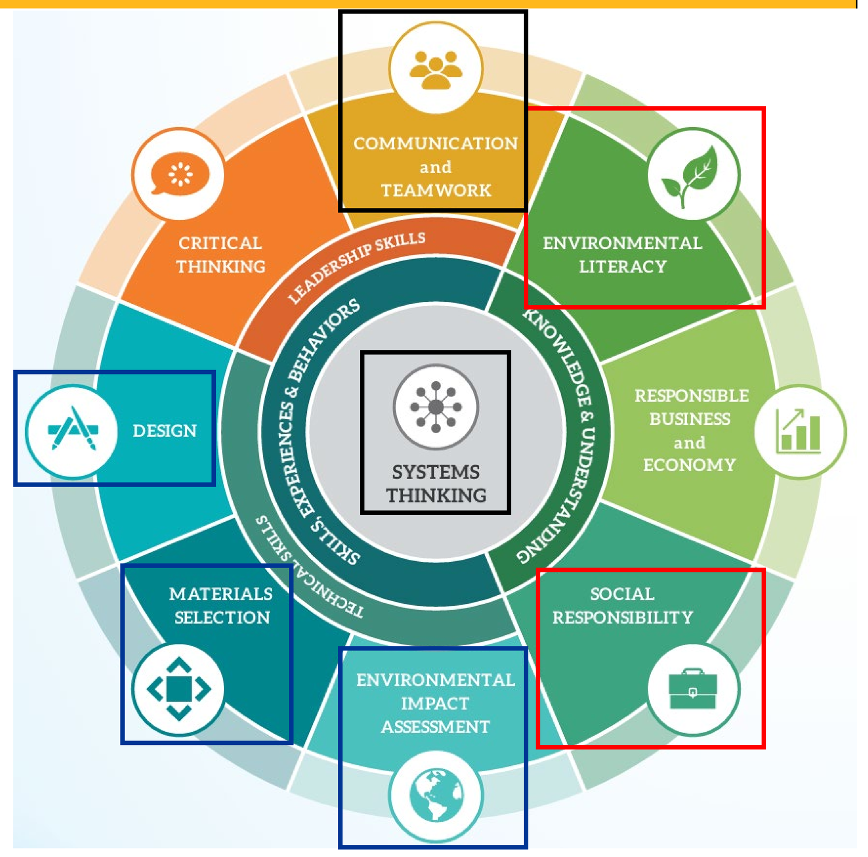


Fig. 7: EOP Framework Integration

Acknowledgments

We like to heartedly thank the Lemelson Foundation and ASEE for their support of pilot project. A very special thanks to out great mentor, Dr. Irene Mena; without her guidance in evaluation and assessment, this work will never have seen the light. Last but not least, many thanks to all our colleagues who helped in administering the developed educational modules and various forms of assessment and evaluation.

References

[1] https://arxiv.org/pdf/2311.16863.pdf
[2] https://iee.psu.edu/news/blog/why-ai-uses-so-much-energy-and-what-we-can-do-about-it
[3] https://www.holisticai.com/blog/environmental-impact-ai-llms