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Are Open-Source Electronics Innovation Drivers? A Context-Paradox Study of User-behaviours in a Nigerian Polytechnic Setting

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ABSTRACT

Open-source electronics and platforms have promoted inclusive learning for many learners and teachers. The ubiquity of open-source electronics has attracted behaviours that have paradoxically affected the development of critical thinking, problem-solving, high-level thinking, and electronic design skills in some cohorts of users. A non-hypothetical, context-paradox study of a cohort of physically archived capstone project reports in the repository of an engineering department of a Polytechnic is presented in this study. The study examined how open-source electronics and platforms have contributed to driving innovation and developing critical thinking, problem-solving, and innovative skills in students who have used them for their capstone projects. We applied qualitative and quantitative methodologies to identify and review 738 capstone project reports physically archived between 2002 and 2021 for elements of innovation and originality based on circuit schematics and descriptive metadata. Semi-structured interviews of a targeted student population were used to complete the data collection instruments. The findings from the study suggested that the efficacy of open-source electronics as innovation drivers is behaviour-dependent on how the users leverage them to incubate innovative and inventive skills. We recommend departmental cultural changes, curriculum updates, entrenchment of codes of ethics and paradigmatic changes to pedagogical methods, and collaboration with strategic stakeholders and professional societies, for a new regime of capstone project governance, with consequences for attaining the sustainable development goals for quality education.

Keywords: *Capstone project, open-source electronics, innovation, innovation driver*

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INTRODUCTION

Engineering education challenges are not localized to any region, as the quest to break new grounds in technological development continues to expand global horizons. Engineering education has been the key to technological development in modern times and one of the key components for the attainment of sustainable development goals (SDG) (Uvalić-Trumbić & Daniel, 2016; Hales & Birdthistle, 2022). Engineering education inculcates into learners and teachers, ways to translate scientific knowledge into creative engineering solutions and contrivances (electrical, software, mechanical, and materials) that drive the world's economic, social, healthcare, security, and technological growth. Engineering education is dynamic. Consequently, it has been described as volatile, uncertain, complex, and ambiguous (Madheswari & Mageswari, 2020), because as technological advances occur, previous knowledge is rendered obsolete on the rat race fields and tracks. Several schools of thought have argued that engineering education has disproportionately impacted the technological development of African countries when compared to its transformative effect on growth in other countries of Europe and the Americas. Several factors have been adduced as responsible for the challenges of functional engineering education in Africa such as funding, facilities, student enrolment, curriculum, and pedagogical strategies (Falade, 2023). Poor quality of education manifesting through overbearing theoretical contents and outdated curricula has also been factored as one of the causes of low engineering capacity in Sub-Saharan Africa (Matthews et al., 2012).

The disparity in the outcome of engineering education in the context of technological development of Africa is very pronounced when situating the outcome of electronic engineering education in the context of Africa's innovation and invention capability and capacity during the last half of a century. Electronic engineering is one of the fundamental fields of engineering that deals with the study and application of electron dynamics to the development and production of electronic hardware that is used in our multi-sectoral world. The subfields of electronic engineering have continued to expand in scale and scope. From digital electronics that produce microprocessors and microcontrollers for the invention of smartphones, digital televisions, and computing machines, to communication electronics that create wireless communication devices, and medical electronics that specialize in the development of hi-tech devices for monitoring human system dynamics, and to industrial applications of electronics in power systems, automotive, the relevance of electronic engineering is entrenched deeply in our societal fabrics.

During their course of study, electronic engineering students are expected to demonstrate that they have acquired innovative problem-solving skills that can be applied to translate theoretical knowledge into engineering solutions. The development of final year capstone projects comes into play where students conceptualize, innovate, and invent circuits, systems, and devices using off-the-shelf components, or leveraging open-source resources to facilitate the realization of their concepts. Open-source resources have in recent years gained prominence among science and technology educators and students because of the philosophy surrounding their utilization (Eppa & Murali, 2022).

Capstone projects

The Glossary of Education Reform defines a capstone project as "*a multifaceted assignment that serves as a culminating academic and intellectual experience for students, typically during their final year of high school or middle school, or at the end of an academic program or learning pathway* (Great Schools Partnership, 2016). Capstone projects are of different types such as research-based, design-based, performance-based, and community and outreach-based. In many higher education institutions, the capstone project is the culminating point that showcases individual-level skills or competence acquired during the learning period and their readiness as problem-solvers in the labour market or research centers. Capstone projects have contributed in diverse ways to the development of students, including enabling students to use their acquired skills to design and analyze prototypes (Sasipraba et al., 2020), think fundamentally, and learn new content (Shurin et al., 2021), hone their technical skills, strengthen their commitment, self-confidence, and self-esteem to promote creativity (Tell & Hoveskog, 2022). Capstone projects can evolve innovative ideas in students (Núñez et al., 2017). Engineering capstone project development generally involves problem identification, system analysis, design, testing, performance analysis, documentation, and report (Narayan & Meena, 2015), just as there are several methodologies conceptualized and used by several institutions.

Open-source electronics and platforms

The term open has become a part of the standard vocabulary in the digital era, used to describe resources that offer free ideas, codes, insights, software, or hardware (Schrape, 2017). Some of these resources, such as "open science", "open education", "open-source electronics", and "open-source platform", amongst others, have revolutionized the ways their subject matters benefit society. In the electronic engineering field, open-source electronics resources have challenged the learning, teaching, and development of electronics by making resources available at reduced cost and development time. Open-source electronics benefit users by enabling them to share knowledge and collaborate for system realization. They have been leveraged extensively to teach science, technology, engineering, and mathematics (STEM) and to accelerate comprehension of the complexities inherent in many scales of electronic circuits and systems modeling and designs (Ngo, 2019). Open-source electronics inherently enhance the cognitive capacities of electronics designers when used to innovate and invent new products. Open-source electronic platforms are software and hardware whose designs are available for unrestricted public use for research, education, and product prototyping and development. Such platforms include Arduino, Raspberry Pi, and BeagleBone, amongst others (Ngo, 2019).

Context - Paradox Study

We adopted a context-paradox study approach to explore the dynamics that influence students' paradoxical behaviour towards the use of open-source electronics and platforms within the specific context of a polytechnic setting. A context has been described as a cultural framework or environment in which technical knowledge and skills are taught (Crawley et al., 2008). Paradoxes are described as conflicting demands, opposing perspectives, or seemingly illogical findings (Ybema, 1996). Thus, “context-paradox” as used in this study intends to critically examine the paradoxes embedded in the use of open resources, influenced by contextual factors embedded in an education ecosystem. Their findings may not be generalizable, as they are not universal or absolute. However, they could give insights into some unexplored and underlying factors that can assist in recognizing complex electronic design cognition phenomena in students and teachers, and possible solutions for their mitigation.

Statement of the problem

Open education resources have brought immense benefits to the economy of learning and teaching various disciplines in recent years, driven by the philosophy of free distribution, customization, and openness. Despite these benefits, however, the utilization of open educational resources has not yielded the expected dividends in a section of African learners and teachers of technology due to several conglomerated factors. In Nigeria, thousands of electrical and electronic engineering students graduate annually from universities and polytechnics. While there is no empirical data to pontificate on the number of these graduates who are not well-equipped with electronic design cognitive skills to engage in electronic system design, innovation, and invention, most of these graduates are also not employable for research and development in the electronics manufacturing industries. Several causal factors have been hyped by stakeholders as reasons for the lack of critical thinking, innovativeness, and inventiveness of electrical and electronic engineering education products. Among these are funding deficit, educational facility deficit, and the fraternity perspective of the lack of institution-industry collaboration. However, not much attention has been focused on the behavioural perspectives of learners to the utilization of high-impact resources for skill-specific development. To address this challenge, it is essential to survey the design behaviours of students towards the use of open-source electronics and platforms to drive their innovative and inventive capabilities during their educational program.

Scope of the study

The study is a setting-contextual study, which may be generalized across higher education institutions in Nigeria. It focused on the student's behaviour towards utilizing open-source electronics and platforms to design and implement capstone projects with implications for the development of problem-solving, teamwork, innovation, and inventive skills.

Limitation of the study

The study is context-specific, with its population size relative to the research setting; however, the findings can be generalized to polytechnics or universities in Nigeria with similar cultures and characteristics.

Literature review

Several authors have written on the hydra-headed challenges facing engineering education in Africa. Many of these writings provided insights into the nature and peculiarity of challenges that have constrained the development of engineering, engineering education, and some revolution in these fields. Most documented literature on engineering education in Africa dwelt on the quantitative dimensions of growing engineering education to meet global criteria necessary for sustainable impacts for competition and meeting the growing challenges facing modern societies of Africa. Engineering education in Africa’s higher education institutions is constrained to achieve expectations and has been the subject of discourse for nearly half of a century. At various times in history, the idea of technological transfer and reverse engineering (Lavoie & Daim, 2019, Ajibo et al., 2019), have been pursued by stakeholders across the continent, with disproportionate benefits over the years. This has led to questions on whether engineering development and resultant self-reliance can be Africanized and sustained. The search for an answer has been engaging over the last decades. Except for a sprinkle of African countries including South Africa and Egypt, sub-Saharan African countries struggle to find their feet in the highly-relevant technological dimensions of national development and self-reliance.

There is also extensive literature on skill development in engineering and engineering education in Africa. However, most of this literature and discourses focused on acquiring hard skills with little emphasis on developing the qualitative aspects of critical skills essential to sustainable development which comes primarily through educational channels. Many researchers have therefore recommended a slew of approaches to ameliorate these challenges. Fomunyam (2020) recommended the globalization and internalization of engineering education through the diffusion of ICT to produce skilled engineering products. Yadav et al., (2011) identified pedagogical strategies as a weak link in engineering education in Africa. They proposed a shift from lecture-based methods to student-based methods that are problem-based learning. Mashiyane et al., (2023) pinpointed technological changes, pace, and engineering practices from social and professional contexts as factors affecting engineering education in sub-Saharan Africa. Munakata & Vaidya (2015) argued for project and theme-based learning to encourage creativity in science, which can also apply to engineering. Mukhtar & Saud (2019) proposed the integration of sustainability thinking into the curriculum of electrical and electronic engineering in Nigerian polytechnics.

The burgeoning literature on micromanagement of the qualitative dimensions of engineering skill development is scant on empirical investigations into the intellectual, and relevance of cognitive development of African engineering students in higher education institutions, particularly in Nigeria. A search of popular databases for empirical studies on the subject matter of capstone project design, design cognition and OSE in the Nigerian engineering educational setting shows that an in-depth attention has not been devoted to the subject matter.

On the importance of final-year capstone projects as facilitators of creativity and innovation, Stresau & Steiner (2020) proposed a framework for developing a deeper understanding of the factors that affect the outcome of capstone project design based on a survey. They identified individual student interests, technical guidance, teamwork, design process, and role models as critical success factors. Shaban (2002) suggested integrating design courses among the regular curriculum courses to orient students towards design before exposure to capstone projects. Bakrania & Jha (2020) proposed upgrading capstone projects to reflect real-world experiences using the engineering clinic model. Lantada & DeMaria, (2019) proposed the promotion of open-source collaborative project-based learning experiences to enhance the mentoring of students in capstone project designs, while Umoh (2000) advocated the use pf breadboard-based hardware prototyping as a strategic tool as an innovation driver for the learning of electronics.

Similarly, documented literature fails to provide ample information on the status and utilization of open-source electronics in higher education institutions in Nigeria. Critical appraisal of the challenges associated with the prolific utilization of OSE and their impacts on the cognition processes that involve electronic system design is also difficult to come by.

METHODOLOGY

The following research questions aided the selection of data collection tools used in the study.

Research questions

(a) How does computer simulation of electronic circuits, in conjunction with hardware prototyping, enhance students' understanding of electronic circuit design and analysis?

(b) Do open-source electronics drive innovation in the context of capstone project development?

(c) What factors contribute to the unethical use of open-source electronics among undergraduates of higher education institutions?

(d) What impact do teachers/facilitators have on the learning and understanding of electronics?

(e) How do learning and teaching facilities impact the capstone project economy of undergraduates?

Data collection tools

The study uses four tools to collect primary and secondary data as described and depicted in (Figure 1).

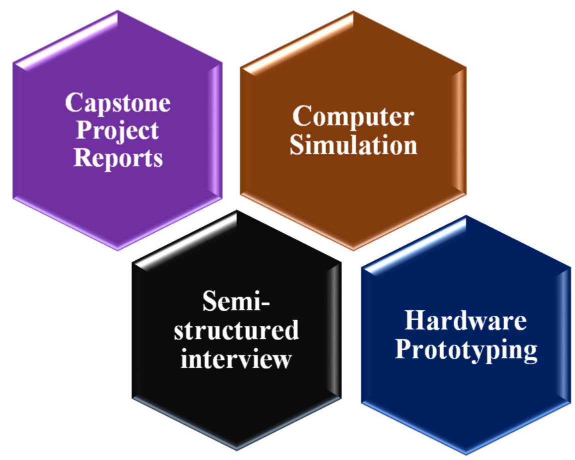

Figure 1: Data collection tools

(i) We curated physically archived capstone project reports from the Department's project repository

(ii) We subjected the selected students to a computer simulation exercise using electronic capture software installed on desktop computers.

(iii) We engaged the selected students with hardware prototyping of the circuits captured during computer simulation using breadboards and discrete electronic components.

(iv) Lastly, we conducted a semi-structured interview on the selected students in (ii) and (iii) based on their experiences using the computer simulation and breadboarding and other issues that affect their overall learning experiences.

Curation of archived capstone project reports

We curated 738 physically archived capstone project reports of electrical and electronic engineering technology graduates in the study setting, with enrolment comprised mainly of Nigerians from 2003 to 2021. We analyzed the project reports for their topics, year of publication, circuit schematics, and focus areas without reference to gender polarity. In our attempt to mine data from these project reports, we examined the established processes adopted by the department during the yearly student capstone project activities. The department adopted a wellstructured formality to guide graduating students into the capstone project design activities. These processes, which generally span an academic session, which comprises two semesters, give preeminence to design and development activities as depicted in (Figure 2).

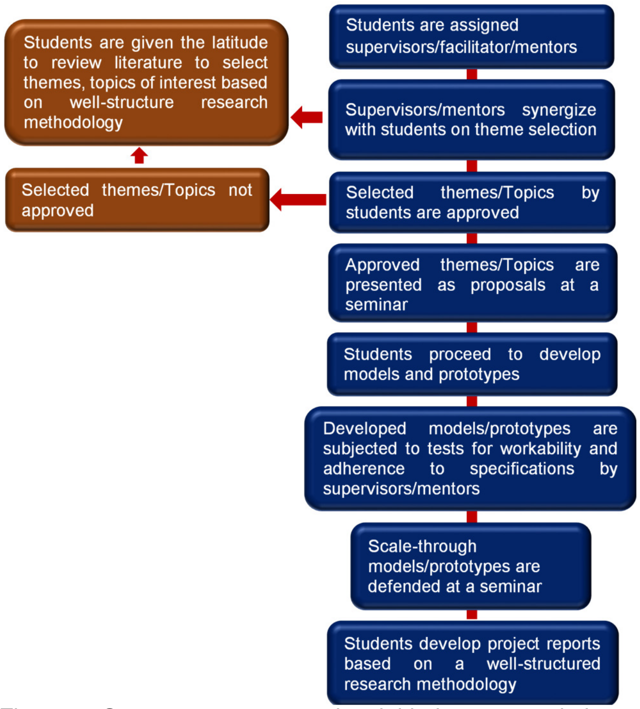

Figure 2: Steps to capstone project initiation to completion.

Computer simulation of electronic circuits

An electronic circuit drafting and simulation exercise was organized for a group of over 30 students of the targeted population. Of these students, 10 were randomly selected as participants in the study. A non-complex circuit featuring discrete components and an analogue integrated circuit was used as a reference circuit for the simulation exercise. Multisim® circuit capture software was installed on desktop computers for use for the exercise.

Hardware Prototyping with Breadboards

Breadboards, or protoboards, are solder-free, plug-and-play platforms made from polypropylene. They allow hobbyists or students to build temporal electrical and electronic circuits using discrete components and integrated circuits. Breadboarding allows for speedy connections of components to test circuits' functionality before being implemented on printed circuit boards and stripboards (Fox, 2023). In this study, the 10 randomly selected students were equipped with breadboards and components to implement identical electronic circuits.

Semi-structure interview

Randomly selected students who participated in the breadboarding exercise were returned for a semi-structured interview. The questions revolved around the computer simulation of circuits and breadboarding they had participated in. The interview sought their opinions on the impact or otherwise of the two learning approaches on their understanding of the principles of electronic circuits and the generality of their experience during their learning periods. The students' responses were transcribed and processed for inference and deductions.

RESULTS

In this section, we present the summary of our findings built around the research questions and the datasets we collected using the tools mentioned in the study.

Capstone projects

The number of selected archived project reports with essential bibliographical information during the years under review is tabulated in (Table 1). The capstone project reports were subsequently classified according to subject areas such as communication circuits and systems (CoC), measurement and testing systems (MTS), basic control devices and systems (BTS), timing and counting Circuits (TCC), sensing and detecting devices (SDS), Power supply systems (PSS), lighting systems (LTS) and hybrid systems (HYS) with their respective tally as shown in (Table 2). A plot showing the aggregates based on the subject areas is shown in (Figure 3). The percentage of the subject areas relative to the aggregates were computed as follows: CoC (21%), MTS (11%), BTS (8%), TCC (6%), PCS (10%), SDS (9%), and PSS (19%), LTS (9% 0 and HYS (7% 0 as depicted in (Figure 4)

Table 1: Capstone project reports tally according to year.

	Class/Level		
Year	Higher National Diploma (HND)	National Diploma (ND)	Total
2003	1	1	2
2006	Nil	5	5
2007	Nil	86	86
2008	Nil	85	85
2009	45	34	79
2010	60	63	123
2011	56	40	96
2012	41	Nil	41
2013	Nil	1	1
2014	4	Nil	4
2015	14	1	15
2016	12	Nil	12
2017	10	15	25
2018	14	4	18
2019	2	Nil	2
2020	Nil	Nil	Nil
2021	32	86	118
Total	283	455	738

Furthermore, we distinguished projects that used open-source electronics from open-source platforms. The open-source platforms that appeared in the reports were Arduino and Atmega microcontroller-embedded systems. Examination of each project shows that only four (4) projects utilized OSE platforms for design and implementation, constituting a paltry 0.5% as shown in

Table 2: Capstone project reports segregated based on broad subject areas.

Subje□t area	Class/Level		Aggregate
	Higher National Diploma (HND)	**National Diploma (ND)**	
Communi□ation □ir□uits (CoC)	**39**	**119**	158
Measurement and testing systems (MTS)	44	31	75
Basi□ □ontrol devi□es and systems (BTS)	34	26	60
Timing and □ounting □ir□uits (TCC)	31	11	42
Prote□tion and se□urity devi□es (PCS)	25	50	75
Sensing and dete□ting devi□es (SDS)	36	31	67
Power supply systems (PSS)	48	90	138
Lighting systems (LTS)	8	61	69
Hybrid systems (HYS)	18	36	54
Total	283	455	738

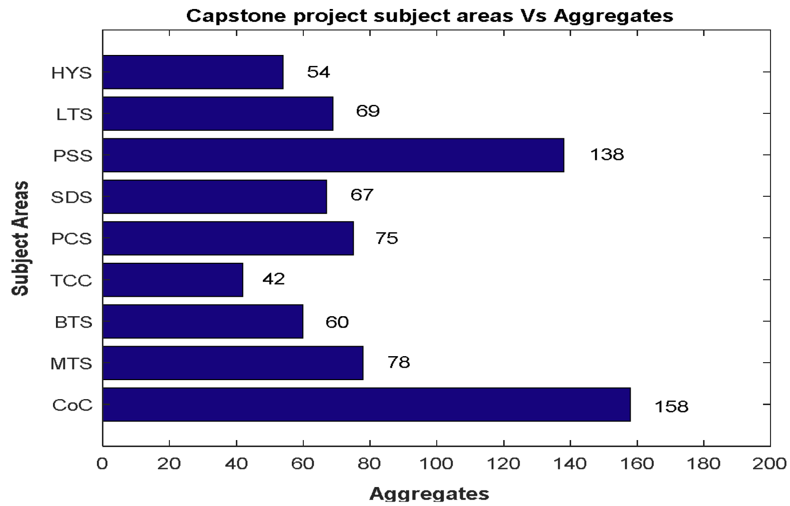

Figure 3: Capstone project subject areas and aggregates.

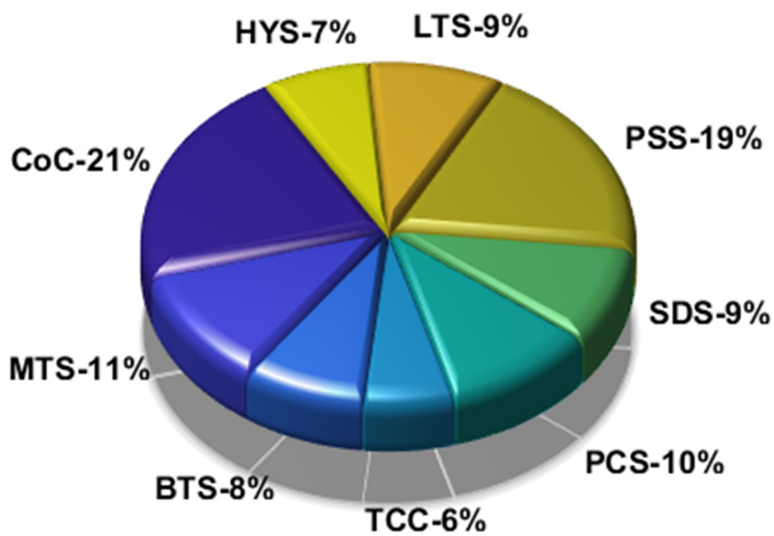

Figure 4: Percentage of subject areas relative to the Aggregates.

(Table 3). Semi-structured interview questions. Ten (10) students who consistently participated in both computer simulation and hardware prototyping exercises constituted the interviewees. This sample size is justified based on consistency and population size factors. The interview questions were juxtaposed with the research questions to synchronize their rhythms and perspectives on the subject matters of the study (Figure 5). The questions are as follows:

(**a**) Why do students use OSE circuits without modifying them in their capstone projects?

(**b**) Did the computer simulation and hardware

Table 3 Open-source circuit schematics and platforms used in capstone projects.

Subject area	Aggregate	OSE circuit schematics	OSE Platform
Communication circuits (CoC)	158	158	Nil
Measurement and testing systems (MTS)	75	75	Nil
Basic control devices and systems (BTS)	60	58	2
Timing and counting circuits (TCC)	42	42	Nil
Protection and security devices (PCS)	75	75	Nil
Sensing and detecting devices (SDS)	67	66	1
Power supply systems (PSS)	138	138	Nil
Lighting systems (LTS)	69	69	Nil
Hybrid systems (HYS)	54	53	1

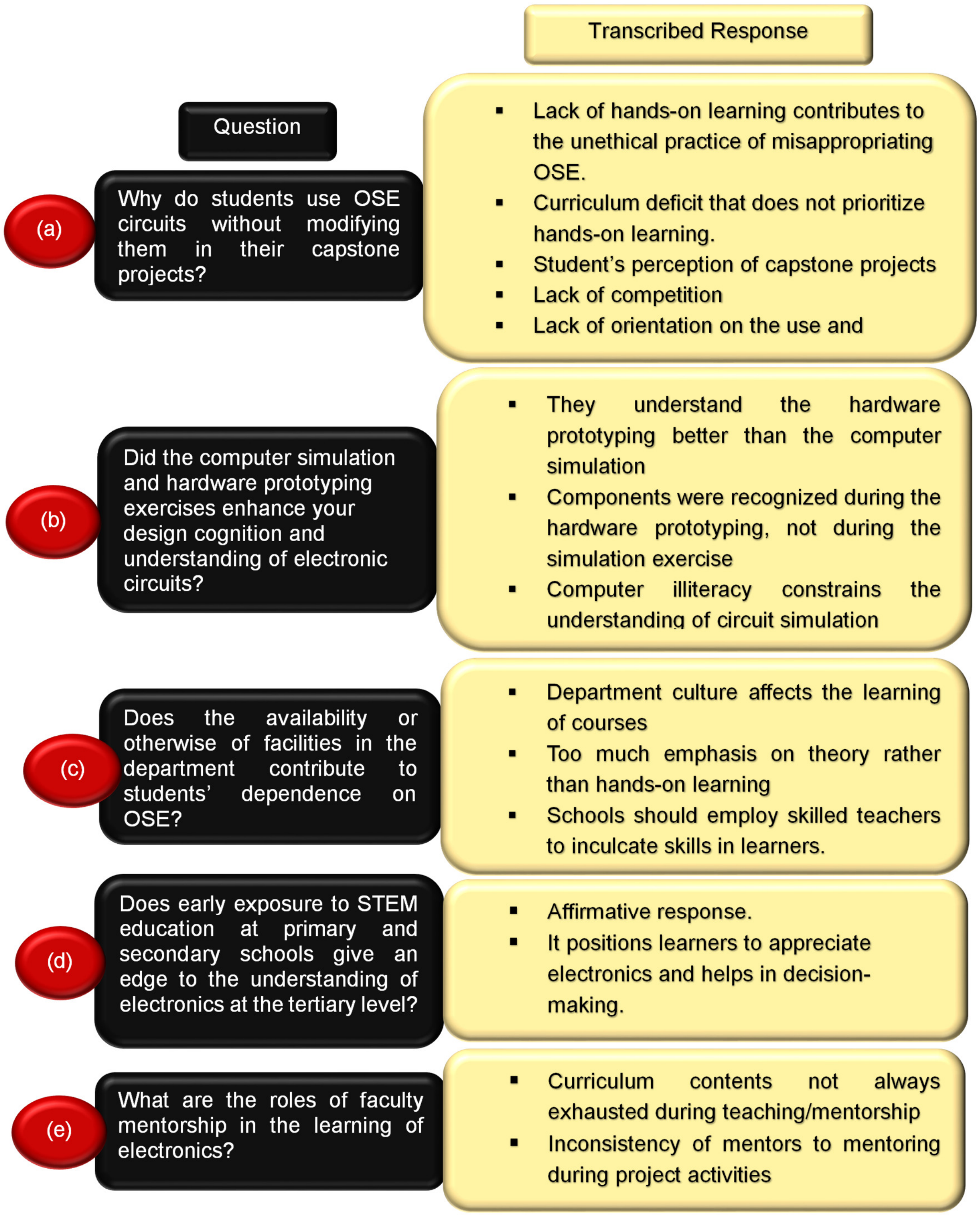

Figure 5: Summary of transcribed responses to interview questions.

prototyping exercises enhance your design cognition and understanding of electronic circuits?
(**c**) Does the availability or otherwise of facilities in the department contribute to students' dependence on OSE?
(**d**) Does early exposure to STEM education at primary and secondary schools give an edge to understanding electronics at the tertiary level?
(**e**) What are the roles of faculty mentorship in the learning of electronics?

The responses of the students to the questions are presented in (Figure 5).

DISCUSSION

Inductive Inference from the Capstone Project Reports

We compared circuits embedded in reports to those downloaded from the plethora of electronic circuit websites developed by hobbyists and other open-source electronics designers. Over 90% of these circuits bear a parametric and structural resemblance, with few or no alterations to component values and circuit layouts. Other circuits that were not culled from websites were sourced from extant undocumented project reports from motley sources. Inference from the capstone projects implies that they promote a culture of intellectual laziness and lack of design merits among the students who have had access to OSE resources during their project design periods. The leveraging opportunities that OSE provides to complement learning through the deepening of insights, crystallizing the understanding of electronic circuits and systems, and the discretion to modify, upscale, or innovate circuits and software to suit user-specific design objectives were spurned for wholesale adoption of circuits without modifications. Consequently, the OSE resources tend to have become the albatross of critical thinking, and incubation of design cognition among these cohorts of students.

Deduction from the interviews

We deduced the following from the responses of the students to questions during the interview.

Plagiarization of open-source electronic resources

There are contextual factors embedded in the responses of the interviewees which paradoxically affected the findings related to the capstone projects. Some of the reasons adduced by students for plagiarizing OSE resources such as lack of hands-on experience in hardware prototyping, and curriculum deficits are generally corroborated in other studies on functional engineering education (Nyinkeu et al., 2016), however, student perception of the relevance or otherwise of capstone projects as a crucial aspect of skill contents has a profound implication on the training of electronic engineering students. Perception is a precondition for commitment to capstone project development. Students who perceive capstone projects as a critical requirement of the culmination of skills and experience will generally improve their problem-solving skills and design competencies. Conversely, students who rationalize the importance of capstone projects are prone to trivialize and plagiarize OSE resources due to cognitive detachment. The low-hanging capstone research works are generally not upgraded beyond prototypes. Thus, their useful life cycle terminates in the archives, with no competition and marketability. As also observed by (Nyinkeu et al., 2016), some students have a genuine lack of understanding of the concept of plagiarism in open-source resource utilization. When students are not guided by enforceable codes of conduct in the use of resources, plagiarism can become a norm. in the study setting, students preparing for capstone project works are taught plagiarism as part of a mandatory course on research methodology in engineering. However, enforcement needs a revisit for a paradigm shift.

Computer simulation and hardware prototyping

The respondents' views shed light on the imperative of hands-on replicating the theories that students are fed in the classrooms. All the respondents emphasized hardware prototyping as the avenue to deepen their understanding of computer simulations and enhance their troubleshooting skills. The response further corroborates the numerous findings of studies on the importance of hands-on practices through workshops, problem-solving learning approaches, and fieldwork (Yadav et al., 2011; Knudstrup, 2004). The responses also show that emphasis on virtual learning less impacts cognitive capability than hardware prototyping. The most important lesson from the response is the complementary role of software and hardware prototyping in the understanding of electronic circuits and systems.

Impact of institutional facilities on the use of OSE resources

The respondents were unequivocal on the role of learning facilities in how they approach the use of OSE resources. Department culture is the conditions which directly or indirectly support. Inhibit teacher estate concerning research and teaching, and also impact the learning outcomes of students in a department (Mohammadi et al., 2024; Audu, 2018; Kapadia, 2008; Shanmugaramanan, 2019). The respondents advocated for the availability of state-of-the-art learning and teaching facilities to enhance their interest in, and metacognition of electronic circuits. It would seem the respondent rue the inadequacy of training facilities and the estate of their teachers who are constrained by limited teaching facilities.

Impact of early exposure to STEM education

Respondents opined that early exposure to STEM education enhances the understanding of electronics. A condition for admission into higher education institutions to study electronic education is having a credit pass in STEM courses such as mathematics, physics, chemistry, basic technology/electricity, and/or technical drawing at the secondary school level. While several studies corroborate the role of STEM in the learning of science and engineering (Baptista & Martins, 2023; Astawan et al., 2023), it is intriguing that students with this background are still caught up in the OSE conundrum. Whether it is a case of a wobbly foundation in STEM needs further research.

Role of Faculty Mentorship

Respondents expressed that the curriculum is not often exhausted during the allocated periods of the session, resulting in incomplete coverage, with the consequences on their learning experiences. In Nigeria, where disruption to the academic calendars of higher education institutions occurs frequently, full curriculum coverage is difficult for teachers and mentors. Mentorship is critical to grooming students during capstone project activities as they serve as role models, feedback synthesizers, and guides to students. Nevertheless, their impact is predicated on commitment and competence (Carberry & Baker, 2018).

Context and Paradox, and their interplay in the study

Context opens scenarios that the culture of the context can define. An institution's ecosystem provides the experiences that shape teachers and learners in educational settings. These experiences summed up the culture (peculiar norms, strategies, instructions, pedagogies) that define them. Concerning the findings about the capstone projects, it is apposite to say that the context fueled the desire of the students to plagiarize OSE circuits as inferred from the interviewees' responses. The option of plagiarizing electronic circuits without innovative modifications is subjective, contextual, and paradoxical in the context of open-source resource use. When this paradox is situated in the bigger picture of the design cognition development of students, it is easy to understand one of the factors militating against the development of high-thinking skills that are essential to innovation and invention among electronic engineering students in the study setting. Based on this position, it is easy to classify open-source electronics as resources that foster innovation in users. Several studies corroborate this perspective. Innovation involves modifications, alterations, revisions, and scalability, all provided by open-source learning platforms. We can therefore posit that when students are exposed to software and hardware design experiences without comprehension and understanding of the exercise, they become vulnerable to plagiarism of OSE resources during the capstone project work.

Factors that promote unethical use of OSE in capstone project design

From the findings of this study, the factors that promote the unethical use of OSE are prevailing department culture, shallow understanding of the principles of electronic circuits and systems, deficiency in mentorship during project supervision, misconception of plagiarism and poor feedback mechanism during capstone project design cycle, as depicted in (Figure 6).

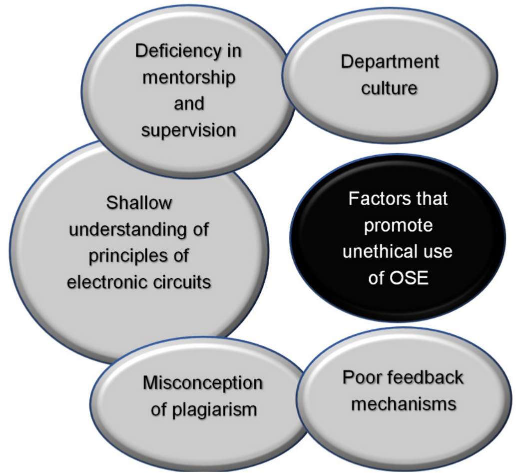

Figure 6: Factors that promote the unethical use of OSE

Mitigating the Conundrum

It is interesting to understand that the challenges faced in contextual frames are not extraordinary. They are essentially challenges that are yet to be tackled with available strategies and the plethora of resources made available by stakeholders around the globe. Whenever resources meet action, solutions are provided, and problems are solved. Therefore, strategizing to mitigate the conundrum under study may require the leverage of existing resources. Thus, to usher in a new paradigm of learning and understanding in engineering education in the study setting, there is a need for the active involvement of stakeholders beyond the perimeter of faculties and departments. A tailored engineering curriculum is insufficient to inculcate in learners all the requisite concepts, and soft and hard skills required to become functional, high-level thinking students. This can be corroborated by the fact that in countries with high stakes in engineering education, there are various layers of cradle interactions between the school and professional societies, industries, and government policymakers which have facilitated a holistic development of engineering students from kindergarten to higher education levels (Tsai et al., 2007; Suma et al., 2018; Mohd Shahali et al., 2016; Preston, 2017). Adopting a pragmatic framework to initiate these strategies into the Nigerian engineering education systems will lead to a bright future for tomorrow's engineering. Other strategies that could engineer a paradigm shift from the current state of capstone project governance include the following:

Dynamic changes in department culture

The engineering department needs to establish collaboration and linkage with industries, engineering professional societies, and entrench best practices in teaching and educational administration to liberalize the space for access to quality resources, funding, and manpower development. (Okanlawon et al., 2023; Aisien & Aisien, 2018; Muthukumar. & Thirumalaesh, 2020).

Experiential learning

Experiential learning is an experiment-based learning that integrates theoretical concepts and knowledge acquired through pedagogical activities into modules that foster hands-on experience. Without hands-on experience in electronic circuit design, theories are not impactful, and are not translatable by learners. Although this approach is part of the subsisting curriculum, it is not prioritized like theoretical classroom learning. Thus, prioritizing experiential learning strategies will aid students in understanding the principles of the operation of electronic circuits. When integrated into the fabric of the curriculum, experiential learning can enhance design thinking and project development skills (Shaban, 2002; Lehane, 2020; Silli & Valsecchi, 2023). Complementing physical hands-on experience with virtual experience creates a balanced and sustainable experience in electronic circuit design. It can also aid the students in their sensory perception of circuit dynamics, adding to their interest and enjoyment of learning (Sivaramakrishnan & Ganago, 2013; Alamatsaz & Ihlefeld, 2020).

Project-based learning

Project-based learning (PBL) is a holistic teaching-learning methodology for training engineering students on real-life engineering problems (Lantada & DeMaria, 2019). PBL has been described as a catalyst for student engagement and holistic learning (Kumar & Revathy, 2024; Ingale, 2023). Many institutions have collaborated with relevant stakeholders to challenge students and develop solutions that address specific challenges in communities. An example of such a platform is the Institute of Electrical and Electronics Engineers (IEEE) Engineering Project in Community Service (EPICS in IEEE) which provides funding, support, and mentorship for students to identify and design projects that serve communities (Kam, 2015; Mauricio et al., 2024).

Competition-based hardware prototyping workshop

In recent years, competition-based training of engineering students has gained prominence in several institutions, and at various levels of education. Students are grouped into teams or individually to design and simulate real-world electronics and mechatronics systems using different open-source electronic platforms like Arduino and others. In several HEIs, students are encouraged to affiliate with professional societies that provide a platform for holistic development, such as the IEEE, which organizes Hackathon competitions (IEEE Hackathon) (Covic & Manojlovic, 2019; Grover et al., 2014).

Entrenchment of codes of ethics and conduct to govern the use of open-source resources during capstone project activities

Plagiarism of OSE resources thrives in institutions that have not entrenched a code of ethics in the utilization of database resources and open-source resources for academic undertaking. In recent years, developers have increasingly turned to craft codes of conduct and ethics to govern the use of the myriad of OSE resources among diverse users across the world. As a corollary, engineering departments need to entrench these codes to promote the ethical use of OSE resources among their students. (Tourani et al., 2017; Frluckaj & Howison, 2024).

Curriculum update

A well-designed curriculum in conjunction with student-centered pedagogical delivery is critical to the attainment of the goals of learning. The challenges of updating curriculum to match the dynamics of our technological world have remained an open problem. A curriculum that reflects the advances in the field of electronic engineering and response to the changes in the real world is needed in Nigeria's HEIs. A new curriculum that incorporates novel and advanced strategies for modelling and designing electronic circuits and systems will contribute to reducing the challenges faced by students in design tasks (Eguzo et al., 2017).

Conclusion

Capstone project activity is a much-desired, and much-awaited ritual in higher education institutions across the world. Accordingly, much emphasis is placed on the governance and outcomes of these activities. As knowledge advances with the increasing democratization of learning spaces, some resources like open-source electronics and associated platforms have offered lifelines to students of all genres. One of the consequences of the free use of OSE is plagiarism, with the consequences of loss of opportunities for the development of critical thinking, high-level thinking, problem-solving, and design thinking skills among students, with far-reaching implications for the attainment of sustainable development goals (SDG-4). In this study, we set out to examine a paradox in the capstone project report collections of a Polytechnic institution and to examine the role that context played in the findings. We found the consequential paradox of stunted skill (design, cognition, prototyping, teamwork) development, all weaved into the fabric of the unethical Plagiarization of OSE resources for capstone project over a period that spanned nearly two decades. These worrying antecedents may be curtailed through the entrenchment of codes of ethics, departmental culture changes, and paradigmatic changes to pedagogy and the educational ecosystem of the context of study. We have therefore recommended the mitigation measures that could, in our opinions, reinvent capstone project governance in the study setting. Concerning future research on the subject matter, the study should be extended to other polytechnics, and the university system to broaden understanding of the challenges associated with the utilization of Ose in capstone project works.

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