WIP: Integrating Green Computing Competencies Into Southern African Curricula

Vuyelwa David Ruwodo
Department of Computing
University of Turku
Turku, Finland
0000-0002-2275-5370

George Mufungulwa
Department of Computer Science
The Copperbelt University
Kitwe, Zambia
mufungulwac@gmail.com

Sibonile Moyo
Department of Information and Analytics
National University of Science and Technology
Buluwayo, Zimbabwe
0000-0003-0408-2341

Lannie Uwu-khaeb
Department of Computing
University of Turku
Turku, Finland
0000-0002-6070-8444

Nikodemus Angula
Department of Commerce, Human Science and Education
Namibia University of Science and Technology
Windhoek, Namibia
0000-0002-3963-0267

Erkki Sutinen
Department of Computing
University of Turku
Turku, Finland
0000-0002-1020-3325

***Abstract*—This is work-in-progress research-to-practice. Computer-based solutions are viewed as key to many technological problems, especially in reducing the impact of technology on the environment. At the same time, these computing solutions have their negative impacts. Such negative impacts are not understood by many computing specialists, as computing graduates have not been made aware of these undesirable impacts of their solutions. Based on frameworks such as CC2020, most computing curricula in Southern Africa, do not incorporate sustainability concepts. This means computing graduates of these African institutions will continue to view the quality of their computing solutions as defined by curricula that lack emphasis on sustainability. However, Africa's contribution to engineering education with a green twist can address this predicament. By integrating sustainability principles into computing and engineering curricula, African higher education institutions (HEI) can pioneer a new generation of professionals equipped with knowledge and skills to develop sustainable green technological solutions. Such an approach will not only address local challenges but will also position Africa as a major contributor to green computing and sustainable engineering practices, which are increasingly crucial in the global effort to mitigate environmental degradation. Using Design Science Research (DSR), incorporating Action Research, this paper discusses the process of formulating a green-friendly computing curriculum for use by five African universities, participating in a European Union-funded project, Grow Green Africa (Gr2A). This hybrid approach to curriculum development ensures the viability of the resulting curriculum and its adaptability and sustainability over time. The designed curriculum incorporates sustainability principles aimed at fostering sustainable practices in the computing sector. The competency-based learning model encompasses knowledge, skills, and dispositions required to execute tasks in various fields of computing. Such an approach transcends the traditional "knowing-what" paradigm and encompasses the "know-how" and "know-why" aspects of applied tasks. Developing competencies in areas such as green computing and sustainability is proposed as vital for meeting the demands and future trends in Southern Africa. By revamping curricula to include sustainability aspects, higher educational institutions can equip students with the necessary knowledge and skills enabling them to integrate sustainable practices into their computing endeavors, thus reducing the negative impact of computing on the environment. This proactive approach not only promotes environmental stewardship but also aligns with the broader goals of human development and prosperity in the Southern Africa region. Furthermore, it positions Africa as a hub for innovative and sustainable green engineering solutions, contributing to the global effort to address environmental challenges while driving economic growth and social development. This research would also be important to curriculum developers as it gives a clear process to follow when incorporating sustainability concepts into engineering curricula in general and computing in particular.**

Keywords—green computing, Gr2A, education, Southern Africa

I. Introduction

Africa has seen substantial advancements in computing technology and infrastructure, offering great potential for digital transformation across the continent. However, this rapid technological growth often overlooks sustainability, leading to long-term ecological impacts that could undermine technological benefits. As global environmental challenges intensify, it is crucial to integrate sustainability into Africa's technological development, starting at the higher education level. Embedding green computing principles in university curricula can prepare a new generation of technologists who are skilled in computing and mindful of environmental responsibilities, thereby enhancing Africa's socio-economic competitiveness.

Green computing in Africa faces two main challenges: intrinsic and extrinsic. Intrinsic challenges include issues directly related to computing, such as e-waste management and a lack of awareness about the environmental impact of technology use. Extrinsic challenges involve broader environmental issues, like droughts, poaching, and urban pollution, which could be mitigated through innovative digital and green computing solutions.

Addressing these challenges requires a comprehensive strategy, including policies that promote recycling and sustainable technology development, along with educational programs that raise awareness about green computing’s role in solving environmental problems. By

tackling both types of challenges, Africa can advance its technological capabilities in a way that supports sustainability and environmental stewardship.

II. Research Focus

This paper proposes a focused study on the integration of sustainability, specifically green computing, into the computing curricula of African universities. Green computing encompasses practices and strategies for designing, manufacturing, using, disposing, and recycling of computers and computer-related products in environmentally friendly ways, aimed at reducing energy consumption and minimizing environmental impact [2]. This paper will use the terms green computing and sustainability interchangeably. The research questions guiding this study are:

1. What is the current status of green computing education in institutions of higher learning in Southern Africa?
2. How can green computing curricula be effectively designed and implemented in African academic institutions using contemporary educational methodologies?

The Grow Green Africa (Gr2A) project serves as the focus for curriculum analysis and design. The overarching goal is to position African universities at the forefront of green computing education on the global stage. Gr2A is a European Union-funded initiative aimed at enhancing climate resilience across Africa by Integrating green computing content into selected computing courses. The success of the Gr2A initiative should serve as a springboard from which all other initiatives with a similar aim could be launched. The lessons learned from this project will pave the way for the development of robust sustainability educational programs in the future.

III. Related Work and Concepts

The integration of green computing into African university curricula emerges as a strategic imperative with potential implications for the job market. [3] Shed light on the pivotal role of environmental sustainability practices in shaping offshoring decisions, underscoring the value of African academic institutions with a focus on green computing. Given the pressing issue of unemployment in many African nations, fostering increased offshoring activities could serve as a pathway to economic empowerment. This highlights the importance of exploring how African universities can leverage green computing education to enhance their relevance and competitiveness in the global marketplace.

A popular computer science framework Computing Curricula 2020 (CC2020) only mentions sustainability in the context of Sustainable competency. Sustainable competency refers to the ability to (a) adapt to change and competitiveness of the future society, (b) be creative based on the missions and technology, and (c) perform and promote social and technical development, while considering the environmental impact and long-term viability of computing practices [1].

The Computer Science Curricula 2023 (CS2023) report offers valuable insights on integrating sustainability concepts into computing education. It defines sustainability as "development that meets the present needs without compromising future generations' ability to meet their own needs." The report emphasizes the growing environmental impacts of computing through energy usage and e-waste [4]. It recommends equipping students with the knowledge to recognize these issues and engage in computing sustainably. Suggested topics include exploring local and global impacts of systems usage and disposal, tradeoffs in blockchain consensus models, systemic effects of computer-mediated phenomena, and pervasive sustainable computing applications. Additionally, it provides illustrative learning outcomes for core Computer Science (CS) areas around identifying sustainable practitioner practices, evaluating the environmental impacts of projects, and investigating social, environmental, and economic influences in system designs.

CS2023 identifies the following learning outcomes for sustainability:

- Identify ways to be a sustainable practitioner
- Enumerate the environmental impacts of a project's deployment
- Illustrate global social and environmental impacts of computer use and disposal
- List the sustainable effects of modern practices and activities
- Describe the environmental impacts of design choices in computing
- Investigate the social and environmental impacts of new system designs
- Identify guidelines for sustainable IT design or deployment
- Investigate pervasive computing in various areas
- Assess computing applications with respect to environmental issues

Moreover, the CS2023 report [4] provides valuable guidance on competency-based curriculum design, highlighting that competency models are intended to complement, rather than replace, traditional knowledge models. Competencies are characterized as the practical application of knowledge, skills, and dispositions within professional settings. The report outlines how competency areas such as Software, Systems, and Applications are linked to specific knowledge units and topics. Additionally, it identifies authentic workplace tasks, competency statements aligned with those tasks, and the skill levels required to execute them effectively. This mapping between tasks, competencies, and skills serves to bridge the gap between theoretical knowledge and practical application. It also offers a framework for defining green computing competencies that are specifically tailored to the African context, drawing from relevant knowledge areas.

CC2020 identifies 5 key stakeholders when applying a competency-based curriculum:

1. Prospective students and their parents
2. Current students
3. Industry professionals
4. Educators

5. Educational organizations and authorities

Prospective students and their parents often lack a full understanding of computing subdisciplines when choosing universities, seeking comparisons based on curriculum standards, career outcomes, and industry needs. **Current students** and **industry professionals,** also evaluate programs to ensure relevant competencies align with job requirements. Computing **educators** and **educational authorities** ensure curricula meet industry standards and regulatory guidelines. The authors highlight the need to include **government bodies** as key stakeholders in green computing, emphasizing the importance of engaging decision-makers, civil society, and international organizations. Government involvement is crucial for aligning the curriculum with environmental and societal goals, influencing policy, and promoting sustainable practices. This comprehensive engagement fosters a curriculum responsive to both local and global needs, preparing professionals to address environmental challenges through green computing.

Competency-based curriculum design is gaining recognition for its focus on developing skills that can be applied in real-world contexts. As defined by [5], competency is "the ability to successfully meet complex demands in a particular context." This approach emphasizes holistic development by not only fostering knowledge but also the skills, attitudes, and values necessary for professional excellence, making it particularly effective for teaching sustainability.

In contrast, traditional education often emphasizes formal qualifications—such as degrees, certificates, or diplomas—required for specific roles, particularly in government or regulated industries. While these qualifications meet professional standards, they do not necessarily ensure practical competence. An individual may hold formal credentials yet lack the practical skills needed for effective performance, or be highly competent without holding the required formal qualifications.

Competency-based education aims to close this gap by ensuring learners gain both theoretical knowledge and practical skills. This method prioritizes the application of learning, preparing students to meet professional demands with confidence. In sustainability education, this practical focus is essential, as it enables students to apply sustainable practices in real-world situations, not just understand the theory behind them.

A notable project that demonstrates the integration of sustainability concepts into computing and engineering curricula using a participatory and competency-based approach was led by [6]. This initiative was implemented across seven Southeast Asian universities. It aimed to develop a participatory framework for curriculum planning, enhance capacity building for university staff, and foster interdisciplinary learning. The project adopted a participatory approach to defining green computing competencies tailored to local demands within these universities.

Key outcomes of this project included the successful engagement of diverse stakeholders, the development of a dynamic curriculum model that integrates sustainability, and significant revisions in university curricula to embed sustainability concepts effectively. The project highlighted the effectiveness of participatory approaches in addressing educational and sustainability challenges, providing a valuable model for similar adaptations in different contexts, including Africa. However, it is important to note that in most African universities, such curriculum revisions could take years, if not decades, to implement fully, underscoring the need for sustained efforts and ongoing collaboration to achieve meaningful change.

Tumaini University in Tanzania has developed a comprehensive environmental technology course designed to address the intersection of ICT and environmental sustainability. The curriculum includes a detailed examination of the environmental impact of ICT manufacturing and transportation, with a focus on resource exploitation and the consequences of irresponsible mining practices. Students are introduced to local and international environmental laws, such as the Polluter Pays Principle and Extended Producer Responsibility, and are tasked with evaluating local e-waste disposal practices. The course incorporates environmental assessment tools, including Strategic Environmental Assessment and Life Cycle Assessment, to analyze hypothetical scenarios, such as computer installations in rural settings. Additionally, the course emphasizes energy efficiency in computing, green technology initiatives, and effective e-waste management strategies. By integrating discussions on environmental ethics and the responsibilities of IT professionals, the course aims to cultivate a global and ecological awareness among students, encouraging them to take proactive steps in minimizing the environmental impact of ICT. [7].

The recognition of Design Science Research (DSR) as an effective methodology for developing and refining educational tools and frameworks that address specific needs within academic curricula has been growing. [8] outline the process of DSR as one that evolves through iterative cycles of design, development, testing, and refinement, making it particularly suited to the dynamic and complex nature of educational innovation. This methodology has been successfully applied in various fields to create artifacts (in the iterative design cycle) that solve practical problems (identified in the relevance cycle from the environment) while learning from and contributing to theoretical knowledge (by the rigor cycle). In the context of integrating green computing into curricula, DSR provides a structured approach to create and evaluate educational artifacts, such as syllabi, teaching materials, and digital platforms. These artifacts are specifically designed to meet the unique educational requirements and cultural contexts of African universities.

Action Research is characterized by its dual focus on action (change) and research (understanding) and is particularly valuable in settings where participant involvement and iterative improvement are crucial. According to [9], Action Research is collaborative, situational, and responsive, making it ideal for educational projects where faculty and students are co-creators in the learning process. In integrating green computing competencies, Action Research allows for the practical implementation of new curriculum elements within the classroom setting while continuously assessing and refining these changes based on direct feedback from participants. This method fosters a participatory culture within the educational institution, enhancing the relevance and effectiveness of the curriculum. For example, a study by [10] highlighted how Action Research empowered teachers and students to collaboratively develop sustainability-focused content in undergraduate courses at the University of

Southampton, leading to more engaged learning and improved environmental awareness.

Integrating both DSR and Action Research provides a comprehensive approach to curriculum development and implementation. While DSR focuses on the creation and initial testing of educational artifacts, Action Research emphasizes real-world application and iterative refinement. This combination ensures not only the practical viability of educational innovations but also their adaptability and sustainability over time.

A notable example of the effective combination of these methodologies can be seen in the work of [11], where DSR was used to develop a new software learning platform, which was then rolled out using Action Research to adapt the platform based on user feedback and evolving educational needs. This approach ensured that the platform was continually improved while being sensitive to the specific requirements of the users, which might also change or become clearer as the users actively participated in or co-designed the project.

IV. Results

To address the first research question, "**What is the current status of green computing education in institutions of higher learning in Southern Africa?**" a comprehensive literature review was conducted, including an examination of the curricula at participating institutions. The review revealed that while existing frameworks like CS2023 and CC2020 offer valuable insights for integrating sustainability into computing curricula, they need adaptation for the African context. Tumaini University's environmental technology course illustrates a tailored approach, focusing on ICT-related environmental issues in Tanzania. Our proposed course builds on this by targeting at least five universities across different countries, each with unique ICT laws and conditions, requiring a flexible and dynamic curriculum design approach.

Regarding the second research question, "**How can green computing curricula be effectively designed and implemented in African academic institutions using contemporary educational methodologies?**" the study advocates for a competency-based approach. This ensures students can apply their knowledge practically, crucial for integrating green computing principles into professional environments. The study proposes combining Design Science Research (DSR) and Action Research to develop and implement these curricula effectively. DSR enables the systematic creation of educational artifacts tailored to Southern Africa's needs, while Action Research focuses on applying and continually improving these curricula in real educational settings through iterative cycles of planning, action, observation, reflection, and revision.

Integrating DSR and Action Research into Action Design Research (ADR) [12] creates a feedback loop, where artifacts developed through DSR are refined through Action Research cycles and further improved based on stakeholder feedback. This iterative process is demonstrated in a pilot course deployment, with subsequent Action Research cycles gathering data and refining the curriculum, gradually expanding its scope across multiple courses and universities.

The Gr2A curriculum development workshop produced an initial syllabus, identifying specific computing courses across five institutions for sustainability integration. This syllabus includes a comprehensive sustainability module to provide foundational knowledge and practical green computing skills. Key outcomes include integrating green computing principles into existing curricula and refining these courses through DSR feedback cycles. The study emphasizes stakeholder engagement and contextual adaptation in curriculum development, with insights from the workshop guiding future curriculum enhancements across regions.

V. Conclusion

The integration of green computing principles into African university curricula is essential for promoting sustainable technological development across the continent. This study advocates for a tailored approach that leverages established methodologies, adapted to the unique contexts of Southern African academic institutions. For instance, Copperbelt University, located in a mining town, will focus on green mining technologies to mitigate environmental impacts and address climate change, integrating practices specific to the mining industry. Meanwhile, The National University of Science and Technology in Zimbabwe, an agricultural nation, will emphasize climate change models for agriculture, developing information systems to support sustainable farming practices.

This strategy ensures that green computing principles are customized to address the specific environmental and industrial needs of each institution. By combining Design Science Research (DSR) and Action Research, the curriculum development process becomes both systematic and adaptive. DSR enables the creation and refinement of educational tools such as competency frameworks and syllabi based on empirical evidence, while Action Research ensures these innovations are continuously tested, refined, and adapted to real-world educational settings through iterative cycles of planning, implementation, and evaluation.

This dual approach enhances the relevance and effectiveness of the curricula and promotes a participatory development culture, engaging educators, students, and industry partners. This fosters a shared commitment to sustainable computing practices, laying the groundwork for long-term impact and helping universities integrate education, research, and community engagement, thus aligning academic programs with industry needs and contributing to sustainability advancements.

The proposed DSR and Action Research framework will be implemented in the Gr2A project to develop and integrate green computing curricula across select Southern African universities. Future studies will document the application and outcomes of this methodology within the Gr2A initiative, assessing success through curriculum acceptance, feedback from students and faculty, and alignment with international standards.

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