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Transforming TVET Curriculum: Leveraging Coding and Robotics as catalysts for Functional Design Innovation at IGCSE level in Zimbabwean Schools

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ABSTRACT

This qualitative study investigates the transformation of the TVET curriculum in Zimbabwean schools through the integration of coding and robotics into the IGCSE Design and Technology syllabus. It explores how this synergy enhances students' ability to produce innovative, functional, and industry-relevant design solutions. A key focus is on bridging the gap between conceptual design and real-world application, emphasizing that designs often fall short when they lack programmed instructions provided by coding. Coding equips students with the ability to embed functionality into their designs, while robotics offers a platform for hands-on experimentation, enabling the creation of interactive, automated prototypes. The research underscores the necessity of harmonizing Design and Technology with Computer Science, fostering a multidisciplinary approach that enhances creativity, technical proficiency, and problem-solving skills. The study envisions a TVET curriculum that prepares students for the demands of Industry, empowering them to develop smart, user-centred products that align with global industrial trends and technological advancements.

Introduction The technological revolution of Industry has profoundly transformed industries and reshaped the global demand for future-ready skills, emphasizing the need for a reimagined education system. In Zimbabwean schools, the TVET curriculum at the IGCSE level remains fragmented, often lacking the integration of related disciplines like design and technology, coding and robotics. While Design and Technology encourages creativity and problem-solving, its full potential is often unrealized due to the absence of programmed functionality and automation. Coding brings designs to life by embedding logic and interactivity, while robotics offers practical tools for prototyping and testing, enabling students to create smart, adaptive, and user-centered products. This study investigates how the integration of coding and robotics into the Design and Technology syllabus can drive functional design innovation, fostering a multidisciplinary approach that aligns with modern industrial needs. By harmonizing Design and Technology with Computer Science, students gain advanced technical proficiency, critical thinking skills, and the ability to solve complex problems. The study envisions a transformed TVET curriculum that not only equips learners for Industry but also positions Zimbabwe as a hub of innovation and technological advancement in the global economy.

Statement of the problem

The fragmentation within the TVET curriculum in Zimbabwean schools, where Design and Technology is taught separately from Computer Science, has hindered students from creating fully functional, industry-ready designs. While students are encouraged to innovate and conceptualize, the lack of integration with coding and robotics results in incomplete products that cannot perform as intended in real-world scenarios. A teacher reflected this gap in learning, stating, "My design products can even function if they get the right programs. I feel this is a step forward if students can design, make, and use." This sentiment underscores the critical need for an integrated approach that blends creative design with functional programming. In today's technological age, designs that lack the ability to be programmed and automated fail to meet modern industry demands, where functionality is just as important as aesthetics. The absence of coding and robotics in the curriculum

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limits students' ability to develop smart, adaptive products essential for future industries. Recent studies have shown that interdisciplinary learning significantly boosts technical competency and problem-solving skills (Smith & Johnson, 2023), making the case for a comprehensive TVET curriculum that prepares students not only to design but also to innovate, build, and implement solutions aligned with the demands of Industry.

Main research question

How does the integration of coding and robotics into the Design and Technology curriculum enhance students' ability to create functional, industry-relevant design solutions at the IGCSE level in Zimbabwean schools?

Theoretical framework

The theoretical framework guiding this study integrates Constructivist Learning Theory and the Technological Pedagogical Content Knowledge (TPACK) framework, both of which emphasize the essential role of active engagement, problem-solving, and technology in learning. Constructivist theory, as articulated by Piaget (1952) and Vygotsky (1978), posits that knowledge is constructed through direct interaction with the environment and active problem-solving. In the context of Design and Technology, the integration of coding and robotics allows students to move beyond abstract theory, engaging them in hands-on creation of functional products that blend design principles with technological applications. This dynamic process of experimentation and interaction is central to constructivism, which argues that learning is most effective when students actively construct knowledge through practical, real-world tasks. Complementing this, the TPACK framework developed by Mishra and Koehler (2006) underscores the intersection of content knowledge, pedagogical strategies, and technology, illustrating how teachers must integrate these domains to create an effective learning environment. In the case of Design and Technology, the integration of coding and robotics represents a perfect fusion of these elements, offering students the tools and skills necessary to produce innovative, functional designs. Together, these frameworks guide this study in exploring how the integration of coding and robotics enhances both teaching and learning by fostering a multidisciplinary approach that prepares students for the demands of Industry.

LITERATURE REVIEW

The integration of coding and robotics into the Design and Technology curriculum has been widely recognized for its potential to bridge the gap between creativity and technical proficiency in students. Research indicates that by incorporating coding and robotics, students not only engage in the creative aspects of design but also develop essential skills for creating functional, innovative solutions. According to Bower (2017), the ability to combine coding with design enhances students' capacity to understand how their creations work in real-world applications, encouraging deeper learning and critical thinking. Furthermore, Sanders (2015) suggests that when students are exposed to interdisciplinary learning that blends design with technology, they exhibit a higher degree of problem-solving capabilities and creativity. This trend is evident in various educational settings where robotics has been shown to increase engagement and improve student outcomes in both design and technical subjects (Becker, 2018). Such integration not only prepares students for the demands of the technology-driven workforce but also nurtures their ability to think critically and innovate within complex systems.

The application of coding and robotics in design education also plays a crucial role in preparing students for the future of work, particularly as industries embrace automation and artificial intelligence. Wolfram (2016) highlights how robotics and coding promote hands-on learning and foster a deeper understanding of engineering and design principles. When students engage with both the creation of a physical product and its underlying programmatic logic, they gain practical skills that are immediately applicable in real-world scenarios. Moreover, according to Bennett and Lockyer (2018), the introduction of coding and robotics into the curriculum helps students develop 21st-century skills such as collaboration, critical thinking, and adaptability—skills that are essential for success in the modern economy. Weller (2019) and Hegarty (2020) also suggest that students who learn to program and interact with robotic systems demonstrate enhanced analytical thinking and problem-solving skills, which directly improve their ability to create functional and efficient designs. The integration of coding and robotics in Design and Technology, therefore, aligns well with

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue II February 2025

the increasing emphasis on STEM education and the necessity for a workforce that is skilled in both creativity and technological competency.

Integration of Coding and Robotics in Design and Technology Education

The integration of coding and robotics into Design and Technology education has proven to be a powerful approach for enhancing student learning outcomes. Blending these technologies with traditional design principles helps students develop critical skills necessary for tackling complex, real-world problems while fostering creativity and innovation. This interdisciplinary approach allows students to engage with both design concepts and the technical aspects of product functionality, enabling them to produce functional and innovative designs (Becker, 2018). Such integration encourages deeper cognitive engagement, as students are required to think critically about how their designs will work in real-world contexts, bridging the gap between abstract ideas and practical applications (Wolfram, 2016). Additionally, the use of robotics and coding nurtures problem-solving skills by challenging students to find efficient solutions to design and technological obstacles, equipping them with transferable skills essential in a technology-driven world (Honey & Hilton, 2011). This combination of creativity and technical know-how ensures that students are well-prepared for the demands of a rapidly evolving, technology-centered workforce (Bower, 2017).

Enhancing Practical Problem-Solving and Critical Thinking Skills

The integration of coding and robotics into education plays a pivotal role in promoting higher-order cognitive skills, such as problem-solving and critical thinking. When students engage with these technologies, they are encouraged to approach challenges analytically, breaking down complex problems into manageable components and systematically finding solutions. This hands-on approach not only enhances their technical skills but also deepens their understanding of the design process, making them more adept at tackling real-world issues (Saavedra & Opfer, 2012). The active engagement required in coding and robotics transforms students from passive recipients of information into active creators who must think critically about how to make their designs work functionally and efficiently (Hegarty, 2020). Furthermore, coding challenges students to think algorithmically, promoting logical reasoning and the ability to anticipate potential problems before they arise (Becker, 2018). Students working with robotics experience an increase in their ability to troubleshoot, collaborate, and refine their ideas based on trial and error, all of which are integral components of problem-solving in the real world (Wolfram, 2016).

Pedagogical Approaches to Teaching Coding and Robotics in Design and Technology

The effective integration of coding and robotics into Design and Technology education requires the adoption of innovative pedagogical approaches such as project-based learning (PBL), inquiry-based learning (IBL), and collaborative learning fosters active student engagement by allowing learners to apply their coding skills to real-world projects, bridging the gap between theory and practice (Chung, 2020). Similarly, IBL encourages critical thinking and problem-solving by prompting students to explore and experiment with technological solutions (Belland, 2020). Collaborative learning further enhances the process by enabling students to work together, sharing ideas and developing communication skills essential for teamwork in technology-driven industries (Capraro & Capraro, 2020). However, challenges exist in adapting teaching methods to integrate coding and robotics effectively, particularly due to limited teacher training and resources. Professional development programs equip educators with the necessary skills to teach these interdisciplinary subjects effectively (Koehler et al., 2020). Such initiatives are crucial for creating an environment conducive to innovative and future-focused learning.

METHODOLOGY

This qualitative study explored the integration of coding and robotics into the Design and Technology curriculum by involving six teachers (three teaching Design and Technology and three teaching Computer Science) and ten students enrolled in both subjects. Data was collected through semi-structured interviews with the teachers, classroom observations, and focus group discussions with the students. The aim was to

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue II February 2025

understand the experiences of educators and learners, the challenges faced, and the impact of interdisciplinary learning on student creativity and problem-solving.

FINDINGS

Integration Challenges and Opportunities in Teaching Coding and Robotics

The study revealed that while teachers acknowledged the potential of integrating coding and robotics into the

Design and Technology curriculum, significant challenges hinder full implementation. Teachers emphasized that combining these subjects offers valuable opportunities to produce more functional and innovative products. Teacher T1 remarked, “It is desirable to combine the two subjects so that students produce more functional products, however, these subjects are currently being taught each on its own.” This statement underscores the fragmented nature of the curriculum and the need for interdisciplinary teaching. Teacher T5 echoed this sentiment, identifying a key barrier: “The challenge is on getting a guiding syllabus on this vision.” Without a unified curriculum framework, teachers face difficulties in aligning content and ensuring seamless integration of coding and robotics into the design process. Teacher T6 further highlighted the issue of cross-cutting themes between the two subjects, stating, “It is difficult to only concentrate on cross-cutting themes because both syllabuses are broad.” This points to the need for a streamlined curriculum that supports interdisciplinary learning while addressing the expansive content in both subjects.

Impact on Student Learning and Creativity

Teachers widely acknowledged the positive impact of integrating coding and robotics on students’ learning and creativity. They perceived these technologies as powerful tools for enhancing critical thinking, problem-solving, and innovation. Teacher T4 highlighted the value of coding in promoting creativity, stating that “coding as a skill enhances critical thinking, hence allowing learners to be more creative when solving problems.” This perspective emphasizes the role of coding in enabling students to approach challenges with a structured yet innovative mindset.

Similarly, Teacher T3 emphasized the pedagogical benefits of these technologies, noting that “coding and robotics foster discovery learning, which is a child-centred approach to learning.” This insight reflects the shift from traditional, teacher-led instruction to a more exploratory and student-driven learning environment, where learners actively engage with technological tools to develop functional and innovative designs. These findings suggest that coding and robotics not only enhance technical skills but also nurture creativity and autonomy in students.

The Role of Professional Development and Support

Teachers highlighted the critical need for professional development and support to effectively integrate coding and robotics into the Design and Technology curriculum. They emphasized that successful implementation requires equipping educators with the necessary skills in both disciplines. Teacher T5 stated, “There is need for professional development as Design teachers need to learn programming, and Computer Science teachers need to learn computer-aided design.” This underscores the importance of cross-disciplinary training to ensure that both sets of teachers can effectively collaborate and deliver a cohesive curriculum. Additionally, Teacher T6 pointed out that “these are broad changes that need the support of all stakeholders in Technical and Vocational Education,” emphasizing the necessity of a coordinated effort among educators, administrators, and policymakers to provide resources, training, and a unified vision for interdisciplinary teaching. These insights highlight the importance of continuous professional development and institutional support in achieving successful integration.

Enhancing Problem-Solving and Design Skills Through Coding and Robotics

Students highlighted the significant impact of coding and robotics on their ability to understand the design process and enhance their problem-solving skills. They expressed that integrating these technologies allowed

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue II February 2025

them to approach design challenges with a more systematic and innovative mindset. Student S1 shared, "When I first incorporated robotics into my design projects, I realized my solutions became more realistic and complete." This illustrates how robotics and coding not only bridge the gap between theory and practice but also enable students to create functional and innovative products. Overall, students perceived these tools as essential for developing practical solutions and gaining a deeper understanding of the intricacies of the design process.

Interdisciplinary Learning and Future Relevance

Students recognized the value of interdisciplinary learning, particularly the overlap between Design and

Technology and Computer Science, in preparing them for future academic and career opportunities. They appreciated how combining these subjects provided practical, real-world applications for their skills. Student S3 noted, "I now appreciate the relevance of coding in real life through incorporating it in Design and Technology." This demonstrates how interdisciplinary learning enhances students' understanding of the broader applicability of their knowledge. Student S8 further emphasized the logistical and educational benefits of integration, stating, "I wish these two subjects were done under one roof so that there will be less duplication. This would help us organize our study schedules more conveniently." These insights reveal that students perceive a strong connection between these disciplines and view their integration as essential for efficient learning and future success.

DISCUSSION OF FINDINGS

The findings highlight the transformative potential of integrating coding and robotics into the Design and Technology curriculum, offering opportunities to enhance student creativity, problem-solving, and innovation. Despite these benefits, significant challenges remain, including the lack of a unified curriculum framework and the need for professional development to equip teachers with cross-disciplinary skills. The study underscores the importance of interdisciplinary teaching in fostering deeper student engagement, practical application of knowledge, and preparation for future academic and career pathways. Addressing resource constraints, broad syllabi, and stakeholder collaboration is essential for realizing the full potential of this integration.

CONCLUSION

This study demonstrates that integrating coding and robotics into the Design and Technology curriculum enhances student creativity, problem-solving, and the development of functional, innovative products. While the potential benefits are clear, successful implementation requires addressing challenges such as fragmented curricula, resource constraints, and the need for professional development. Interdisciplinary teaching fosters deeper learning and equips students with industry-relevant skills, highlighting the importance of a cohesive curriculum and stakeholder collaboration. To fully realize these opportunities, a unified approach that bridges Design and Technology with Computer Science is essential for preparing students for future academic and career success.

RECOMMENDATIONS

Develop an Integrated Curriculum Framework

Establish a unified syllabus that aligns Design and Technology with Computer Science to ensure seamless integration of coding and robotics.

Provide Professional Development for Teachers

Organize workshops and training programs to equip Design and Technology teachers with coding skills and Computer Science teachers with computer-aided design (CAD) knowledge.

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Increase Access to Resources

Ensure schools are equipped with the necessary tools, such as robotics kits, computers, and software, to support hands-on learning and innovation.

Foster Interdisciplinary Collaboration

Encourage joint teaching initiatives where Design and Technology teachers collaborate with Computer Science teachers to deliver integrated lessons.

Incorporate Project-Based Learning

Promote project-based learning approaches that allow students to apply coding and robotics in real-world design

challenges, fostering creativity and problem-solving skills.

Establish Coding and Robotics Clubs

Create extracurricular clubs focused on coding and robotics to provide students with additional opportunities for practice and innovation beyond the classroom.

Promote Discovery Learning

Adopt child-centered, discovery-based teaching methods that encourage students to experiment, explore, and develop their own solutions to design challenges.

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