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Tackling The E-Waste Problem Through Innovative Teaching of Electrical and Electronic Engineering.

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Abstract

This paper presents a proposed innovative way to teaching basic Electrical Engineering by incorporating a zero-waste philosophy and approach. Traditional topics being taught in basic Electrical Engineering include introduction to Direct Current, Alternating Current, circuit theory laws: Ohm's law, Kirchhoff's laws (current and voltage), Superposition theorem etc. The proposal is that when zero –waste as a thinking is introduced ab-initio to Electrical Engineering syllabi, it will promote modular green designs and circular solutions that have the best of two worlds: of Science and Technology on the one hand, humans and the environment on the other hand. The proposal goes to show that in dealing with e-waste, Electrical Engineering is very central and that focusing on the students is pivotal in solving today's and ultimately eliminate what would have been tomorrow's e-waste challenges. It details this using a garden fork prong analogy. An implementation of the first prong was made by using e-waste in teaching basic electrical machines. The results indicated a better learning experience for the course participants. This paves the way for introducing analysis with a design oriented approach as a future study, in which human-centredness, environmentally friendly materials and methods can be introduced.

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Keywords: E-waste, Electrical Engineering, Innovative teaching, Zero-waste, Circularity, Improved learning.

1. Introduction

The importance of environmental functional integrity for any system, sub-system or systems of systems cannot be overemphasized (Guerrette, 1986; Wang et al., 2018). From quantum levels up to the macroscopic subsistence, the same assertion holds true. The environment is the super-system housing the sub-systems in which humans live and function. Virtually, every aspect of human functioning today is permeated with electrical and electronic systems, components, devices and processes. Unfortunately, these electrical systems have contributed in no small way as far as environmental damage and degradation is concerned. As of 2016, 44.17 million metric tonnes of e-waste were reported by the United Nations University (UNU) to have been generated globally (Forti et al., 2018). This is due in part to some of the toxic materials used as well as the design and fabrication processes to begin with. process.

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There is therefore a need to pay attention to the training of electrical and electronic engineering professionals as they are central in this.

The waste sector is currently receiving significant amounts of e-wastes in addition to the growing municipal and industrial wastes (Hossain et al., 2015; Heacock et al., 2016). Municipal and industrial wastes generally contain hazardous and toxic substances dangerous to human health and the environment; yet e-wastes present a more serious issue in hazardous and toxic substances that constitute a major percentage of the device components (Perkins et al., 2014; Vats et al., 2014).

The high turnover rate of electrical and electronic devices due to rapid production, innovation, competition and increasing demand has contributed immensely to e-waste generation (Vats et al., 2014; Hossain et al., 2015; Li et al., 2015). There is also a projection of global e-waste generation of 74.7 Mt by 2030, a 39% increase from 2019 (Forti et al., 2020). These e-wastes are many times disposed (especially in less buoyant economies) in ways that add to environmental degradation. It is not uncommon for some e-waste to be found in landfills with consequent impact on the environment, especially the soil and groundwater, which in turn affect the food we consume among other things (Dharini et al., 2017; Panwar and Ahmed 2018).

Several paradigms and approaches for solving the e-waste problem (StEP) have been developed and implemented (Hoeltl et al., 2017; Widmer et al., 2005). Results have been a mix of positive and not-so positive outcomes (Pedro et al., 2021). As a result of this, there is a need for new approaches (or modifications) that have at their core, sustainability and zero-waste (Hoeltl et al., 2017). Sustainability is about ensuring that the environment, from which we derive resources for life, is left at least as good as we met it, preferably better. It implies that resources (of which human-beings are central) are left in a better state after our production and utilization processes (Glavĭc and Lukman 2007). However, despite the existing understanding and action steps to implementing zero-waste and sustainability, the challenge of e-waste has been on the increase.

Understanding the E-waste problem

The e-waste problem implies that mostly end-of-life or decommissioned electrical (including electronic) equipment occupy space that could have been used for other things, amongst other undesirable and toxic effects they cause (Widmer *et al.,* 2005). This has many implications on life such as human and animal health, ecological, social, economical etc.Taking a critical look into the causes of e-waste (such as short equipment life time, consumer spending capacity, etc.), the key factor behind e-waste lies in the most critical resource on planet earth – human thought processes (Gollakota *et al.,* 2020). Human wants and spending capacity, coupled with insatiable wants have been severally highlighted as no small contributors to the growing e-waste problem (Premalatha *et al.,* 2014).

Human thinking being the most critical variable needs to be positively excited in order to solve the e-waste problem, it is then imperative to lay out a plan-of-attack (POA), highlighting clear approaches, expected challenges and mitigating strategies (Jayaraman, *et al.*, 2019). A typical engineering undergraduate student spends anything from four to five years learning courses such as electric circuit theory, containing topics such as series and parallel circuits, maximum power transfer theorem (usually involving some reasonable level of mathematical proficiency) in order to equip them to provide solutions to human problems based on the manipulating of electrical charges. The end-product is the electrical engineer (in the industry or academia) providing solutions based on the paradigms obtained from these courses. Howbeit, a closer look at a number of these courses, especially foundational ones will show that there is close to zero incorporating of zero-waste and sustainability in the design and implementation of such courses (COREN BMAS 2013).

Zero-waste is a sustainable thinking paradigm borrowed from nature that encapsulates the ideology that there is no waste in nature (Song *et al.,* 2015; Zaman and Lehmann, 2011). One of these is the inhalation of Oxygen, O_2 (released by plants) by humans, and the utilization of Carbon (IV) Oxide, CO_2 by plants, released by animals and other anthropogenic activities (Zaman and Lehmann, 2013).

MATERIALS AND METHODS

Electrical engineers are equipped with tremendous tools and capabilities which enable them to tackle a variety of problems (especially when properly yoked in multidisciplinary collaborations). This can be useful in achieving zero-waste. However, there are still gaps to be filled that could be key in utilizing the capabilities that electrical engineering possesses.

This section proposes modifications to current strategies in the teaching (as well as learning) of electrical engineering, especially at the undergraduate level, as a means to mitigating not only the effects of e-waste, but more so eliminating the root causes of e-waste. This article proposes that by using the same tools employed by electrical engineers, the thinking of these students can be influenced. By establishing the importance of a zero-waste, sustainability philosophy and approach to the teaching of electrical engineering, the stage would be set. Thereafter, the individual contents can be justified and aligned in the light of this. This will call on different learning methodologies such as research-based learning (RBL), outcome-based approaches, etc.

A Practical Approach.

In executing this, a method / approach presented is that of a garden. The students are seen as the garden which is to be cultivated and the teacher/instructor as the gardener. The tool used by the teacher is the garden fork which symbolizes the methods presented here. A typical garden fork has three (3) prongs, with each prong representing the three (3) foci points of this article: learning by making / creating, zero-waste and sustainable making, and making to minimize and eventually eliminate e-waste. Although these are presented in sequence, there's no rule saying that they cannot be run in parallel in the same manner that the three prongs of a typical garden fork would operate.

Learning By Making

Learning is best done when in addition to a value placed on the subject matter at hand, as many senses (hearing, seeing, etc.) as possible are actively involved in the learning process. In order for the senses to be fully engaged, it is critical that there is an intersection of the present value system (PVS) of the instructor(s) with those of the students in question. This value system is expected to be studied by problem-solving approaches. This will include recognizing the fact that wherever the students may be, they already have tools that they are likely to use when they encounter problems (especially those, defined to be electrical engineering problems). Electrical engineering today is mostly taught by a teacher introducing the subject – usually with the aid of writing materials such as boards, pens and in some cases, projected slides. How do we learn by making? We learn by making/creating, real demonstrations of concepts, equations. This is the first prong of our garden fork. Making concepts, equations, etc. in electrical engineering as clear as possible, engaging as much of the value space of as many students with a view to engaging as many senses as possible. In engaging the value space of these students, it will be necessary for the teacher(s) to incorporate non-technical but influential factors respective to the students within the context of the task at hand. Why are they in school to study electrical engineering? Even when a definite, certain reason cannot be readily obtained due to present limitations, a realized reduced value space can be obtained from generic data which can be good starts for practical iterations. The goal here is to lead students in demonstrating concepts in electrical engineering for themselves. Take for example Ohm's law, $(v = Ri)$[1] the goal here is not only for students to identify where it is at work, but to come up with demonstrations of the same concept different from previously identified ones. Ohm's law states that for resistive elements, the potential difference across the two points which define the terminals of such a resistive element, is directly proportional to the current through such an element on the application of the potential difference. The constant of proportionality being the resistance, R. An alternative way is that Ohm's law could be stated mathematically as $i = Gv$ [2]. Alternating approaches can be helpful for different students.

The students will be required to design any system (process or device) of their choice that

demonstrates this concept. They will also be required to creatively document their experiences as well as review these, using a methodology called Do, Document and Review (DDR). The process of creating/making/demonstrating such concepts is hinged on five (5) fingers. The human hand which houses the five fingers is designed to have good grasping. Similarly, it is expected that the utilization of these five fingers in the process of learning by making/creating will lead to good grasp. The five fingers are: design, simulate, fabricate/construct, test and evaluate. Suffice to say that not all fingers will always be needed for every scenario, just like humans don't use the five fingers all the time. Nevertheless, it is of great importance that the five fingers are present even in a number of scenarios where all, though not very visibly in use, are playing other roles such as stability.

1 Where v is the voltage, i, the current and R the resistance.

2 Where σ (Conductance) is the inverse of the resistance, given by $G = 1/R$.

Making In The Light Of Zero-waste And Sustainability

Getting the students to create concept demonstrations is a significant accomplishment, but not where we are stopping. There is then a need to engage their value space using electrical engineering tools (for example mathematical and other appropriate models) to connect their making with the important aspects of zero-waste and sustainability. It is important that their value space is connected to for any lasting and true impact to be made. In order to truly "make" in the light of zero-waste and sustainability, there will then be a need to design in the light of such. This will then imply that there will be a need for modified models or altogether development of new models that incorporate zero-waste and sustainability in the design process. This will imply the development of electrical engineering models for zero-waste and sustainability.

Making to Minimize and Eliminate E-Waste Altogether

The last but critical step will be designing to minimize and ultimately eliminate e-waste. This step is expected to be a mostly natural flow, built on the foundation of the existing zero-waste and sustainability electrical engineering models. These existing models can then be fine-tuned to design for the elimination of e-waste.

Making Everything Work – Understanding And Optimizing Humanity

Here we show that the three-prong method – works like a garden fork with a single handle. The single handle is shown to be a human-centred design approach.The well-being and development of the individual thus becomes the focus with the caveat that our rules of engagement are the earlier method. For this to work, the link between the prongs and the handle must be solid. This is such that once the handle is held and moved, the three (3) prongs move along. This then is the core of the job – linking the three (3) prongs to the handle.

It is anticipated that the mathematics will then be shown to be depicting the relationships between physical quantities, in the case of Ohm's law, the current and voltage. The limitations of many of our models will be obvious to the students. This will be extremely beneficial. For example, students will see that the popular Ohm's law does not tell us all about resistors but only indicates the relationships between the voltages across and currents in ohmic resistances. Thereafter, due to increased experiential knowledge of complexities via making and then additions of zero-waste and sustainability considerations, students are expected to be able to deal with more complex mathematics, thereby improving abstraction skills so needed in electrical engineering to deal with the multifaceted issues of zero-waste and sustainability.

Apart from experiential knowledge coming in the design and construction phases, an anticipated result is character transformation. Learning to work with others as well as learning to own one's work among other skills are expected to be gained by the students in this kind of approach. The knowledge gained in this way is more easily retained as well as used. This can be a bedrock for further creativity. Students, due to the ownership mindset this gives them, are expected to be much more motivated to read and learn in other ways. It also helps them develop professional awareness as well as soft skills such as team dynamics. Itcan also be a gateway to entrepreneurial thinking and appreciation for laws, regulations and responsibility towards others. Equally important is developing know-how in designing systems (processes, devices, etc.) that meet the requirements for zero-waste and sustainability. It is expected that over time, the average electrical engineering student will think of solutions that vitally incorporate zero-waste and sustainability.

RESULTS AND DISCUSSION

An aspect of the learning to make approach prong was implemented in a topic on basic electrical machines as part of a course on basic electrical engineering taken in one semester. One of the aspects of the machines was that of transformers which are fundamental to understanding electric motors and generators. Apart from live demonstrations in class (size N = 41) to demonstrate concepts, an out-of-use E-I transformer provided an opportunity to lay foundational work along the lines discussed earlier. The transformer was dismantled and the students were shown the constituent parts. Plate 1 shows two (2) of such plates. This enabled the students to conceptualize possible physical realisations. Thereafter the students were instructed to actually construct dummy transformers with a single coupling ratio and simple geometry as reported by (Yu, 2004) and (Tozzi et al.,, 2009), (see right side of plate 1).

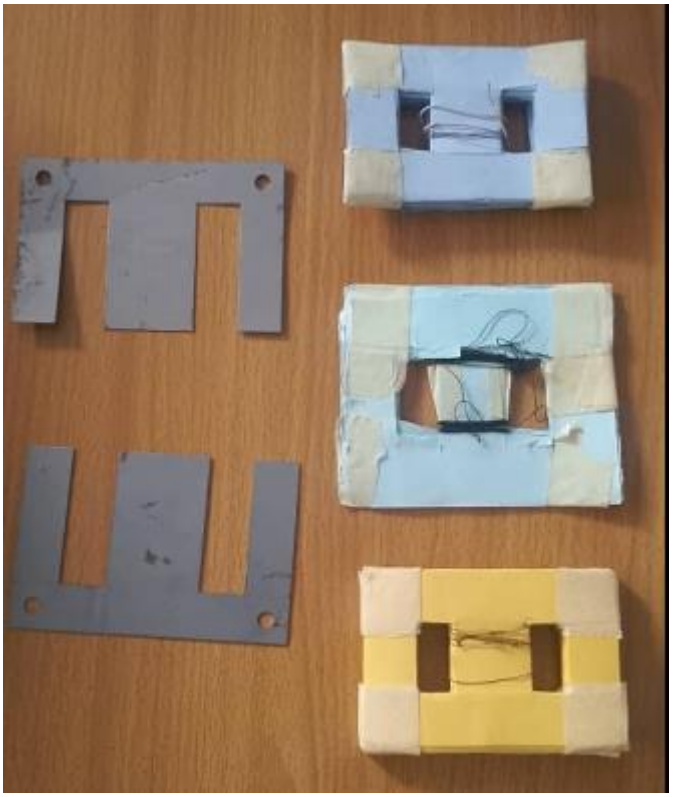


Plate 1: Left- E-Plates of a dismantled E-I Transformer. Right – Dummy transformers constructed by some students

Survey Results

A survey was run to see the impact of such an approach in teaching using Likert scales :1 – 5 (1 – Poor, 2 – Fair 3 – Good , 4 – Very Good, 5 – Excellent) and the results shown in Figure 1. Another aspect of the survey used Likert scales:1 – 3 (1 – Negative, 2 – Neutral and 3 – Positive). The results of this are displayed in Figure 2.

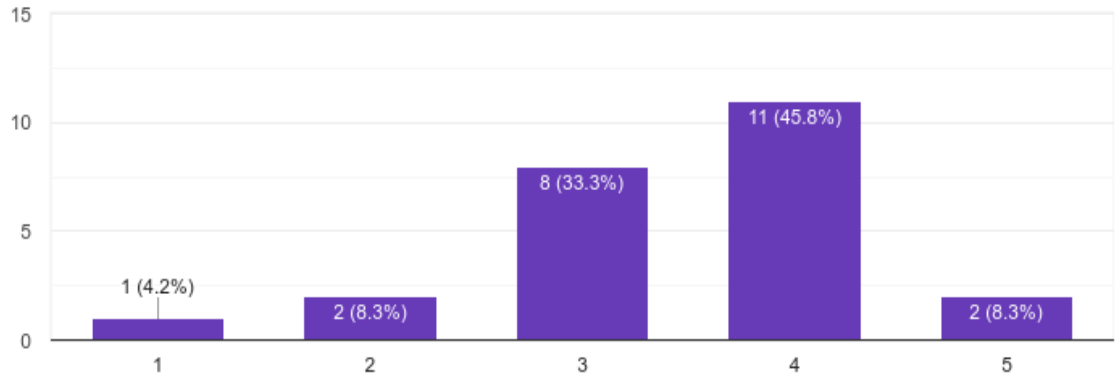


Figure 1: How has the demonstrations in Class helped your understanding of Basic Electrical Machines?

From Figure 1, we see that about eighty seven percent (87.4%) of the respondents which was roughly 21 students reported the approach to be at least good. Similar reports were presented by Kirkwood and Price, (2014). Figure 2 shows that about forty six percent (46%) reported a positive impact. Only eight (8%) reported a negative impact, while the rest forty six percent (46%) were neutral. This result is consistent with the findings of Wortha et al., (2019) who reported little to

no improvements in learning after improving teaching methodology.

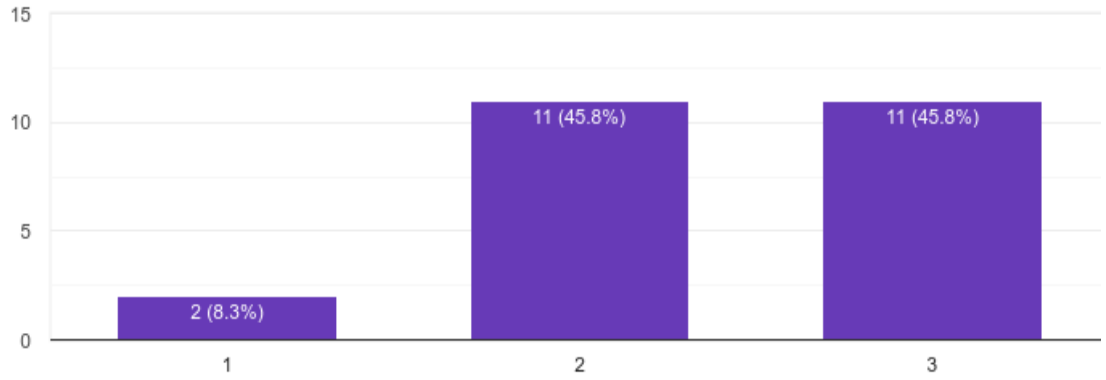


Figure 2: How did your construction of the Dummy Transformer affect your knowledge of Transformers

A further aspect of the survey involved getting responses from the students on the impact of the activities on their ability to construct real transformers. A three (3) choice response (Yes, No or Maybe) was chosen. The results are presented in a pie-chart (see Figure 3) due to its visual illustrative strengths.

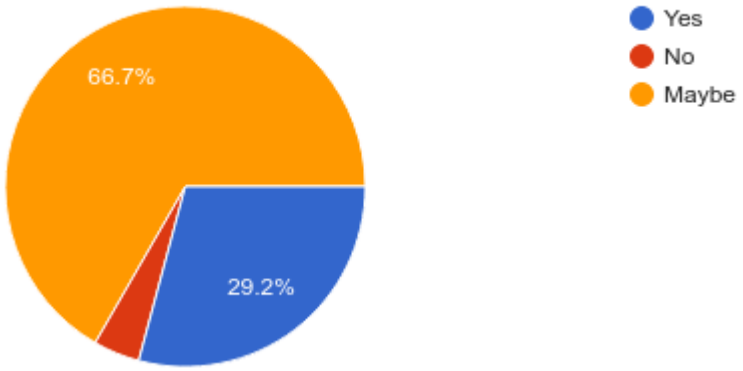


Figure 3: Do you think you are likely to find it easier to design and construct a real transformer now?

Figure 3 shows the distribution of responses as to whether the activity will help them in designing and constructing real transformers. Twenty-nine per cent (29%) responded it would. However, the majority, sixty-seven per cent (67%) were unsure. Further probing, by asking the question "Why?" brought the following responses shown in Table 1. These are in agreement with the study by Manfredi *et al*., (2021) who reported that a zero-waste approach and waste recycling will lead to a sustainable use of materials and non-renewable resources.

Table 1: Effect of Dummy Transformer Construction and Reason Given

S/N	Response	Reasons for Responses
1.	Yes	Constructing the dummy transfer made me understand transformers and how to design them/Nothing / I dont understand /Because the dummy transformer has given me an insight of the real transformer. / Cause I was able to understand the physical structure of a transformer in hand size / It gave us a greater idea on how the transformer works / Because im sure I can do it
2.	May be	I don't get all the concepts / Because of transformer is not made of cardboard / Thinking of the time we have left before exam / Nothing actually / Because we're still learning / Because i dont really understand it. / At least with the idea of transformers through the practical, it's possible if am given real materials I can try to construct with the help of the Lecturer / Cause of how you are trying to make us understand. / Cause of how you are trying to make us understand / I Still need more knowledge in some aspects. / Need more understanding / Cos I don't really understand it. / Simply because I may have a little understanding of a transformer. /The way I understand I have basic understanding of the concept. /Kinda sure
3.	No	Didn't really have the knowledge on how to

CONCLUSION AND FURTHER WORK

This article has presented a case for the development and implementation of new electrical engineering models that incorporate zero-waste and sustainability. It is expected that we will begin to see electrical engineering models that incorporate zero-waste and sustainability in curricula at very fundamental as well as advanced levels. Ultimately electrical engineers should not just see themselves as problem solvers or even incorporating green paradigms, but important parts of the teams that are building a sustainable, zero-waste future.

An implementation of the first prong: learning by making was executed. Early results in this showed enthusiasm among the course participants to participate in this approach to teaching the course. This is expected to pave the way for future studies employing the last two (2) prongs.

Studies to be done to test out this proposal in varied practical scenarios. Furthermore, electrical engineering models that cover the gamut of zero-waste and sustainability to be developed. These models need to be implemented across the board in electrical engineering courses being taught. A more detailed breakdown of the mentioned concepts into the specifics is required in order to enable easier implementation. Also, studies that capture in a holistic framework the sustainable, zero-waste environment need to developed. Electrical engineering will be indispensable for the development and implementation of such an environment.

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