SECTION 6. SHAPING INDUSTRY 5.0: THE SYNERGY OF INTELLIGENT AUTOMATION, DIGITAL COMMUNICATION & ADVANCED ELECTRONICS FOR A SUSTAINABLE SMART FUTURE

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TWO DECADES OF SHAPING ADAPTIVE ELECTRONIC ENGINEERS FOR SUSTAINABLE INTELLIGENT TECHNOLOGIES AND DIGITAL TRANSFORMATION: THE CASE OF THE ELECTRONIC ENGINEERING DEPARTMENT AT HARARE INSTITUTE OF TECHNOLOGY, ZIMBABWE

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Abstract. This paper presents a longitudinal case study of the Department of Electronic Engineering at the Harare Institute of Technology (HIT), Zimbabwe, examining its evolution over two decades as a mandate-driven hub for competence-based, innovation-oriented engineering education. Since its establishment in 2005, the department has pioneered Zimbabwe’s Education 5.0 framework, embedding technopreneurship, prototype-driven pedagogy, and direct industrial engagement into its curriculum. The study situates HIT’s model within global discourses on engineering education reform, the Fourth and Fifth Industrial Revolutions (4IR/5IR), and the growing emphasis on entrepreneurial engineers. Evidence of impact includes programmatic expansions (Biomedical Engineering, Industrial Automation, and Telecommunications), graduate outputs, industry collaborations, and tangible innovations addressing national challenges. The findings position HIT’s approach as a replicable model for higher education institutions in developing economies aiming to align engineering education with sustainable development and digital transformation.

Keywords: Engineering Education, Education 5.0, Competence-Based Curriculum, Technopreneurship, HIT.

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Introduction. African universities are under critical pressure to adapt to rapid global changes and drive the continent's industrialization, innovation, and sustainable development [1, 2]. Unlike conventional universities, the Harare Institute of Technology (HIT), established in 2005, was specifically designed as a hub for technology research, incubation, transfer, and commercialization [3]. The Electronic Engineering Department fosters "hands-on" graduates for high-tech entrepreneurship, using a teaching framework that anticipated Zimbabwe's national adoption of Education 5.0, a model that adds innovation and industrialisation to the university's traditional mission [4, 5]. This paper presents the department's evolution as a case study in mandate-driven engineering education, contextualizing its methods within literature on competence-based learning, entrepreneurial engineering, and sustainable technologies.

Literature Review

A. Engineering Education Reforms. Engineering curricula globally have undergone significant reforms to address the mismatch between theory-based education and industry demands. Frameworks like CDIO (Conceive – Design – Implement – Operate) use project-based learning to develop problem-solving and innovation skills [6]. According to Crawley et al. [6], Engineering education must shift from rote technical training to a model that enables students to create real-world systems.

B. Education 5.0 and African Higher Education. Zimbabwe’s Education 5.0 framework extends earlier models by mandating innovation and industrialisation as integral university functions [4]. African higher education policy increasingly positions universities as engines of economic development [8]. As Chikoko [4] notes, “Education 5.0 redefines the university as a factory of ideas and industries, not merely a site of teaching and research ”HIT’s EE Department is notable for having operationalised these principles from inception.

C. Technopreneurship and Engineering Practice. Globally, there is rising emphasis on training engineers as technopreneurs innovators who translate technical knowledge into commercial ventures [9]. Min et al. [9] Reflecting the proven link between technopreneurship education and student start-ups, HIT's mandatory prototype-driven projects systematically foster an environment of innovation.

D. Industrial Revolutions and Curriculum Adaptation. The 4IR and 5IR demand specialised skills in automation, robotics, telecommunications, and intelligent systems [11]. Universities are adapting curricula to meet these challenges, with postgraduate programs increasingly focused on advanced technologies and digital transformation [12]. Sony [12] argues that to meet Industry 4.0's demand for adaptive, innovative, and cross-disciplinary engineers, EE introduced MTech programs in Industrial Automation and Telecommunications & Wireless Systems.

E. Design Projects in Engineering Curriculum. Design projects are a cornerstone of modern engineering education, where students apply their knowledge to solve complex, real-world problems. According to Howe and Wilbarger [14], “Design modules bridge the gap between theory and professional practice”. They allow students to tackle open-ended challenges in teams, developing prototypes in industry-like environments. This process strengthens crucial professional skills like project management, communication, and ethics, which are highly sought after by employers [15]. Design projects are particularly valued for generating locally relevant innovations that drive socio-economic development [16]. HIT's mandatory prototype projects serve as a capstone experience, reinforcing both technical competency and entrepreneurial readiness by requiring students to apply their knowledge to solve complex, real-world problems. According to Howe and Wilbarger [14], "capstone design courses provide the critical link between theory and professional engineering practice". They enable students to address open-ended design challenges, work in teams, and develop prototypes under conditions that mimic industry practice. Moreover, these projects strengthen professional skills such as project management, communication, and ethics, which are increasingly demanded by employers [15].

F. Student Mentorship Programmes in Engineering Education. Student mentorship programs are vital to engineering education, offering structured guidance that boosts both academic and professional success. Crisp and Cruz [13] argue that "mentoring relationships in higher education positively influence persistence, academic performance, and career development". It connects students with experienced lecturers, industry professionals, and peers, allowing for transfer of tacit knowledge, industry practices, and career insights [17]. Lutz and Paretti [18] highlight that mentorship fosters identity formation within the engineering profession, particularly by building confidence in problem-solving and teamwork. For electronic engineering students, mentorship programs are crucial for developing technical skills, innovation, and entrepreneurship. Simultaneously, they promote inclusivity and help correct gender imbalances by providing vital role models and targeted support for underrepresented groups [19]. At HIT, the mentorship model unites lecturers, senior students, and industry partners. This approach reinforces the department's production-based pedagogy and aligns with the best global practices.

Two Decades of Programmatic Evolution. Over the past two decades, the Electronic Engineering Department's growth has been a deliberate and strategic adaptation to emerging technological trends and pressing national needs. Its programs have evolved from foundational education to high-level specialization, a success underpinned by robust local and international collaborations with both industry and university partners.

The Foundational Years (2005): The Bachelor of Technology in Electronic Engineering

The department's journey began with its flagship BTech (Hons) in Electronic Engineering program, designed from its inception to produce "technopreneurs". The curriculum's focus on innovation, prototype construction, and solving real-world community challenges established the hands-on, entrepreneurial philosophy that has become the department's hallmark, equipping graduates to innovate across a wide spectrum of critical technology sectors.

An Incubator for New Disciplines (2020): The Genesis of Biomedical Engineering

In 2020, the department demonstrated its strategic maturity by launching a Biomedical Engineering program to address national healthcare challenges. Acting as a strategic incubator, the Electronic Engineering department leveraged its core expertise in electronics and systems design to nurture the program until it achieved the critical mass to become its own standalone department. This evolution showcases the department's capacity to incubate and launch new, high-impact disciplines, directly fulfilling HIT's institutional mandate to develop technology at a disciplinary level.

Ascending the Value Chain (2023): Postgraduate Specialization for the Fourth Industrial Revolution

In a targeted response to the 4IR, 5IR and national priorities, the department launched two MTech programs in 2023. The MTech in Industrial Automation is designed to modernize Zimbabwe's industrial sectors, while the MTech in Telecommunications and Wireless Systems aims to cultivate the expertise needed for national digital transformation and next-generation connectivity like 5G and the IoT. This strategic postgraduate expansion solidifies the department's role as a critical enabler of Zimbabwe's technological future by producing high-level specialists capable of leading its advancement.

D. Graduate Output and Impact.

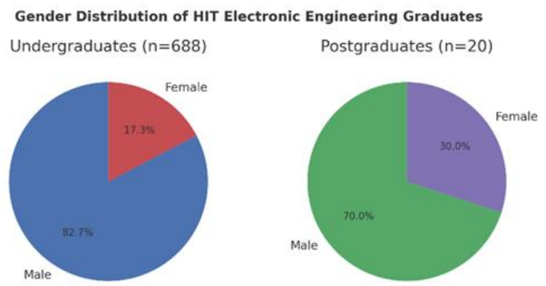

Figure 1 – Graduate Statistics

To date, the department has produced over 688 undergraduates (17.3 % female) and 20 postgraduates (30 % female). Graduates are employed in industry, research, and entrepreneurial ventures, contributing to national innovation and industrialisation.

Discussion

Alignment with Global Engineering Education Reforms. While HIT's production-oriented pedagogy aligns with global, project-based learning frameworks like CDIO (Conceive – Design – Implement – Operate), it goes a step further by deeply integrating innovation and enterprise development (Crawley et al., 2014) [6]. However, HIT extends this paradigm by embedding prototype-driven assessment, where students' progression depends on producing functional artefacts with commercial potential. As Crawley et al. [6] argue, "engineering education must move beyond rote technical training to a holistic model that enables students to conceive and implement real systems". HIT operationalises this by coupling prototype development with entrepreneurship, positioning graduates not only as job seekers but as potential employers and innovators. This model resonates with Lee's (2019) [7] view that competence-based curricula in Asia have accelerated student readiness for rapidly evolving industries, suggesting that HIT's framework is globally relevant for emerging economies.

Comparative Framework: CDIO vs HIT Model

CDIO Model	HIT Model
Conceive	Conceive
Design	Design
Implement	Implement
Operate	Operate
nan	Commercialise/Spin-off

Operationalisation of Education 5.0

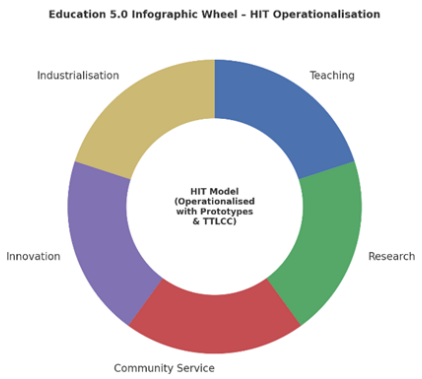

Figure 2 – HIT Operationalisation

Zimbabwe's Education 5.0 framework redefines higher education by mandating innovation and industrialisation alongside teaching, research, and community service (Chikoko, 2021) [4]. Many African universities have embraced this discourse at policy level but struggle with implementation (Teferra, 2014) [8]. HIT's Electronic Engineering Department is a rare example of operationalisation, as evidenced by its integration of student prototypes into the Technology Transfer, Licensing, and Commercialisation Centre (TTLCC). Kanhukamwe (2020) [5] underscores that "Education 5.0 requires a restructured pedagogy where innovation outputs are systematically linked to industrialisation pathways". The department's spin-offs and industrial collaborations exemplify this, bridging the gap between academic rhetoric and industrial practice in Africa.

Technopreneurship as a Pedagogical Driver. The insistence on progressive prototype modules (HIT200 – HIT800) embeds technopreneurship into the curriculum as a non-negotiable component of engineering training. Unlike many institutions where entrepreneurship is taught as an optional add-on, HIT makes market readiness an assessment criterion. Min et al. (2019) [9] note that "technopreneurship education is positively correlated with the likelihood of student start-up formation". HIT validates this claim by producing graduates who have launched ventures in automation, telecommunications, renewable energy, and biomedical applications *inter alia*. Rae (2006) [10] further argues that embedding entrepreneurship in higher education transforms universities into "breeding grounds for innovation-driven development". HIT's pedagogy therefore contributes a unique African model where entrepreneurial engineering is not supplementary but structurally integral.

Contribution to National and Regional Development. HIT's responsiveness to national needs is evident in the launch of the Biomedical Engineering programme (2020), which bridges healthcare and engineering innovation. This aligns with Teferra's (2014) [8] assertion that African universities must serve as "engines of socio-economic transformation". Graduate outputs have influenced Zimbabwe's broader digitalisation agenda through employment in industry, academia, and start-ups. The contribution of HIT to healthcare engineering is particularly notable in a context where resource-constrained nations must localise technological solutions. Globally, similar responsiveness has been observed where universities link curricula with pressing societal challenges, as in the case of Industry 4.0 curricula in Asia and Europe (Sony, 2021) [12]. Thus, HIT demonstrates that mandate-driven institutions in Africa can shape national development trajectories.

Implications for Policy and Practice. The HIT model underscores that higher education reform in Africa must go beyond curriculum redesign to embrace innovation ecosystems that integrate pedagogy, research, and industrialisation. This finding aligns with Cloete & Maassen's (2013) [2] argument that African universities should be "developmental in mandate, not only academic in orientation". Policymakers could adopt HIT's approach by institutionalising prototype-based progression models and mandating technology transfer centres within universities. At the same time, collaboration with global institutions experienced in scaling prototypes to industry such as those under the CDIO network could enhance HIT's impact. As Sony (2021) [12] argues, engineers in the 4IR/5IR era must be "technically competent, adaptive, and innovative in cross-disciplinary environments". Thus, HIT's model provides both a practical framework and a policy lesson for African and global higher education reform.

Future Prospects. Looking forward, HIT's expansion into MTech programmes positions it to contribute to postgraduate research in automation, telecommunications, and intelligent systems. With the global shift toward 5IR, characterised by human – machine collaboration and ethical technology, the department is strategically placed to align African engineering education with frontier developments. However, sustained success will depend on addressing gender equity, funding models, and regional collaboration to ensure long-term relevance and impact.

Conclusion. For two decades, the evolution of HIT's Electronic Engineering Department has shown how mandate-driven, competence-based education can directly fuel national innovation and industrialisation. By embedding Education 5.0 principles from its inception and strategically expanding its programs–from a foundational BTech to specialized MTech degrees–the department has actively contributed to Zimbabwe's industrial agenda, proving responsive to evolving societal and technological needs. [4, 6, 12]. This trajectory reflects Crawley et al.'s [6] emphasis on experiential learning while also validating Sony's [12] call for curricula that prepare adaptive engineers for Industry 4.0 and 5.0.

Graduate outputs, start-up formation, and industrial collaborations confirm that HIT's prototype-driven pedagogy fosters technopreneurship in practice, echoing findings by Min et al. [9] that link entrepreneurship education to innovation-driven economic development. The department's contributions to key national sectors – including renewable energy, automation, telecommunications, and healthcare through biomedical engineering – show how engineering education can address pressing national challenges. This aligns with the view that African universities must be engines of development [8]. Gender imbalances (with only 17.3 % female undergraduates) mirror broader STEM disparities across Africa [19], while resource limitations and fragile pathways from prototype to full commercialisation constrain impact. As Rae [10] and others note, institutional entrepreneurship requires strong ecosystems, including financing and policy support, which remain underdeveloped in Zimbabwe.

Ultimately, the HIT model demonstrates that higher education institutions in developing contexts can successfully integrate pedagogy, innovation, and industrialisation when guided by a clear national mandate. It offers a replicable framework for other African universities aiming to move beyond knowledge transmission toward socio-economic transformation through education, innovation, and enterprise creation [1, 2].

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AN ICT-ENABLED UNDERGROUND MINE SAFETY SYSTEM FOR COLLISION AVOIDANCE AND REAL TIME TRACKING

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Abstract. Underground mining operations pose critical safety hazards which can be fatal. The ICT-enabled mine safety system discussed in this paper enables real-time monitoring of underground mining operations. RFID technology was utilized for real-time zonal localisation of miners and mobile equipment. GPS technology was incorporated for precise localisation. Echolocation technology was utilized for collision avoidance and alerts. A web application supported by a database is included to enable historical data acquisition as well as mining operations visualisation from a centralised control station. Implementation of this system demonstrates the potential for technology to significantly improve safety standards in the mining industry.

Keywords: mine safety, tracking, collision avoidance.

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Introduction. The mining industry has been considered as one of the industries with the highest occupational mortality rate and injuries [1]. The mining environment is characterized by complex and hazardous operations that present critical safety hazards which can lead to collisions between mobile equipment and humans or other mobile equipment causing injuries and fatalities [2]. Poor visibility in underground mines can arise due to darkness, short lines of sight and dust concentration [3].

The Safety System Building Blocks. Sensors and modules embedded on load-haul-dumpers (LHD) and