



HUMAN-CENTRED DESIGN AS A TOOL FOR INCLUSIVE STEM EDUCATION: STRATEGIES FOR UNDERSERVED COMMUNITIES

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ABSTRACT

The need for sustainable development has transformed the priorities in the education sector globally but learners from the underserved communities of Sub-Saharan Africa, and Zimbabwe in particular, are structurally marginalised in their inability to access the education system because of the curricula that were never designed with their realities in mind. This paper looks at Human-Centred Design (HCD) as a pedagogical innovation for Engineering education in resource-limited environments, and how such an approach can break down exclusionary norms and provide equitable STEM learning outcomes by focusing on learning through the lens of empathy and grounded in the community. A mixed-methods research design was adopted, comprising a systematic literature review and qualitative analysis of three engineering programmes that aim to integrate HCD in Southern Africa. Thematic analysis was used to explore the enabling conditions, barriers and transferable strategies. Results show that incorporating HCD elements in STEM education positively contributes to student engagement, cultural relevance, and problem-solving skills, even in settings with extreme lack of infrastructure, for learners from underserved communities. The ability to build strategic partnerships between local communities, industry, and universities proved to be a key driver in achieving long-term impact. HCD is not only a pedagogical decision, but one for equity in STEM education. The study provides an implementation framework for educators and policymakers who want to make engineering education accessible, relevant and inclusive in the Global South.

Keywords: Zimbabwe, Human-Centred Design; STEM Education; Inclusive Engineering Pedagogy; Underserved Communities; Community-Based Learning; Sustainable Development; Engineering Education Reform

1 INTRODUCTION

Individual mobility and national development through STEM education is more clearly emphasized than ever before. Globally, governments, development agencies and academic institutions have been spending vast amounts of money in science, technology, engineering and mathematics; the building blocks of a competitive and innovative economy [1] [2]. However, for millions of students in the Global South, this promise has not yet been realized. Young people from low-income, rural, and historically marginalised communities face engineering curricula, which, like much of Sub-Saharan Africa, are epistemologically alien; curricula that are rooted in the assumption of their access, familiarity with their culture, and socio-economic stability that do not represent their lived experiences [3] [4] [5].

This leaves an unequal and deepening injustice. Transformative education is given to learners who need it most, but in a way that fails to engage with their contexts as assets to be developed, instead portraying them as deficits to be fixed [4]. One of the current problems in Southern Africa is that the rate of attrition of first generation engineering students is very high, and their persistence often comes at significant personal cost to their cultural identity and sense of belonging [6] [7] [8]. This is not only a social tragedy, it is an economic and development tragedy. It is clear that the engineering talent that Sub-Saharan Africa so desperately requires to help meet its infrastructure, energy, and manufacturing needs is being systematically lost by educational systems, which were never designed in that region, for that purpose.

Human-Centred Design (HCD) is a different philosophy that provides a much more effective way to solve problems in practice. HCD has revolutionized product development, urban planning, healthcare services, and social innovation globally, from a place of empathy, iteration, and enduring engagement with the end-user. Its fundamental idea, which is to look at the problem through the user's eyes instead of the designer's, aligns with the issues of inclusive pedagogy. In this context, HCD transforms the learning enterprise itself—in this case, the engineering education enterprise: the community becomes the laboratory, the problems that exist in the community become the learning problems, and the knowledge of the community becomes a learning resource instead of being a barrier [9].

This paper explores the issue of embedding the HCD approach in a systematic manner into STEM education in resource constrained settings as applied to engineering programs in Sub-Saharan Africa. It suggests that HCD is a pragmatic and scalable approach that, when implemented well, can enhance learning outcomes, build community engagement and fill students with the technical and human literacy needed to promote sustainable development in their own environments.

2 LITERATURE REVIEW

2.1 The Equity Gap in Global STEM Education

In the last 20 years, the number of people enrolled in tertiary STEM programmes has increased significantly worldwide, but this increase has been marked by consistent structural inequities. According to UNESCO, the poorest 25% of students are 3.5 times less likely to earn a STEM degree than the richest in developing countries [10] [11]. In Sub-Saharan Africa these differences are exacerbated by geographical, gender, language and ethnic differences. This is what Marginson calls “educational stratification by design,” as it is still the inheritance of colonial pedagogy that shapes who has access to high status STEM knowledge and who does not [11].

While the majority of the population in Zimbabwe comes from rural and peri-urban areas, students from those areas represent less than 22% of STEM enrolments, according to the enrolment data published by the Zimbabwe Council for Higher Education (ZIMCHE) [12]. For those who do join, there is a “curriculum culture shock”, where they are presented with cases, problem sets, and instructional material that is predominantly presented in an Euro-American context related to industrial problems, contexts, and technologies that are quite different from the ones that encountered in their own contexts [13]. The alienation that is the result is not a lack of ability on the part of the student; it is an “abnormal” design situation.

2.2 Human Centred Design: Theoretical Foundations

HCD has a long, rich and interdisciplinary history. By defining design as a science of the artificial, Simon has laid the foundation for evaluating the efficacy of designed artefacts in terms of the needs of those who live in them [14]. It has been argued that expert knowledge is not just applied to problems, but built up through repeated interaction with the particulars of context, as Schon's theory of the reflective practitioner has indicated [15] [16]. The design community then put these ideas into practice with processes like IDEO's Design Thinking methodology and Stanford d.school's five-stage process: Empathise, Define, Ideate, Prototype, and Test [17] [18] [19] [20].

HCD differs from conventional engineering design approaches by turning the subject of engineering design on its head. Conventional engineering problem-solving usually starts with a technical specification, while co-creating a solution with the communities it serves does not. Unlike conventional engineering problem-solving that begins with specifying a technological solution, HCD begins with listening, observing and co-creating with the community for which the solution is being created [21] [22]. The human first approach is not just a matter of the methodology; it is also an epistemological one which asserts the validity and primacy of lived experience as a source of knowledge.

HCD has been used in educational settings with different labels such as ‘learner-centred pedagogy’, ‘community-based learning’ and ‘participatory design education’. The common thread through them all is a shared emphasis on starting with the learner's own world as the basis for developing technical skills [23].

2.3 HCD in STEM Pedagogy: Evidence from Practice

Research has emerged and it is increasingly used to support the effectiveness of pedagogical strategies in the context of STEM education that incorporate HCD principles, especially in low-resource environments. Problem-based learning (PBL) is a close relative of HCD, and has been shown by Hmelo-Silver [24] [25] [26] to lead to better conceptual understanding and transferable skills than lecture-based learning. Dym et al. demonstrated that the design-based learning model in engineering learning positively affects students' motivation and learning identity, especially for students with non-traditional backgrounds [27] [28].

The few studies from the African context are illuminating. In South Africa, Tshikovhi and Shambare reported that the retention rate for students involved in community integrated engineering projects was significantly higher compared to those in conventional engineering programmes, also those students had a better professional self-efficacy [29] [30]. Melo and Nhampossa found that HCD workshops integrated into an ICT curriculum in Mozambique were found to increase students' problem framing skills and help them make the proposed technical solutions more relevant to the local context [31].

There are also recurring issues as noted in the literature. However, there are significant constraints to implementing HCD, especially in public universities in Sub-Saharan Africa, including limited access to the laboratory, lack of digital infrastructure, and large classes [32] [33] [31] [34]. A second issue is faculty capacity: many engineering instructors have been trained in, and continue to use, and “transmissive” pedagogic model that do not mesh well with HCD's facilitative and emergent model [24] [35]. The challenge of working within institutional opposition to pedagogical innovation is, therefore, a real challenge as well as designing the innovations themselves.

2.4 Tri-Sector Partnerships as Enablers

One of the major recurring themes in the literature about how STEM education is successfully reformed is the importance of collaboration and partnerships between industry, the civil society and the university [36]. From an HCD perspective, partnerships are not just helpful, they are essential. HCD is a process that needs real problems, real communities, and real feedback loops; elements that can't be created in a university alone.

Partnering with industry partners affords students real-world challenges and industry design process [37]. By working with community organisations, student projects are able to reflect real needs not imagined needs and their work will involve local knowledge at all stages of the design process. University-to-university partnerships, in turn, can facilitate the transfer of knowledge and capacity building for pedagogical innovation. Together, these tri-sector relationships constitute ‘communities of practice’ that ‘beyond the classroom’, support learning [38].

3 METHODOLOGY

3.1 Research Design

The study used a mixed methods approach, combining a systematic literature review with qualitative case analysis. Mixed methods were used because the research questions required the broadness of the evidence synthesis and the depth of the context provided by case-based inquiry. The overall philosophical perspective is interpretivist, as the meaning of ‘effective pedagogy’ is contextually determined and cannot be abstracted into universal measures.

3.2 Systematic Literature Review

The systematic review was conducted in accordance with the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [39]. Three conceptual clusters; Human-Centred Design/Design Thinking, STEM/engineering education, and inclusive education/underserved communities/Sub-Saharan Africa, were used to build the search terms, which were then searched in SCOPUS, Web of Science, ERIC, Google Scholar, and African Journals Online (AJOL). The search was conducted in English and only included publications that had gone through the peer review process and were published between 2005 and 2024.

3.3 Case Analysis

The three selected HCD integrated engineering programmes in Southern Africa were identified using purpose sampling criteria of:

- relevance to the field of Engineering,
- operating in a resource constrained university and
- having programme documentation and availability of key informants.

The data collection process included semi-structured interviews with a subset of faculty, students, industry partners, and community members from April to August 2024, as well as documentary analysis of programme reports, curricula, and student project portfolios. English and Shona (with translation) were used for interviews, which ranged in length from 45 to 75 minutes. Data analysis was undertaken using the six stages of thematic analysis developed by Braun and Clarke [40] [41] in NVivo 14, with member-checking to enhance credibility and an external peer reviewer to check coding framework for confirmability.

3.4 Ethical Considerations

Participants provided written informed consent and individual identifiers were anonymised in the study so as to protect confidentiality.

4 FINDINGS AND ANALYSIS

4.1 Theme 1: HCD Reframes the Learner's Relationship with Engineering

In each of the three cases, the most frequent mention of the impact of HCD integration was a change in student's perspectives on themselves as engineers. In traditional engineering learning, students expressed their attitude to the discipline as deference, receiving knowledge, applying formulas, producing solutions that are approved by others. That's the opposite of what HCD did.

That refocusing is not a trivial one for identity development and staying. This is a message that often gets passed down, unspoken and unspoken, to students from under-resourced communities: Engineering knowledge is for others. The epistemological starting point of HCD is to start with what the student and his/her community know, thus establishing a different starting point than the traditional one. The finding is consistent with Maton's [42] Legitimation Code Theory, which states that academic self-concept is established based on whether academic codes of knowledge are congruent or incongruent with the codes of knowledge in the home context.

4.2 Theme 2: Empathy as a Technical Competency

One surprising result was the fact that empathy was not considered an 'extra' or a 'soft skill' but as a technically productive competency, enhancing the quality of engineering solutions in all cases. Students who used structured exercises of empathetic learning (community interviews, shadowing and participative observation) were able to generate problem definitions and design specifications that were more precise, more technically feasible, and more contextually appropriate than those developed through traditional needs-analysis approaches.

They discovered that projects that started from a community empathy visit typically needed fewer iterations in redesigning solutions than projects that were based on a technical brief only: the initial effort to see the context from the user's perspective minimised the number of times the technical solution was misaligned with the needs of the user. This is in line with Brown's [43] discovery that the empathy part of Design thinking has a very strong instrumental value, and not only humanistic value.

4.3 Theme 3: Strategies for resource constrained implementation

One of the major challenges in the study was finding ways to apply HCD given the typical resource base assumed by design education (prototype labs, digital fabrication tools, immediate access to industry partners) that is rarely available. The analysis of the three strategies identified as enabling were:

- **Low fidelity prototyping using local materials:** All three institutions used materials from their local communities to construct design prototypes (salvaged metal, agricultural waste, locally produced parts). This restriction did not result in a compromise; it encouraged more creative, context-driven problem-solving. One faculty participant described it as 'frugal ingenuity' which is a skill which is becoming more critical in the global engineering practice.
- **Community spaces as design studios:** Lacking design laboratories, design workshops were run by the students in community centres and school classrooms. The unexpected side effect of this departure from the standard university lab was that this brought the design process right into the community context, making it more accessible for community members and enhancing the quality of co-design.
- **Empathy as a toolkit:** Mobile technologies were used as tools for the students' community empathy research, such as voice recorders, photography and video documentation, as well as WhatsApp feedback channels for collecting rigorous qualitative data, without the need for expensive specialist software, equipment or space.

4.4 Theme 4: Tri-Sector Partnerships and Their Structural Requirements

Organising for industry and community engagement was a strength for all three programmes, though the level of involvement and sustainability of such partnerships differed significantly. Programmes that depended on informal relationship-based partnerships were more fragile and difficult to scale.

The more successful partnerships had four defining features: a clearly defined division of roles and mutual-benefit agreements, dedicated staff from the university to manage community relations, industry involvement in the development of assessment design, rather than just project briefing, and community representation in the review of the curriculum. The latter was the most important, as programmes with a formal role for community members in curriculum discussions had higher levels of student project relevance and ownership.

5 A FRAMEWORK FOR HCD INTEGRATION IN RESOURCE CONSTRAINED STEM EDUCATION

This study builds from the literature review and the case findings provided above to suggest a framework of five components in which HCD is integrated into STEM education in resource-limited environments. The framework is designed to be flexible and modular, rather than prescriptive; after all, HCD itself is about context-specificity.

5.1 Component 1: Institutional Commitment and Pedagogical Leadership.

However, HCD integration can't be merely top-downed from individual faculty members, it needs to be deliberately supported by institutional endorsement: the deliberate incorporation of HCD modules within curriculum frameworks, allocated faculty time for pedagogical development, and the incorporation of HCD outcomes in quality assurance processes. Academic leaders need to openly advocate for the adoption of empathy-as-a-core-engineering-skills approach instead of it being a 'soft skills' program.

5.2 Component 2: Faculty Development in Facilitative Pedagogy

From teaching to facilitating is not a trivial matter. Structured professional development is needed to help engineering lecturers learn the pedagogy of the facilitation, ambiguity, and assessment skills that are required for HCD. There are several ways to build that capacity that have low entry points, including peer learning communities, faculty exchanges with institutions with experience in design education, and short design sprints.

5.3 Component 3: Formalised Community and Industry Partnerships

As the findings revealed, the level of formalisation of tri-sector partnerships has a direct relationship with their duration and level of formalisation. Structured partnership agreements with clear expectations, timeframes and mutual gains need to be developed and invested in by institutions. These relationships can be formalised and maintained beyond the academic year, as is possible at community liaison offices.

5.4 Component 4: Development of the Low-Resource HCD Toolkit

Creating a practical toolkit adapted to low-resource environments, in a collaborative fashion with faculty and students. It should have an empathy interview guide in the local language, a low fidelity prototype guide based on the local context, a digital data collection template that is optimised for mobile use, and protocols for community feedback. Importantly, the toolkit should remain a 'living document' and be updated as practitioners gain implementation experience.

5.5 Component 5: Equity-Centred Assessment Design

The best indicator of an institution's values is its assessment. Assessment frameworks that capture the quality of problem framing, the depth of community engagement and the iterative design thinking process, rather than just technical correctness and procedural conformance are required to integrate HCD. Portfolio-based assessment, peer evaluation and community stakeholder feedback are complementary to and in addition to traditional technical assessment and should be co-developed with student and community partner rubrics, maintaining throughout the process transparency and legitimate assessment practices.

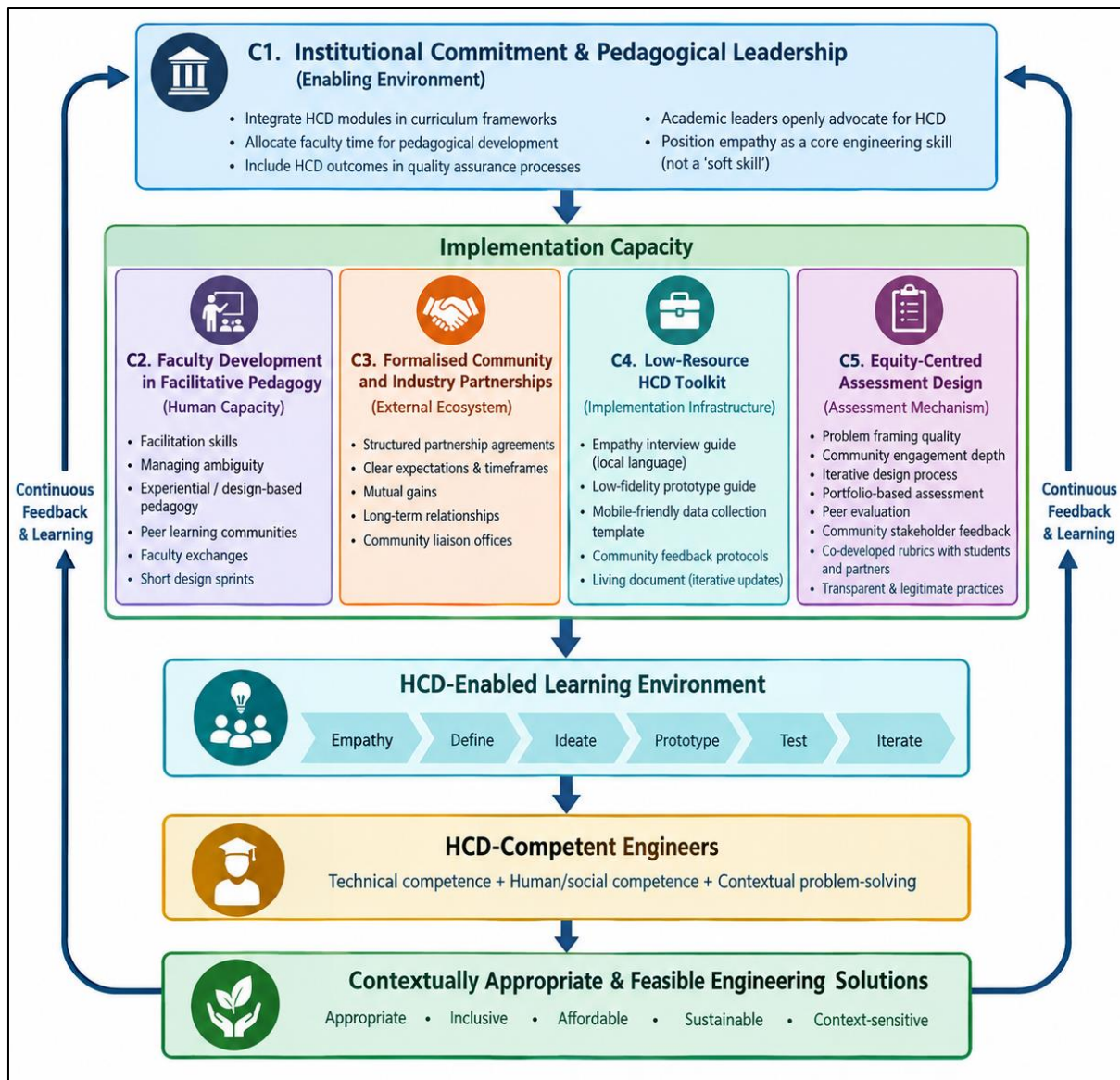


Figure 1: Framework for the Integration of HCD

6 DISCUSSION

6.1 Inclusive Design as an Opportunity for Change.

These findings support and amplify a larger argument: Inclusive pedagogy in STEM is not just about access. Increasing the diversity of students in engineering departments is a prerequisite but not sufficient for achieving equity in the outcomes. What's happening pedagogically inside, how knowledge is being framed, who's experiences are the centre of focus, what is considered as valid engineering intelligence, makes increased access genuine inclusion or a delayed exclusion.

HCD starts with the learning context, which is the context in which engineering knowledge is created, instead of mainstream western industrial contexts, thus challenging the epistemological hierarchy that assumes mainstream contexts are an engineering standard to which all engineering solutions must be compared. In so doing, it opens space for learners all over Sub-Saharan Africa to be makers of engineering knowledge, rather than consumers of it.

6.2 Understanding and checking the similarity between HCD and Technical Rigour. 6.4 Reconciling HCD with Technical Rigour.

Another concern shared by the faculty at the case institutions was that emphasizing empathy and community engagement could be at the cost of technical rigor. That is not the case here. On projects that incorporate HCD, students always developed and applied technical skills; materials analysis, structural design, process optimisation to actual problems, and they did so with motivation and context that often can not be found in traditional courses.

The principle is that HCD is not about the sacrifice of technical content, it's about providing technical content with a purpose, which makes it meaningful. A student who has heard a smallholder farmer talk about the challenges of a manual irrigation pump is investing in a different kind of content than one who comes across the same content as a theoretical textbook exercise. Deep learning requires meaning and that is what HCD provides.

6.3 The limitations and directions for future research are summarized in this section.

The present study has its limitations. While the case sample was purposive, it is limited and focused in Southern Africa, and the findings are not necessarily generalizable to Sub-Saharan African contexts that have differing institutional histories, disciplinary traditions, and policy contexts. The qualitative evidence of student engagement is rich, but is not sufficient to make causal claims about learning outcomes, as would be done with a longitudinal quantitative study that would follow HCD-integrated cohorts until they entered the workforce.

Further research should also explore gender aspects of integrating HCD, as women are under-represented in engineering programmes in Africa, and may be impacted in different ways if they shift to a community-embedded learning experience. There is a need for a specific study of how tri-sector partnerships can be scaled to different institutional contexts, as well as a study of how digital HCD tools can enable communities to stay engaged in these places where physical interaction is limited.

7 CONCLUSION

This paper has argued that Human-Centred Design offers a coherent, evidence-based, and practically implementable framework for making STEM education more equitable, relevant, and effective in resource-constrained settings. Drawing on a systematic literature review and case analysis of three Southern African engineering programmes, the study has shown that embedding HCD into STEM curricula produces measurable gains in learner engagement, problem-solving competency, and cultural relevance while generating engineering solutions of genuine community value.

The five-component framework proposed here, formalised partnerships, low-resource toolkits, and equity-centred assessment, offers practical guidance for institutions seeking to operationalise HCD within the constraints of real-world resource scarcity. It is not a blueprint for wholesale adoption, but a set of generative starting points, meant to be adapted, contested, and refined through the same iterative, community-engaged process that HCD itself advocates.

The stakes of this work extend well beyond pedagogical innovation. Zimbabwe and its neighbours face engineering challenges of enormous complexity and consequence; ageing infrastructure, energy insecurity, water scarcity, climate adaptation, and the demands of nascent industrial development. Meeting them will require engineers who are technically capable and deeply attuned to the social, cultural, and material realities of the communities they serve. Human-Centred Design, embedded in STEM education from the earliest stages of formation, is one of the most promising tools available for producing engineers of exactly this kind. It is not merely a pedagogical choice. It is an equity imperative.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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