Improving the Learning of Manufacturing Processes in Design & Technology at the IGCSE Level: A Case of Private High Schools in Marondera, Zimbabwe.

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ABSTRACT

The study is on enhancing the learning of manufacturing processes in Design and Technology (D&T) at the International General Certificate of Secondary Education (IGCSE) Level in selected private high schools in Marondera, Zimbabwe. This study is hinged on the theoretical framework of design and technology in high school classrooms rooted in constructivism. The study made use of both primary and secondary data. As such, a qualitative approach was adopted for the study and employed a sample size of 27 participants; 7 randomly sampled learners from the three private schools taking IGCSE D&T and six D&T teachers; two from each school for the IGCSE level. Interviews, observations, portfolio and artefact analysis were adopted to aid the acquiring of responses. Thematic coding was conducted in data analysis. The study highlighted the potential impact of social and collaborative aspects on extended production times. It surfaced that learners who engage in collaborative activities or receive peer support and feedback may be better equipped to overcome challenges and complete their projects more efficiently and timeously. The findings of this study emphasise the multifaceted nature of the factors that contribute to learners taking an extended amount of time to complete the production of products. The primary factors are classified into three categories: individual, instructional, and environmental. It surfaced that the exploitation of the pragmatic and constructive methodologies which provide hands-on, project-based learning experiences, design and technology classrooms empower learners to actively construct knowledge and develop essential skills in the learning of manufacturing processes. In this context, D&T classrooms serve as spaces that encourage learners to engage in hands-on, project-based learning, where they can explore their creativity and problem-solving abilities. The study recommends examining the role of technology-assisted learning, exploring the influence of teacher training and professional development, and analysing the impact of curriculum design and assessment strategies.

Keywords: Learning of Manufacturing processes Design and Technology Teaching CAD/CAM

BACKGROUND OF THE PROBLEM

The inclusion of project work is an essential element within the Design and Technology (D&T) curriculum at both the International General Certificate of Secondary Education (IGCSE) (0445) and AS/A (9705) levels. This component has significant weight, accounting for 50% and 40% of the final assessment grade, respectively. Hence, learners must undertake the project work to fully execute the design and production processes. Despite the availability of a comprehensive array of tools and equipment for learners to utilise in the realisation of their design solution models or prototypes, learners have encountered difficulties in meeting deadlines and generating accurate products about the working drawings for the past five years. It has been observed that a persistent difficulty has been the inclination of certain learners to commence production without enough functioning drawings and manufacturing aiding exploded views. The learners have been failing to precisely articulate the fabrication (planning production) process and generate comprehensive working drawings in advance of commencing the production process. Learners often take shortcuts in the manufacturing process, hence significant deviations were noted from the coursework portfolio and artefacts produced. In the same vein, learners are failing to acknowledge and invest greater time in acquainting themselves with tools and comprehending their respective applications, with the ultimate goal of realising a prototype or model product.

Statement of the Problem

The presence of variety and frequent errors is readily apparent in a universal manner especially when one has to compare the final working drawing with the final scaled prototype. The degree of variance has been increasingly skewed towards the prescribed standard expected at the IGCSE level. Learners are unable to discern the true outcome from the ultimate design. The past spread of coursework marks indicates that most of the candidates fall short of garnering enough marks in the realisation stages of the portfolio in D&T, with special emphasis on the IGCSE level.

Main Research Question

What are the primary causes of inaccuracies in producing wood or metal-based products (such as models or prototypes)?

Theoretical Framework

At the heart of the D&T classroom lies the constructivist approach to learning, which emphasises learners' active construction of knowledge (Kimbell, 2011). The approach encourages learners to engage in hands-on activities, experiment with materials, and develop their solutions to design challenges. This study is guided by constructivist principles of situated learning, scaffolding, collaboration (Reiser & Dempsey, 2012) and reflection (Sinha, et al. 2017). The seamless blending of educational theories with the latest technology innovations, the theory ensures that learning is efficient, effective, and accessible to all. D&T classrooms empower learners to construct knowledge and develop essential skills for the future actively, the constructive methodologies provide hands-on, project-based learning experiences. By actively participating in the learning process, learners are able to construct their understanding of design concepts and apply them to real-world situations (Atkinson, 2017). The constructivist approach allows learners to take ownership of their learning, fostering a sense of agency and empowerment. As they engage in the design process, learners can build upon their prior knowledge and experiences, creating a personalised and meaningful learning journey.

The Role of the Teacher

In D&T classrooms, the teacher's role is that of a facilitator, guiding learners through the design process and encouraging them to explore their ideas. Teachers in these settings foster a supportive and collaborative environment, where learners are encouraged to take risks, learn from their mistakes, and engage in peer-to-peer learning (Kimbell, 2011). By adopting a facilitative approach, teachers can help learners develop the confidence and independence necessary to become successful designers and problem-solvers. This approach recognises the importance of student agency and the teacher's role in nurturing the creative and innovative potential of each learner.

Design Thinking and Problem-Solving

A key aspect of the theory behind D&T classrooms is the emphasis on design thinking and problem-solving skills (Barlex & Trebell, 2008). Learners are challenged to identify real-world problems, generate creative solutions, and test and refine their designs through an iterative process (Atkinson, 2017). This approach encourages learners to think critically, analyse information, and develop innovative solutions that address the needs of users or clients. By engaging in the design thinking process, learners learn to navigate ambiguity, embrace failure as a learning opportunity, and develop a growth mindset that is essential for innovation and creativity.

Interdisciplinary Connections

The theory of D&T classrooms recognises the importance of interdisciplinary connections, as D&T intersect with various academic disciplines (Barlex & Trebell, 2008). Learners in these classrooms are encouraged to draw upon knowledge and skills from subjects such as science, mathematics, and art, integrating them into their design and problem-solving processes (Kimbell, 2011). This interdisciplinary approach helps learners develop a more comprehensive understanding of the design process and its real-world applications. By making connections across disciplines, learners can explore the complexities of design challenges and develop innovative solutions that are grounded in a multifaceted understanding of the problem at hand.

Authentic Learning Experiences

D&T classrooms are designed to provide learners with authentic learning experiences that mirror the challenges and constraints faced by professional designers and engineers (Atkinson, 2017). By engaging in project-based learning, learners are exposed to the iterative nature of the design process, the importance of user-centred design, and the need to consider factors such as materials, cost, and sustainability (Barlex & Trebell, 2008). These authentic experiences help learners develop a deeper appreciation for the design field and its impact on society. Additionally, the emphasis on real-world applications and constraints encourages learners to think critically about the practical implications of their designs, fostering a more holistic understanding of the design process.

Assessment and Evaluation

The assessment and evaluation of student learning in D&T classrooms are crucial components of the theoretical framework (Kimbell, 2011). Teachers in these settings often use a combination of formative and summative assessments, including portfolios, design presentations, and hands-on projects, to evaluate student progress and provide meaningful feedback (Atkinson, 2017). This holistic approach to assessment helps learners understand their strengths, identify areas for improvement, and develop the skills necessary to become successful designers and problem-solvers. By incorporating both formative and summative assessments, teachers can provide learners with ongoing guidance and support, ensuring that their learning is not just measured, but actively nurtured and developed.

LITERATURE REVIEW

The Concept of Precision in Design and Technology

Precision is a crucial factor in determining the outcome of any product within the field of Design and Technology. The concept encompasses the qualities of correctness, meticulousness, and the capacity to consistently attain desired outcomes (Javidinejad, 2021). Accurate manufacturing is essential for the successful completion of D&T projects. One strategy for improving accuracy is the implementation of computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies (Gaughran 2002). These technologies can enhance the precision of product designs and the subsequent manufacturing processes leading to improved accuracy in the final product (Moalosi 2017). Additionally, the use of digital fabrication tools such as 3D printers and laser cutters can contribute to increased accuracy by reducing the potential for human error (Blikstein 2013). Another approach to improving accuracy is the incorporation of quality control measures throughout the manufacturing process. This may include regular dimensional checks the use of precision measurement tools and the implementation of standardised procedures for each step of the manufacturing process (Gaughran 2002). The use of precision in design not only serves to enhance visual attractiveness but also to assure the optimal operation and efficiency of the product or system. From the above, the researcher problematises the lack of precision and a culture of quality control by learners in IGCSE D&T as fundamental to the manufacturing processes ultimately affecting the outcome (prototype).

Design Processes in Education

Design thinking is a fundamental aspect of the design process, which involves a systematic approach to problem-solving (Razzouk & Shute, 2012). This process typically includes the following steps: empathizing with the user, defining the problem, ideating possible solutions, prototyping, and testing (Koh et al., 2015). In an educational context, design thinking can be applied to a wide range of challenges, from developing innovative learning materials to designing effective classroom layouts (Henriksen et al., 2016). One of the key benefits of incorporating design thinking into education is the emphasis on user-centered design. By focusing on the needs and experiences of learners, teachers can create learning environments and resources that are more engaging and effective (Razzouk & Shute, 2012). The iterative nature of the design process encourages learners to embrace a growth mindset, where failure is seen as an opportunity for learning and improvement (Koh et al., 2015).

The design process in education can also foster creativity and innovation among learners. By engaging in the various stages of design thinking, learners can develop their problem-solving skills, learn to think outside the box, and explore new and innovative solutions to complex challenges (Denson et al., 2015). This approach can be particularly beneficial in STEM (Science, Technology, Engineering, and Mathematics) education, where design thinking can be used to enhance the learning and application of scientific and technological concepts. The integration of design processes in education can help prepare learners for the demands of the 21st-century workforce.

Technology Processes in Education

The integration of technology into educational settings has also become increasingly important. Technology can be used to enhance the learning experience, facilitate collaboration, and provide access to a wealth of information and resources (Denson et al., 2015). Some key technology processes in education include the use of digital tools for research, communication, and content creation, as well as the implementation of learning management systems and online learning platforms (Henriksen et al., 2016). One of the primary benefits of incorporating technology into education is the ability to personalise the learning experience. By leveraging digital tools and resources, teachers can tailor instruction to the unique needs and learning styles of their learners (Denson et al., 2015). Additionally, technology can foster greater collaboration and communication among learners, as well as between learners and teachers (Henriksen et al., 2016).

The use of technology in education can also enhance the accessibility and inclusivity of learning experiences. By providing digital resources and assistive technologies, educators can ensure that all learners, regardless of their abilities or backgrounds, have equal opportunities to engage with the curriculum and develop their skills (Koh et al., 2015). The integration of technology in education can prepare learners for the demands of the digital age. As technology continues to shape the way we live, work, and communicate, learners must develop the necessary digital literacy and technological skills to succeed in the 21st-century workforce (Denson et al., 2015).

The Concept of Streamlining Production in High School D&T

D&T classes in high schools play a crucial role in preparing learners for the ever-evolving world of innovation and manufacturing. Streamlining production involves optimising the manufacturing process to reduce costs, improve efficiency, and ensure the highest quality output. Streamlining production in high school D&T provides learners with practical and experiential learning opportunities. Through the implementation of efficient manufacturing techniques, learners can learn hands-on skills that enable them to problem-solve, think critically, and work collaboratively (Kuo, et al. 2016). Another important aspect of streamlining production is ensuring consistent quality control. Minimising fabrication time is another crucial aspect of enhancing the efficiency of manufacturing processes in D&T classes (Barlex 2017). One strategy for reducing fabrication time is the use of modular design approaches where products are designed in a way that allows for the efficient assembly and disassembly of components (Eggleston 1996). This can streamline the manufacturing process and reduce the overall time required to complete a project. Gaughran (2002) underscores that the implementation of lean manufacturing principles such as the elimination of waste and the optimisation of workflow is key to reducing fabrication time. This may involve the use of just-in-time material delivery the implementation of standardised work practices and the identification and mitigation of bottlenecks in the manufacturing process (Moalosi 2017).

The integration of automation and robotics can also contribute to reduced fabrication time in D&T classes (Blikstein 2013). For example, the use of computer numerical control (CNC) machines or robotic arms can automate certain repetitive or time-consuming tasks freeing up learners to focus on more complex aspects of the manufacturing process. Ndlovu and Nyoni (2017) share the view that the integration of lean manufacturing principles into D&T classes can also contribute to enhancing accuracy and reducing fabrication time. Lean manufacturing emphasises the elimination of waste the optimisation of workflows and the continuous improvement of processes (Mapuranga and Maposa 2018). Mupfiga and Mapuranga (2019) opine that by incorporating these principles into the manufacturing process learners can develop a deeper understanding of efficiency quality control and the importance of systematic problem-solving. This approach can lead to more streamlined fabrication processes reduced errors and increased productivity (Chimedza and Chikwature 2016).

Furthermore, streamlining production in high school D&T helps learners develop skills that are transferable to a wide range of industries. Manufacturing processes are not limited to one field but are applicable across numerous sectors, such as automotive, aerospace, and electronics (Kuo, et al. 2016). It is essential to understand how streamlining production can give learners a competitive edge in the job market by making them versatile and adaptable to different industries. Similarly, streamlining production, in high schools D&T empower learners to become well-rounded individuals capable of contributing to efficient and optimised manufacturing processes (Kuo, et al. 2016). It aligns with the industry-driven approach to education, which emphasises the development of practical skills and knowledge that are directly applicable to the workplace (Denton, 2017). By exposing learners to efficient production methods, they can gain a better understanding of the real-world challenges and best practices that they may encounter in their future careers. Streamlining production can enhance the overall quality of student projects and foster a sense of professionalism. When learners are taught to optimise their design and manufacturing processes, they are more likely to produce high-quality, functional products that meet the specified requirements (Barlex, 2017). This can boost their confidence and prepare them for the rigours of the design and technology industry.

The integration of streamlining production into the high school D&T curriculum can also have a positive impact on the learning environment. By emphasising the importance of efficiency and optimisation, educators can foster a culture of continuous improvement, where learners are encouraged to critically analyse their work, identify areas for enhancement, and implement solutions. This mindset can not only benefit their design and manufacturing skills but also their overall problem-solving abilities, which are highly valued in the industry.

Challenges faced in implementing effective manufacturing processes in D&T

a. Lack of Funding and Resources

One of the primary challenges in implementing effective manufacturing processes in D&T high school classrooms is the lack of adequate funding and resources (Hope, 2015). High-quality manufacturing equipment, tools, and materials can be expensive, and many schools struggle to allocate sufficient budgets to acquire and maintain these necessary resources (Barlex, 2007). This lack of funding can limit the range of manufacturing processes that can be taught, as well as the quality of the learning experience for learners.

b. Material Availability and Properties

Extending from the above, Makoni and Mudavanhu (2019) suggest another often neglected constituent in design and manufacturing, that is material selection.

They allude that the importance of material selection and its impact on the accuracy and efficiency of the manufacturing process cannot be overemphasised. Chimedza and Chikwature (2016) hint that studies have shown that the inherent properties of different materials such as wood metal and polymers can significantly influence the ease of manipulation the precision of shaping and the overall fabrication time. Similarly, Ndlovu and Nyoni (2017) reason that by developing a comprehensive understanding of the unique characteristics of these materials teachers can guide learners in selecting the most appropriate materials for their projects ultimately enhancing the accuracy and reducing the time required for the manufacturing process. In addition to material selection the incorporation of smart materials into D&T curricula has the potential to revolutionise the manufacturing process (Mapuranga and Maposa 2018). Mupfiga and Mapuranga (2019) support the inclusion of smart materials citing that they (smart materials such as shape-memory alloys and piezoelectric materials) possess the ability to respond to external stimuli allowing for greater control and precision during the fabrication stage. Similarly, Chimedza and Chikwature (2016) infer that by integrating the use of these advanced materials into D&T classes learners can explore innovative solutions and develop a deeper understanding of the relationship between material properties and product design.

c. Insufficient Teacher Expertise and Training

Effective implementation of manufacturing processes in D&T classrooms requires teachers to have a deep understanding of the relevant technologies and techniques (Hope, 2015). However, many D&T teachers may not have received comprehensive training in these areas during their pre-service education or ongoing professional development (Barlex, 2007). This lack of expertise can make it challenging for teachers to effectively teach and demonstrate manufacturing processes, as well as to troubleshoot issues that may arise during practical activities. Henceforth, the role of effective instructional strategies and teacher professional development cannot be overlooked as alluded to by Bester and Bester (2016).

Dube and Mapfumo (2018) hint that teachers who are well-versed in the latest techniques technologies and best practices in D&T education are better equipped to guide their learners towards achieving greater accuracy and efficiency in the manufacturing process. Makoni and Mudavanhu (2019) buttress the significance of andragogy and professional development (PD) programmes in D&T in their submission that by engaging in continuous learning and collaboration teachers can stay abreast of industry trends share knowledge and implement innovative teaching methods that cater to the diverse needs of their learners. Hahlani et al (2023) shared the same sentiments on the significance of PD in D&T classrooms as it serves as the stepping stone to bridge the classroom and industry. Technology andragogy aids in the delivery of 21st content in high school classrooms which is critical to effective engagements. It is from the exposure to the world of work, field trips and industrial visits that teachers can dispel or teach complex industrial processes (Hahlani et al 2023).

d. Technological Advancements and Rapidly Changing Landscape

The manufacturing landscape is continuously evolving, with the introduction of new technologies, materials, and techniques (Hope, 2015). Keeping up with these advancements and ensuring that the curriculum and teaching practices remain relevant can be a significant challenge for D&T teachers (Barlex, 2007). This requires ongoing professional development, curriculum updates, and the acquisition of new equipment and resources. Furthermore, Bester and Bester (2016) submit that the implementation of digital fabrication technologies such as 3D printing and computer-aided design (CAD) software has been identified as a promising approach to enhance accuracy and reduce fabrication time. Dube and Mapfumo (2018) echo this submission indicating that these technologies enable learners to create precise digital models which can then be translated into physical products with remarkable precision and consistency. Having said that, Makoni and Mudavanhu (2019) opine that by familiarising learners with these digital tools and techniques teachers can empower them to navigate the design and manufacturing process more efficiently ultimately improving the overall quality and consistency of their manufactured products.

Strategies to minimise production time in product fabrication in D&T.

Ding et al. (2021) recommend a promising approach to D&T which is the integration of advanced manufacturing technologies such as computer numerical control (CNC) machining. CNC technology allows for precise and consistent cutting shaping and drilling of wood and metal components leading to improved accuracy and reduced manual intervention (Ghani et al. 2021). From the research, Kang et al. (2020) submit that by automating various production steps CNC machining can significantly streamline the fabrication process ultimately decreasing the overall production time.

Another strategy to enhance accuracy and minimise production time is the implementation of lean manufacturing principles (Belekoukias et al. 2014). According to Womack & Jones's (2003) submission, lean manufacturing emphasises the elimination of waste streamlining of processes and continuous improvement. This approach to manufacturing bonds well with Belekoukias et al. (2014) research which highlights that by identifying and addressing inefficiencies in the production workflow manufacturers can optimise their operations leading to increased accuracy and reduced lead times. More so, the concept of additive manufacturing explained by Huang et al. (2015) indicates that the adoption of additive manufacturing (AM) or 3D printing technology can also contribute to enhancing accuracy and minimising production time. AM allows for the direct fabrication of complex customised wood and metal-based products without the need for traditional tooling or moulds (Huang et al. 2015). This approach can significantly reduce the time and resources required for product development leading to faster turnaround times and increased accuracy (Gao et al. 2015).

Furthermore, the utilisation of simulation and modelling software can also play a crucial role in improving the accuracy and production time of wood and metal-based products (Mani et al. 2014). These digital tools enable designers and manufacturers to virtually prototype and test their designs identifying and addressing potential issues before the physical fabrication process (Mani et al. 2014). Mani et al. (2014) underscore that by optimising the design and production parameters through simulation manufacturers can enhance the accuracy of their products and streamline the fabrication workflow. This is key, especially in the 21st-century learning landscape. Similarly, the implementation of quality control and inspection processes can contribute to enhancing the accuracy of wood and metal-based products. Therefore, learners must address quality issues at various stages of the production process manufacturers to ensure the accuracy of their products and minimise the need for rework or waste.

Strategies to improve the teaching and learning of D&T

Barlex, (2007) and Hope, (2015) propose that to address the challenges faced in implementing effective manufacturing processes in D&T high school classrooms, a multifaceted approach is necessary. Increased funding and resources from educational authorities and policymakers can help provide schools with the necessary equipment, tools, and materials to support hands-on learning (Dube and Mapfumo 2018). Comprehensive teacher training programs, both during pre-service education and through ongoing professional development, can equip teachers with the knowledge and skills required to effectively teach and demonstrate manufacturing processes.

In addition to the strategies mentioned above the continuous training and upskilling of the workforce, that is the teachers and technicians can also play a significant role in enhancing accuracy and minimising production time. Providing teachers ultimately the learners with comprehensive training on the latest manufacturing techniques quality control measures and problem-solving skills can empower them to make informed decisions identify and address issues more efficiently and contribute to the overall improvement of the production process. More so, Ndlovu and Nyoni (2017) submit that accuracy and prolonged fabrication time in the manufacturing of wood metal polymer and smart-material-based products within private high school D&T classes in Zimbabwe is a multifaceted challenge. Mapuranga and Maposa (2018) infer that through a comprehensive understanding of material properties the integration of smart materials and digital fabrication technologies the application of lean manufacturing principles and the ongoing professional development of teachers the educational landscape can be transformed into a better equipped Zimbabwean learners with the skills and knowledge necessary to excel in the field of design and technology.

a. Integrating Hands-On Learning Experiences

One of the key strategies to improve the teaching and learning of D&T is the integration of hands-on learning experiences (Denton, 2017). This approach allows learners to actively engage in the design and production process, fostering a deeper understanding of the subject matter. By providing opportunities for learners to work with various materials, tools, and techniques, they can develop practical skills and a better grasp of the design and manufacturing process (Gentry, 2020). Incorporating project-based learning, where learners work on real-world design challenges, can further enhance their understanding and application of D&T concepts.

b. Promoting Collaborative Learning

Collaboration is another effective strategy for enhancing the teaching and learning of D&T (Benson, 2019). By encouraging learners to work in teams, they can learn from each other, share ideas, and develop communication and problem-solving skills. This collaborative approach can be particularly beneficial in the context of product design and realisation, as it allows learners to learn from their peers, share their expertise, and work together to solve complex design problems (Denton, 2017).

c. Incorporating Digital Technologies

The integration of digital technologies in D&T education is another crucial strategy for improvement (Gentry, 2020). The use of computer-aided design (CAD) software, 3D printing, and other digital tools can help learners visualise their designs, prototype their ideas, and gain a better understanding of the manufacturing process. Additionally, the use of digital technologies can enhance the learning experience by providing learners with access to a wider range of resources, such as online tutorials and design databases (Benson, 2019).

d. Emphasising Design Thinking

Design thinking is a problem-solving methodology that can be effectively incorporated into the teaching and learning of D&T (Denton, 2017). By emphasising the iterative nature of the design process, including empathising with users, defining the problem, ideating solutions, prototyping, and testing, learners can develop a more holistic understanding of product design and realisation. This approach can help learners think critically, be more creative, and better understand the needs of the end-user.

e. Providing Relevant and Engaging Curriculum

Ensuring that the curriculum is relevant, up-to-date, and engaging is another important strategy for improving the teaching and learning of D&T (Benson, 2019). By aligning the content with current industry trends, technological advancements, and the needs of the local community, the subject matter becomes more meaningful and applicable to learners. Additionally, incorporating real-world case studies, guest speakers, and field trips can help learners connect theoretical concepts to practical applications (Denton, 2017).

f. Fostering Continuous Professional Development for Educators

Lastly, the professional development of D&T educators is crucial for improving the teaching and learning of this subject area (Gentry, 2020). Providing teachers with opportunities to update their knowledge, skills, and teaching strategies can help them better engage learners, adapt to new technologies, and deliver more effective lessons (Benson, 2019). This can involve workshops, training programs, and collaborative learning opportunities that enable educators to share best practices and stay informed about the latest developments in the field.

METHODOLOGY

The study adopted the qualitative research approach. The study explored the perspectives and experiences of both teachers and learners at the three selected private schools in Marondera. Purposive sampling was used to select the schools, with the criteria of teaching IGCSE D&T at their school. The six D&T teachers were interviewed; two from each school with at least fifteen years teaching the IGCSE level D&T subject. An observation checklist was used adjunct to interviews and they enabled the study to compare the notes and themes from the observation with findings from the interviews. This triangulation of data sources was important to check the accuracy of the interpretations. Direct observation of manufacturing classes provided valuable insights into the practical implementation of these processes. Existing finished prototypes within the five-year examination cycle were randomly analysed against the portfolio write-up and working drawings to establish links between the manufacturing processes and the outcomes. The scaled prototypes were analysed, and evaluated for fitness of purpose against the Cambridge Assessment International Education (CAIE) demands.

Ethical Issues

The research utilised pseudonyms and the strict confidentiality of the participants was upheld.

DISCUSSION OF FINDINGS

Cambridge Staff Development Courses on D&T Syllabus

Teachers had this to say;

Response 1: "Yes, I have attended several Cambridge staff development courses over the years, and I can say with confidence that they have been invaluable in enhancing my teaching of the Design and Technology syllabus. One of the most significant benefits of these courses has been the opportunity to engage with experts in the field and learn from their experiences… "

Response 2: "These courses have provided me with the opportunity to stay up-to-date with the latest trends, technologies, and pedagogical approaches in the field. I have learned how to effectively incorporate project-based learning and design thinking strategies into my lessons…"

The responses provided by the D&T teachers highlight several key themes regarding the impact of attending Cambridge staff development. That is pedagogical advancement, technological integration, networking and collaboration, and a comprehensive understanding of the syllabus. The teachers expressed that the courses further helped them develop a more comprehensive understanding of the D&T syllabus and how to best approach its various components. This has enabled them to deliver a more well-rounded and effective learning experience for their learners.

Learners Streaming or Mixed Ability

The debate around streaming or mixed-ability teaching is a longstanding issue in the field of education. D&T teachers play a crucial role in shaping the learning experiences of their learners, and their perspectives on this topic can provide valuable insights.

One D&T teacher responded by stating that they stream their learners based on their academic abilities. This approach involves grouping learners into different classes or groups based on their perceived level of academic performance (Ireson & Hallam, 2021). The teacher argued that streaming allows them to tailor their teaching methods and content to the specific needs of each group, ensuring that all learners receive the appropriate level of support and challenge. The teacher further explained that streaming enables them to focus on the strengths and weaknesses of each group, allowing them to provide more targeted interventions and support. They also suggested that streaming can foster a sense of belonging and confidence among learners, as they are surrounded by peers of similar abilities (Hallam & Ireson, 2022).

Alternatively, another D&T teacher responded by stating that they teach their learners as a mixed-ability group. This approach involves teaching learners with varying levels of academic abilities in the same classroom (Boaler, 2022). The teacher argued that mixed-ability teaching promotes inclusivity and diversity, allowing learners to learn from each other and develop a greater understanding of their strengths and weaknesses. The teacher also further explained that mixed-ability teaching encourages collaboration and peer-to-peer learning, where more capable learners can assist and support their peers. He also suggests that this approach helps to challenge high-achieving learners while providing additional support for those who may be struggling, ultimately leading to a more well-rounded and inclusive learning environment (Boaler, 2022).

While the responses from the teachers present different approaches, a thematic analysis reveals the key themes and implications of these perspectives, which can inform educational policies and practices to ensure that all learners, regardless of their academic abilities, have the opportunity to thrive and succeed. Firstly, there is an issue of differentiation and personalised learning**.** The teacher who supports streaming argues that it allows for more targeted interventions and support, while the teacher who advocates for mixed-ability teaching emphasises the benefits of peer-to-peer learning and a more inclusive approach. Secondly, student confidence and belonging. Thirdly, equity and inclusivity. The mixed-ability teaching approach emphasises the importance of equity and inclusivity, where all learners, regardless of their academic abilities, are provided with equal opportunities to learn and grow. This aligns with the principles of inclusive education, which aim to ensure that all learners, including those with diverse learning needs, can participate and thrive in the educational system (UNESCO, 2020). Fourthly, Collaboration and Peer-to-Peer Learning. The teacher who supports mixed-ability teaching highlights the benefits of collaboration and peer-to-peer learning, where learners can learn from each other and develop a greater understanding of their strengths and weaknesses. This approach is supported by research that suggests that collaborative learning can lead to improved academic outcomes and social-emotional development (Johnson & Johnson, 2009).

Causes of Inaccuracy in the Realisation of Models or Prototypes

The accurate realisation of wood or metal-based products, whether models or prototypes, is a critical aspect of the learning process in D&T education. Understanding the factors that contribute to inaccuracy in these realisations can provide valuable insights for educators, learners, and the broader educational community.

Response 1: Lack of Precision in Measuring and Marking One of the primary causes of inaccuracy in the realisation of wood or metal-based products, as identified by the D&T teachers at school Z, is the lack of precision in measuring and marking. One of the teachers had to say,

"Accurate measurements and precise marking are essential for ensuring the correct dimensions and proportions of the final product. However, learners may struggle with these fundamental skills due to a variety of reasons, such as lack of experience, poor hand-eye coordination, or insufficient attention to detail."

He also highlighted that,

"Learners often rush through the measuring and marking process, leading to errors that are then propagated throughout the production stages.

Additionally, the use of inappropriate or inaccurate measuring tools, such as worn-out rulers or callipers, can contribute to the problem."

It can be noted that the teacher emphasised the importance of instilling in learners the importance of meticulous measurement and marking techniques and providing them with high-quality tools to ensure precision.

Response 2: Inadequate Skill Development in Woodworking or Metalworking Techniques Another significant cause as identified by the D&T teachers at school X, is the inadequate development of woodworking or metalworking skills among the learners.

They note,

"Manufacturing accurate and functional products requires a range of specialised techniques, such as cutting, shaping, joining, and finishing, which can be challenging for learners to master"

The teachers also noted that many learners lack the necessary hand-eye coordination, dexterity, and muscle memory required to execute these techniques with precision. This can lead to issues such as uneven cuts, misaligned joints, or surface imperfections, ultimately resulting in inaccurate final products. The teachers emphasised the importance of providing learners with ample opportunities to practice and develop their woodworking or metalworking skills, as well as ensuring that they receive proper instruction and guidance from experienced educators. A thematic analysis reveals, firstly the importance of precision. Secondly, skill development and practice. The responses underscore the importance of providing learners with ample opportunities to develop and refine their woodworking or metalworking skills through extensive practice and guidance from experienced educators. The teachers recognise that these skills are not innate and require intentional cultivation. Thirdly is attention to detail. The responses suggest that inaccuracy in product realisation is often a result of a lack of attention to detail, whether in the measuring and marking process or the execution of specific techniques. Fourthly, tool quality and maintenance. Ensuring that learners have access to high-quality, well-maintained tools is crucial for achieving precise and consistent results. The theme aligns with the findings of Isiaka (2017), who emphasises the importance of tool handling and maintenance in ensuring the accuracy of the final product. Badiru and Ayeni (2016) also underscore the impact of poorly maintained tools on the manufacturing process, which can lead to inconsistencies and inaccuracies. Mayank (2017) and Kruwa (2022) highlight the critical role of accurate measurement and marking in achieving the desired dimensions and alignment of the final product.

The use of CAD/ CAM

The use of computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies has become increasingly prevalent in the field of product design, offering numerous benefits in terms of efficiency, precision, and innovation. However, the potential impact of these technologies on the accuracy of product design outcomes has been a topic of ongoing discussion and debate.

Responses from D&T Learners

Response 1:

“These technologies allow for precise measurements, detailed 3D modelling, and the ability to simulate and test designs before the physical production."

This response suggests that the use of CAD/CAM can enhance the accuracy of product design outcomes. This aligns with the findings of several scholars who have emphasised the advantages of these technologies in improving design precision and reducing manufacturing errors. For instance, Agrawal and Sharma (2015) highlight how CAD/CAM tools enable designers to create highly accurate 3D models, which can then be used to generate precise manufacturing instructions and minimise the risk of defects. Similarly, Sharma and Gao (2018) argue that the integration of CAD/CAM in the design process can lead to increased product quality and reduced production costs.

However, some researchers have also cautioned that the reliance on CAD/CAM alone does not guarantee accurate product design outcomes. Peng and Gu (2014) suggest that the accuracy of CAD/CAM-based design is heavily dependent on the quality of the input data, the capabilities of the software, and the expertise of the designer. Additionally, Zheng et al. (2019) emphasise the importance of considering human factors, such as the designer's understanding of the design requirements and their ability to interpret the CAD/CAM outputs, in ensuring the accuracy of the final product.

Response 2:

"While CAD/CAM can certainly improve the accuracy of product design in many cases, I believe it can also introduce new sources of error if not used properly. For example, if the designer has limited knowledge of the software or fails to properly validate the digital model, the final product may not accurately reflect the intended design.”

This response acknowledges the potential benefits of CAD/CAM in enhancing design accuracy but also highlights the risks associated with improper use of these technologies. This perspective aligns with the findings of several scholars who have emphasised the importance of user competence and proper implementation of CAD/CAM systems.

Joshi and Deshpande (2017) argue that the effective use of CAD/CAM requires a deep understanding of the software's capabilities and limitations, as well as the ability to critically evaluate the digital models and simulations. Similarly, Nee and Ong (2013) stress the need for designers to develop strong analytical and problem-solving skills to ensure that the CAD/CAM outputs accurately represent the intended design.

Additionally, Sharma and Gao (2018) suggest that the integration of CAD/CAM in the design process can introduce new sources of error, such as data transfer issues, software compatibility problems, and the potential for human error in interpreting digital outputs. Addressing these challenges requires a comprehensive approach to training, software selection, and design validation.

Response 3:

"I think the impact of CAD/CAM on product design accuracy can be quite variable, depending on the specific design requirements and the complexity of the product."

This response suggests that the impact of CAD/CAM on product design accuracy can vary depending on the complexity and customisation requirements of the product.

Peng and Gu (2014) argue that the effectiveness of CAD/CAM in improving design accuracy is largely dependent on the complexity of the product and the specific design requirements. For simple, standardised products, the use of CAD/CAM can indeed enhance accuracy by automating the design and manufacturing processes. However, for more complex, customized designs, the designer’s creativity, problem-solving skills, and ability to interpret the CAD/CAM outputs may play a more significant role in ensuring accurate outcomes.

Similarly, Zheng et al. (2019) emphasise the importance of considering the designer’s cognitive abilities and decision-making processes in the context of CAD/CAM-based design. They suggest that for highly complex or innovative designs, the designer’s intuition, experience, and problem-solving skills may be crucial in identifying and addressing potential sources of error that may not be readily apparent in digital models.

Response 4:

“I believe that the use of CAD/CAM can have both positive and negative impacts on product design accuracy, depending on how these technologies are integrated into the design process. On one hand, CAD/CAM can enhance accuracy by enabling precise measurements, detailed modelling, and virtual testing. On the other hand, if designers become overly reliant on these technologies and fail to critically evaluate their outputs, it can lead to a loss of hands-on skills and intuitive understanding of the design, which may ultimately compromise the accuracy of the final product.”

This response recognises the dual-edged nature of CAD/CAM in terms of its impact on product design accuracy. It acknowledges the benefits of these technologies in enhancing precision and testing capabilities, while also highlighting the potential risks associated with overreliance on digital tools and the loss of hands-on skills and intuitive understanding. Joshi and Deshpande (2017) argue that while CAD/CAM can improve the efficiency and accuracy of the design process, it is essential for designers to maintain a balance between digital and physical design methods to ensure a comprehensive understanding of the design requirements and constraints.

Similarly, Nee and Ong (2013) emphasise the importance of developing a hybrid approach that combines the strengths of CAD/CAM with the designer’s intuitive problem-solving abilities and hands-on experience. They suggest that this approach can lead to more accurate and innovative product designs by leveraging the complementary strengths of digital and traditional design methods.

Workshop Tools and Equipment Manipulation

D&T education plays a crucial role in equipping learners with practical skills and problem-solving abilities. One aspect of this curriculum is the understanding and manipulation of various tools and equipment in the workshop to realise project (artefact) goals. When asked the interview question "Do you think you have understood the various tools and equipment manipulation in the workshop to realise your project (artefact) without close help?” D&T learners provided diverse responses.

These were recorded as follows;

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Response 1:

"Yes, I believe I have a good understanding of the various tools and equipment in the workshop, and I can use them effectively to complete my project without close supervision."

This response suggests a high level of confidence in the learner's ability to manipulate workshop tools and equipment. This aligns with the findings of Barlex and

Steeg (2018) who emphasise the importance of developing learners' self-efficacy and autonomy in D&T education. They argue that when learners feel confident in their skills, they are more likely to engage actively in the learning process and take ownership of their projects.

However, this response may also indicate a potential overestimation of the learner's abilities. Kimbell and Stables (2008) caution that some learners may struggle to accurately assess their competencies, leading to unrealistic expectations. Educators must provide ongoing support and guidance to ensure that learners develop a realistic understanding of their skills and limitations.

Response 2:

"I'm still learning and developing my skills in using the various tools and equipment in the workshop. I think I can manage most tasks, but I would appreciate some guidance and support from the teacher."

This response suggests a more nuanced understanding of the learner's abilities, acknowledging the need for continued learning and support. This aligns with the views of Dakers (2005), who emphasises the importance of scaffolding in D&T education. Dakers argues that learners require structured support and guidance to gradually develop their skills and confidence in using workshop tools and equipment. This response also reflects the findings of Barlex and Steeg (2018), who note that D&T education should foster a growth mindset in learners, where they are encouraged to view challenges as opportunities for learning and improvement, rather than as failures.

Response 3:

"No, I don't think I have a good understanding of the various tools and equipment in the workshop. I'm still struggling to use them effectively, and I would need close help from the teacher to complete my project."

This response indicates a lack of confidence in the learner's ability to manipulate workshop tools and equipment. This aligns with the research of Kimbell and Stables (2008), who found that some learners may experience anxiety or frustration when working with unfamiliar tools and equipment, which can hinder their learning and progress. In this case, the learner's acknowledgement of their limitations and need for support is a positive step. Educators should respond to this by providing targeted interventions and scaffolding to help the learner develop the necessary skills and confidence.

Response 4:

"I have a basic understanding of the tools and equipment in the workshop, but I'm not sure if I can use them effectively to complete my project without close help. I would need to practice more and receive feedback from the teacher."

This response suggests a more moderate and realistic assessment of the learner's abilities. It aligns with the views of Kimbell and Stables (2008), who emphasise the importance of developing learners' metacognitive skills, enabling them to assess their strengths and flaws accurately. The learner's acknowledgement of the need for further practice and feedback from the teacher reflects the findings of Barlex and Steeg (2018), who highlight the importance of providing learners with opportunities for active engagement, experimentation, and reflection in D&T education.

The learner's responses can be analysed through the lens of several key themes like self-assessment and metacognition. The responses range from overconfidence to realistic self-assessment, highlighting the importance of developing learners' metacognitive skills (Kimbell & Stables, 2008). Scaffolding and support: the responses indicate varying levels of need for scaffolding and support from teachers, emphasising the importance of tailored interventions and guidance (Dakers, 2005).

Growth mindset and learning progression: the responses reflect different stages of learning, with some learners demonstrating a growth mindset and openness to improvement, while others may struggle with anxiety or frustration (Barlex & Steeg, 2018). From this, it is, therefore, important that learners need to be guided and channelled to pursue realistic topics for coursework. Overconfidence in ambitious project topics that are beyond the scope of the learner must be discouraged or a more practical topic must be settled for in the situation discovery stage. This will improve their chances of meeting the deadlines and completing the coursework portfolios. Practical skills and confidence: the responses highlight the diverse levels of practical skills and confidence in using workshop tools and equipment, underscoring the need for targeted skill development and opportunities for hands-on practice (Barlex & Steeg, 2018).

Further analysis of the responses reveals the complex and nuanced nature of D&T learners' perspectives. Educators should be attuned to learners' diverse needs and perspectives and provide tailored support and guidance to foster their success in realising design projects. D&T teachers continue to need PD to manage the diversity of learners who need customised scaffolding and support to realise their projects. Some learners, are too shy to explain themselves and would need the teacher to involve and include them in the demonstrations.

Psychomotor Development in Workshop Processes

Psychomotor development is a crucial aspect of education, particularly in workshop-based learning environments.

Demonstration – Motor Skills and Movement Concepts

The first observation focused on the demonstration of motor skills and movement concepts in the workshop setting. Researchers have found that effective demonstration of these skills can significantly enhance student learning and skill acquisition (Magill & Anderson, 2017). In the present study, it was observed that teachers who employed clear, step-by-step demonstrations, coupled with verbal explanations, were able to facilitate better understanding and retention of the targeted motor skills among learners. Furthermore, the study revealed that teachers who emphasised the importance of proper body positioning, weight distribution, and fluid movements during demonstrations were more successful in helping learners develop a deeper understanding of the underlying movement concepts. This approach allowed learners to internalise the essential elements of the task, leading to more efficient and accurate performance.

Lathe-work Manipulative Skills

The second observation focused on the development of lathe-work manipulative skills among workshop participants. The study found that learners who received structured, hands-on practice with the lathe, guided by teachers who provided timely feedback and corrective measures, demonstrated a more rapid progression in their manipulative skills. Additionally, the research revealed that learners who were encouraged to experiment and explore different techniques, while maintaining a focus on safety protocols, were more likely to develop a deeper understanding of the underlying principles of lathe operation (Magill & Anderson, 2017). This approach fostered a sense of ownership and mastery, which in turn motivated learners to continue refining their skills.

Drilling and Brazing Manipulative Skills

The third observation centered on the development of drilling and brazing manipulative skills in the workshop setting. The study found that learners who received explicit instruction and demonstration on proper drilling and brazing techniques, combined with ample opportunities for hands-on practice, exhibited a more consistent and accurate performance compared to those who did not receive such targeted instruction. Furthermore, the research revealed that learners who were encouraged to troubleshoot and problem-solve during the drilling and brazing processes developed a more comprehensive understanding of the underlying principles and were better equipped to adapt to various situations. This approach not only enhanced their manipulative skills but also fostered critical thinking and problem-solving abilities.

Bench-work (Tool) Manipulative Skills

The fourth observation focused on the development of bench work (tool) manipulative skills in the workshop environment. The study found that learners who received explicit instruction and demonstration on the proper use and maintenance of various workshop tools, such as vices, hammers, and files, were more adept at executing precise and efficient bench work tasks. Additionally, the research revealed that learners who were encouraged to experiment with different tools and techniques, while maintaining a focus on safety protocols, were more likely to develop a deeper understanding of the underlying principles of effective bench work, this bonds well with the research finding of Magill & Anderson, (2017). This approach fostered a sense of exploration and creativity, which in turn motivated learners to continue refining their manipulative skills.

The findings from this study align with the existing literature on the importance of effective demonstration, hands-on practice, and problem-solving in the development of psychomotor skills in workshop settings (Magill & Anderson, 2017; Schmidt & Lee, 2019). The observations highlight the critical role of teachers in providing clear, step-by-step demonstrations, emphasising proper body positioning and movement concepts, and offering timely feedback and corrective measures to support student learning and skill acquisition. The findings also highlight the importance of effective demonstration, hands-on practice, and problem-solving in the development of motor skills and movement concepts, lathe work, drilling and brazing, and bench work manipulative skills. The insights gained from this study can inform educational practices and contribute to the ongoing development of effective workshop-based learning environments. Furthermore, the study underscores the value of encouraging learners to experiment, explore, and troubleshoot during the learning process. This approach not only enhances their manipulative skills but also fosters critical thinking, problem-solving, and a sense of ownership and mastery over the subject matter in D&T classrooms.

CONCLUSION

The reflection from this research has highlighted the potential impact of social and collaborative aspects on extended production times. Learners who engage in collaborative activities or receive peer support and feedback tend to be better equipped to overcome challenges and complete their tasks more efficiently. There is a need to incorporate opportunities for peer collaboration and feedback as a strategy for addressing extended production times. D&T professionals should consider the appropriate level of complexity for the learners' abilities and provide scaffolding or additional support to help them navigate the production process more efficiently. It also surfaced that D&T educators need to prioritise the development of core competencies, such as material science, tool operation, and quality control, to provide learners with a solid foundation for efficient fabrication. Secondly, instructional approaches must be aimed at focusing on teaching learners how to analyse and optimise the entire fabrication process, rather than solely concentrating on individual steps in the realisation. This holistic understanding can help learners identify and address bottlenecks, streamline workflows, and minimise fabrication time. The findings also emphasised the urgent need to rigorously review the D&T Curriculum and endeavour to enhance prior knowledge and skills, manage task complexity, develop time management and self-regulation abilities, foster motivation, provide effective instructional support and feedback, optimising the learning environment, accommodating individual differences, and leveraging social and collaborative aspects. This will ensure that educators can better support learners in completing their production tasks more efficiently and within the expected timeframe.

RECOMMENDATIONS

The following recommendations are proposed to improve the learning of manufacturing processes in this context:

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- **Integrate hands-on, practical learning experiences**

Incorporate more practical workshops and onsite (industrial) sessions to allow students to actively engage with and apply their knowledge of manufacturing processes.

- **Utilise multimedia and interactive resources**

Employ visual aids, animations, and interactive simulations to enhance the understanding of complex manufacturing concepts.

- **Encourage collaborative learning**

Foster group-based projects and discussions to promote peer-to-peer learning and the exchange of ideas.

- **Provide relevant and up-to-date curriculum**

Regularly review and update the curriculum to ensure it aligns with industry trends and technological advancements in manufacturing

- **Invest in modern equipment and facilities**

Ensure that the school has access to well-equipped workshops and state-of-the-art manufacturing equipment to provide students with a realistic learning environment.

- **Strengthen industry partnerships**

Establish partnerships with local manufacturing companies to facilitate internships, site visits, and guest speaker sessions, providing students with real-world insights.

- **Provide comprehensive teacher training**

Offer ongoing professional development opportunities for teachers to enhance their knowledge and pedagogical skills in teaching manufacturing processes.

- **Implement continuous assessment and feedback**

Develop a comprehensive assessment strategy that includes formative and summative evaluations, allowing for timely feedback and continuous improvement in the learning process.

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