Developing a Curriculum for Practical Skills-Based Pedagogy in Engineering Education: [A Skills-Driven Teaching and Learning Approach for job Transition Pathways Applicable in Engineering Training and Development for a University of Technology]

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Abstract: The onset of the COVID-19 pandemic has necessitated a shift in focus for graduate engineering students, demanding their swift integration into the workforce. The Engineering Council of South Africa now stipulates that institutions must cultivate specific graduate attributes, particularly in the face of rapid economic and social transformations. This mandate prompts universities to equip engineers with the skills needed to seamlessly adapt to scarce skill positions and emerging roles within diverse disciplines dictated by industry demands. The evolving landscape is shaped by emerging technologies impacting production, manufacturing, and service sectors. Consequently, engineering graduates must acquire skills that facilitate a smooth transition into roles that align with their expertise. The imperative for universities is to fulfill the core mission of engineering education: fostering professionals capable of developing future technology to address upcoming challenges and produce technologists adept at solving present issues using current technology. This study employs a qualitative research method to explain and explore the training of engineers, ensuring that graduates possess the requisite attributes for a successful transition into new occupational roles aligned with industry needs. The focus of the research centers on analyzing the teaching interventions implemented in Industrial Engineering undergraduate programs at a university of technology.

Keywords: Engineering, Skills, Technology, Covid19, Education

1. Introduction

There is evidence that blended classroom models can be effective only when the online elements are active rather than passive, according to a 2010 Department of Education report, undergraduate students in blended classroom settings had better assessment outcomes than purely online or face-to-face classes (Panda, 2014). The reason is that blended courses in which the students spend their time online solving problems, moving through the material at their own pace, and spending half of the class time in the online component of the class, have more positive learning impacts than both face-to-face only and purely online only (Allen, 1992).

Engineering education academics have always explored innovative teaching techniques, and few instructional approaches developed entirely in engineering have achieved widespread acceptance. One that has is cooperative education, which was started at the University of Cincinnati in 1906 (Grayson, 1993). Cooperative programs in which students alternate semesters in school and periods of working in industry continue to be a popular option in engineering education. Another innovation that attracted widespread interest was adaptive digital game-based learning (DGBL). Adaptive DGBL teaching and learning techniques have many similarities to problem-based learning, but it is more structured and relies more on computer technology (Arnab et al., 2012).

The utilization of gaming platforms is not cutting edge in education any longer, but from the perspective of an online distance electronic learning (ODeL) institution in South Africa, it is still a few years from becoming the main attraction and common practice in the lecture rooms, as postulated by Bawden & Robinson (Bawden & Robinson, 2012). Online and large-scale multiplayer educational games are being used in coursework curricula to leverage the best skills and techniques required from graduates by industry (Arnab et al., 2012). The best game theory in education leverages teamwork, leadership, discovery, and tenacity, and these games are social networking games that compel students to create solutions for real-world challenges (Barseghian, 2012).

The largest distance education (DE) institution in South Africa acknowledges the fact that the generation of students enrolled in the university has changed from working adults to young, fresh-out-of-high school students. This new group of students comprises a large percentage of restless digital natives, who spend a big portion of their time online. In this changing teaching and learning (T&L) paradigm, the university has invested resources in figuring out how to use traditional engineering educational content for T&L in a game-based setting.

In this rapidly changing education environment, engineering technology education in a DE setting has to be true to its mission. The mission of technology education is to produce technicians and operators to work with current technology, while that of engineering education is to produce engineers to develop the next generation of technology. While related to engineering in many respects, engineering technology is more hands-on, and thus DGBL is more relevant for teaching and learning in technology education. Therefore, a system with the ability to adapt intelligently to goals, tasks, interests, and other features of individuals and groups of users, is an ideal engineering technology education medium.

Studies have shown that the more students work in cooperative learning groups the more they learn, the better they understand what they are learning, the easier it is for them to remember what they learn, and the better they feel about themselves, the class, and their classmates (Johnson et al., 1998c). Springer et al. (1999) meta-analyzed the research for college-level science, engineering, and technology and found significant effects on students' persistence and achievement in these fields and positive attitudes toward their education.

It is an undeniable fact, especially in DE, that it is no longer possible to treat all students in the proliferating range of e-learning users with very different prior knowledge, backgrounds, learning styles, interests, and preferences, with the one-size-fits-all approach. An educational online system with the ability to adapt intelligently to the goals, tasks, interests, and other features of individuals and groups of users, is mission critical for an online DE environment. Thus, in an attempt to bridge the gap between pedagogy and technology, the potential of new technologies should be used as a means to enhance Teaching and Learning.

An Online Distance Electronic Learning (ODeL) institution provides opportunities for working individuals who are engaged in other things but are keen to acquire a qualification or improve their skill levels through academic interventions. ODeL is a best-fit T&L paradigm for DE because an e-learning framework seeks to establish an environment where students start fast with their learning activity by capitalizing on their downtime and periods of time during which they are not constructively engaged (e.g., riding a bus; waiting in a queue; during lunch and breaks) (Bawden & Robinson, 2012) and (Bommarito, 2014). In an ODeL institution, access is given to all potential students with different competencies of the basic engineering modules such as mathematics and science. Some students have poor grades, while others have very good grades, thus an adaptive T&L strategy is critical.

2. Literature Review

In the realm of engineering education, scholars have long been dedicated to exploring creative teaching methodologies. While numerous instructional approaches have been developed within the field, only a handful have achieved widespread recognition. One such approach is cooperative education, which originated at the University of Cincinnati in 1906, as documented by Grayson in 1993. Cooperative programs, where students alternate between academic semesters and industry work periods, have maintained their popularity within the field of engineering education. Another notable innovation that has garnered considerable interest is adaptive digital game-based learning (DGBL) (Beavis et al., 2015). This approach shares certain similarities with problem-based learning but distinguishes itself through its higher degree of structure and greater reliance on computer technology.

The integration of gaming platforms into education is no longer considered groundbreaking. However, when observed through the lens of an online distance electronic learning (ODeL) institution in South Africa, it is still a few years away from becoming the predominant and universally embraced practice within educational settings, as documented by Barseghian in 2012. Online, large-scale multiplayer educational games have now become a part of course curricula, aiming to cultivate the vital skills and techniques that the industry demands from graduates, as emphasized by Arnab and their colleagues in 2012. These games, grounded in the fundamental principles of game theory in education, place a strong emphasis on fostering teamwork, leadership, discovery, and persistence. They manifest as social networking games that challenge students to formulate solutions for real-world challenges, as underscored by the insights of Bawden and Robinson in 2012.

Research indicates that when students engage in cooperative learning groups, they not only enhance their learning but also improve their comprehension, retention of information, and overall self-esteem. This finding was documented by Johnson and colleagues in 1998. Furthermore, a meta-analysis conducted by Springer and colleagues in 1999 focused on college-level science, engineering, and technology education, revealing significant positive impacts on students' persistence, academic performance, and overall attitude toward their education. In the realm of distance education, it has become evident that employing a one-size-fits-all approach is no longer feasible, given the diverse backgrounds, prior knowledge, learning styles, interests, and preferences of the expanding e-learning user base.

In this context, the development of an online educational system capable of intelligent adaptation to individual and group characteristics, including goals and tasks, is crucial within the online distance electronic learning (ODeL) environment. To bridge the gap between pedagogy and technology, it is imperative to harness the potential of emerging technologies as a means to enrich the teaching and learning experience. This approach was advocated by Springer and colleagues in 1999, underlining the importance of leveraging technology to enhance educational outcomes

The transition to the knowledge era raised the contradiction from something dumb to be avoided, to human capital, to something to be cultivated within organizations (Palfrey & Gasser, 2008). Towards the higher education scenario, lecturers as core knowledge workers and are assigned to the task of developing new ideas and processes, by identifying, capturing, distributing, sharing, and encouraging knowledge development. Therefore, this implies adopting practices consistent with individual and organizational knowledge creation and learning processes (Takeuchi & Nonaka, 1995). However, the inconsistencies, polarities, dichotomies, and oppositions related to knowledge creation should not be considered improper, since it is formed by two complementary components: tacit and explicit knowledge (Takeuchi & Nonaka, 1995). Sveiby (1998) highlights that practical knowledge is largely tacit, which makes the process of discussing knowledge even more complex.

In short, it can be said that tacit knowledge is internalized by the individual in a unique and personal way; therefore, it is not very easily articulated (Takeuchi & Nonaka, 1995). By the way, it results from individual configurations done through data provided by the environment the individual is inserted in, thus it is almost impossible for two or more people to develop the same knowledge when they receive the same information (Takeuchi & Nonaka, 1995). That is why such issues should be carefully treated when discussing the learning processes, hence the focus of this study. Takeuchi & Nonaka (1995) believe that the explicit or codified knowledge which refers to the knowledge transmitted through systematic and formal language, only exists in, lies on, and is created by individuals. Explicit knowledge may be embedded, but its construction takes place when an individual interacts within a certain community.

Thus, explicit knowledge can be expressed in words, numbers, or even sounds that are often shared as data, manuals, audio-visual, and scientific formulas. In this sense, developing knowledge means expanding artifacts created by a group of individuals within organizations. This is what Von Krogh et al. (2012) call enabling context. According to their view, the academic perspective is the enabling context and is composed of the cooperative style of networking activities, team building, and of the support given to learning schemes such as mentoring and coaching (learning relationship that takes place when a more experienced professional takes the mentor/coach position and shares knowledge with the fresh player).

These features promote an environment where ideas are naturally created since knowledge is essentially related to human actions and, its development process depends on the participants and the actions they take (Teicher, 2018). The complexity of the knowledge transmission process that contemplates the learning process, and its requirements and facilitators from the enabling contexts for job readiness, requires the use of Intellectual Capital (IC) taxonomy in three dimensions (Stake, 1995). Since it is one of the most accepted bases for studying intangible assets and their impact on the value creation.

According to Faste (1994), this thinking paradigm encompasses possibilities inherent to the proficient use of both hands in performing an activity and, by extension, the use of the whole body and even the mind leading to wider possibilities linked to synaesthesia as a way of learning. Resorting not only to the symbolic level but also, to the sensory level and also those inherent to recognizing the importance of the brain hemispheres and modes as the basis for decision-making (Bartunek, 2014). The judgment and decision-making process represents the essence and the excellence of the role played by the managers in the Neuro-economics (Setzer, 2001).

Didactic pedagogy and conceptual distance between lecturers focused on the practice and those focused on the theory creates pedagogical noise regarding the academic unit of the undergraduate engineering course. As for an equivalent point of view, Bartunek (2014) discusses the need for pracademics in teaching and in the final delivered product from a university of technology. This transformational paradigm would be achieved by developing an ambidextrous mental model, able to mediate and bring together logic and boundaries that delimitate the academic and the corporate worlds, which are, at first exclusionary (Schwab, 2016).

Scientific rationality and instrumental rationality would need to be reviewed and realigned in order to get better results in the professional education of engineering technologists (from simple training courses in engineering science and mathematics to teaching 3IR skills that will enable graduates to transition into scarce skills positions and new occupations demanded by industry) and allow generating and improving theories that fit into practitioners' daily needs. The inability to deal with the increasing gaps between knowledge produced in universities of technology and that needed, has the industry blocking the research agenda with discussions on relevance and rigor, when, in fact, it should focus on debating relevance and applicability (Nonaka & Konno, 1998).

This T&L perspective would allow escaping the teaching and learning (T&L) traditional logic of industry positioning and operational efficiency planning by providing the institution with good conditions to innovate through exploration and exploitation, alternately. Education institutions would find in the thinking paradigm settled between managers and educators, an effective tool to survive in times of great transformations in students' profiles. This T&L paradigm will increase communication with stakeholders and with the manifesting prospects through guidance based on engineering education authorities such Engineering Council of South Africa (ECSA). More so, forecasting the opportunities will come from the Internet of Things (IoT) and the fourth industrial Revolution (4IR).

3. Research Method

Qualitative case study methodology affords researchers opportunities to explore and explain a phenomenon within its context using a variety of data sources (Baxter & Jack, 2008). This approach ensures that the phenomenon under study is explored through a variety of lenses that allow an in-depth understanding and allow multiple facets of the case under study to be revealed and understood Baxter & Jack (2008). The case study approach aligns with the goals of this research in that the focus of the study is to explore and explain with the aid of a comprehensive example that illustrates whether and how the application of technology tenants of the fourth Industrial Revolution, impact, aligns and integrate how engineers are trained to enable graduates to successfully transition into new occupation, with relevant graduate attributes required in industry. This type of research approach covers the contextual conditions in which the phenomenon under study occurs (Takanishi, 2019).

The unit of analysis (the case) in this study is the impact of technology integration, through vertical and horizontal activity integration, on how engineers are trained to enable graduates to successfully transition into new occupations, with relevant graduate attributes required in industry. The attributes of this research satisfy the definition of a case as stipulated by Patton (2002), and they are in line with Patton (2002) and Yin (1994) stipulations concerning setting boundaries for cases in a case study research approach (Baxter & Jack, 2008). The research also appeals to boundaries stipulated by Creswell, those of time and place (Baxter & Jack, 2008). In line with the boundaries of the definition and context, and the research question (how engineers are trained to enable graduates to successfully transition into new occupations, with relevant graduate attributes required in industry?), the type of case study research adopted, aligns with explanatory and exploratory or descriptive case study as categorized by Yin (1994).

Patton (2002) and Yin (1994) stipulate that a hallmark for case study research is the use of multiple data sources. A strategy that enhances data credibility (Baxter & Jack, 2008). This case study will apply a triangulation of the following data sources i) document analysis and archival records and ii) field notes; and iii) T&L system design applied. It is rational to apply document analysis in this research since it is often used in combination with other qualitative research methods as a means of triangulation. The combination of data collection methods in the study of the one and the same phenomenon enables researchers to draw upon multiple sources of evidence and, to seek convergence and corroboration with different data sources (Baxter & Jack, 2008). This approach ensures improved data and decision credibility and eliminates researcher bias in recommendations and conclusions.

Based on the theoretical framework established by various authors indicated above, the research adopted a qualitative case study approach in which a desktop research approach is engaged. The research applies data collection and analysis methods of i) document analysis and archival records, to establish literature reviews and current status in the teaching and learning in technology education. Then, ii) field notes of previous researchers are examined to capture the reality and the essence of teaching and learning in the institutions of technology and technology teaching and learning in action.

This method is applied in order to gain an understanding of the cold phase with regards to teaching and learning activities, so as to enable superior activity integration in the technology-based teaching and learning design. The last data collection method is iii) the technology teaching and learning data analysis method. This method is applied to collect data required in the design of the technology teaching and learning system and to identify all the required process steps in the application of ambidexterity in the teaching and learning processes. The data collection tools will enable the research to be approached in three ways and therefore the result is an improvement in data integrity.

4. Discussion

The teaching and learning program begins with an engineering curriculum established as a combination of applied engineering theory and hands-on instruction. Courses on mechanical drawing and design of engineering equipment are core in the instruction of engineering technologists. Engineering design is included because it is a linear and morphological process that requires a hands-on approach in instruction. The program is implemented as an engineering technology instruction that emphasizes more on synthesis as opposed to analysis, that is, course content includes design thinking-related courses rather than scientific analysis and mathematical modeling.

In the execution of the teaching and learning program, two components of the program followed are, learning and applying a programming language, in this case, students learn how to use Python. The second component is engineering design, in which students learn how to build equipment using Lego-robot material. In engineering design, students use drafting and drawing methods in the conceptualization of the products and then manufacture the products using Lego components. Students are encouraged to build equipment that requires mobilization, e.g., mining equipment or manufacturing conveyor belts. This type of equipment requires motors, sensors, actuators, etc.

Robots are very mechanical, most of these are still unintelligent mechanical arms. Learning robot technology started to develop in the 1970s, WABOT-1, the first anthropomorphic robot, appeared in Japan in 1973, sparking research on bipedal walking functions in robots into the 1980s (Takanishi, 2019). Robots had to be tediously hand-programmed for every task until about the late 1970s; to overcome this, robotics needed machine-learning technology (Moll, 2021). Increasing demand in the 1980s for robots capable of identifying parts from random selections, or maintaining positional accuracy when objects shift about on assembly lines (Yerkey, 1984), brought machine learning into robotics.

Student are exposed to Machine Learning, which in this program is limited to the capacity of computers to learn from experience by improving their information-processing ability over time by running algorithms to access and process data. Students are encouraged to research further and engage in concepts such as Deep Learning, which is an evolution of machine learning, that creates an artificial neural network that can learn and make decisions on its own. The teaching and learning philosophy adopted is the gradual release of responsibility (GRR), in which students are encouraged and resourced to research further about any of the topics in the 3IR and 4IR space.

The program acquired a 3D printing machine and students were introduced to additive manufacturing, Additive manufacturing 3D printing machine applies a technology known as fused deposition modeling (FDM), which is commonly known as desktop 3D printing because it is the most commonly used form of the technology today. There are other technologies applicable in additive manufacturing such as SLA, and SLS, but FDM makes up the bulk (90%) of our 3D printing teaching and learning program and, clearly, this technology constitutes an enduring, innovative technology of the 3IR.

Students are introduced to the Internet of Things (IoT), which in this program is taught as a system of networked mechanical and digital devices with the ability to transfer data amongst themselves without human intervention. The core technology of the IoT is the Internet, and converters used are from analog to digital (ADC) and from digital to analog (DAC), which students use to link mechanical devices via sensors and actuators into the IoT. Students study and replicate well-known projects such as the Carnegie Mellon University installation of micro-switches in a vending machine to check cooldrink availability from their desks (Von Krogh et al., 2012).

IoT application using converters, sensors, and actuators, is extended to experimenting with regulating the temperature of a fridge remotely, switching lights on and off by clapping hands and topics around smart houses, such as energy-saving IoT projects. Some students in the GRR part of the program ventured into cybersecurity and household security-related topics such as motion analysis and energy consumption. Solar energy-supporting designs that came out of this program include designing a motor that controls solar panels to follow the sun's movement, so as to optimize solar energy generation.

This program pivots around mechanical robot building and mobilization using programming languages such as Python. The program allows students to venture further in deep learning and machine learning, and support is provided to students who want to expand their knowledge with regard to 3IR technologies and the commensurate skills for the 3IR economy. The 3IR technology skills program is at its infant stages and runs for one (1) year, beyond the academic year students become part of the robotics and e-sport club in the industrial engineering department, in order to continue engaging in the 3IR skills program.

Further development of the 3IR skills training program will lead the teaching and learning to focus on ten (10) topics only for an academic year. Students who want to engage further will be well-resourced and supported to research further and to create innovative products. The major topics of 3IR, that the program will focus on are the following: Robotics, Machine learning, IoT, Automation, 3D Printing, Big Data, Digitalization/Digitization, AI, and Augmented/Virtual reality. The reason that our institution operates in Online Distance Electronic Learning (ODeL), makes these technologies favourable.

5. Research Results

Students succeed in completing the first challenge, which is improving current and existing technology. Projects such as automating the university boom gates and installing micro-switches in a vending machine to check cooldrink availability remotely are indications of students' acquired competence in technology improvement. This is an achievement of the mission of engineering technology education (to produce technologists who work with current technology to solve current problems). As this cohort is an Industrial Engineering group, they were challenged to apply continuous process improvement (CPI) techniques to improve the limitations of the systems they have designed and manufactured. While Kaizen is in full swing, it is noticed that the skills in applied engineering theory (design thinking) and hands-on instruction (Ambidexterity), kick in, and students solve numerous technology problems by applying both.

A typical solution manifesting from this stage is the design, manufacturing, and application of a solar panel motor. The solar panel motor improves the efficiency of the solar panel by controlling solar panels to follow the sun's movement, so as to optimize solar energy generation. Production of new technology is proof that students have moved through a tipping point (fig.1), i.e., from improving existing technology to producing technology (from evolution to transformation). At this stage, it is noticed that students are applying skills of design thinking and Ambidexterity with very high competency. This leads to the second tipping point, where students engage in the world of digital technology. In this stage, students produce apps to identify potholes in the university neighbourhood and manufacture pothole-filling material using additive manufacturing skills. A myriad of projects are done in this stage that support the notion that students are working with current technology to solve current problems. Some of the projects done at this level include smart housing and cyber security projects.

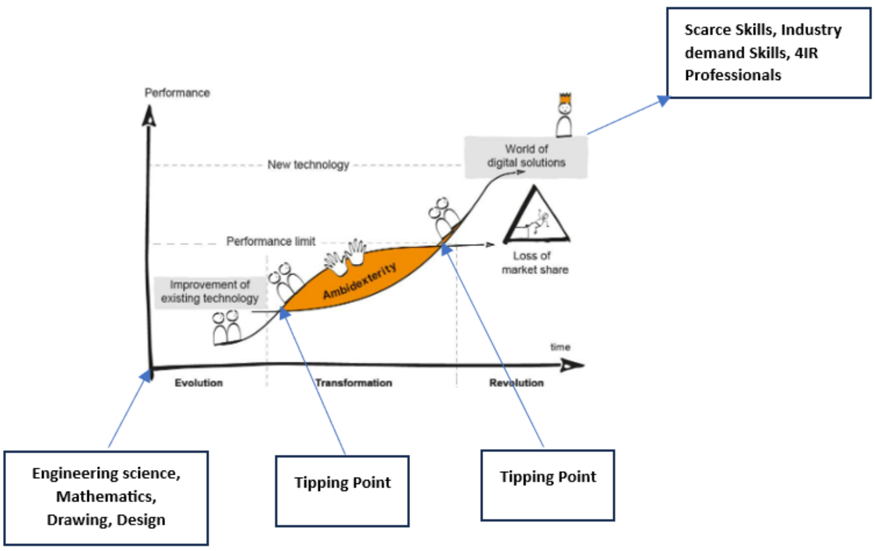

Figure 1: Technology Education mission (Teaching and Learning Model adapted from Duwe, 2018)

Three major aspects of T&L are achieved in this program, i.e. Capture student's interest, Motivate students to progress to higher and more difficult levels of learning, and Learn from and interact with other students. These are typical results of a DGBL environment and GRR pedagogy. Students achieve self-motivation, they collaborate to solve challenges and like in game-based learning they go through solving problems to a higher level. The T&L program proves that an education online system with the ability to adapt intelligently to the goals, tasks, interests, and other features of individuals and groups of users, is mission critical for an online DE environment. Thus, in an attempt to bridge the gap between pedagogy and technology, the potential of new technologies is used as a means to enhance Teaching and Learning in a distance learning setting.

6. Conclusion and Recommendations

The realization that all the technologies in the program represent a gradual evolution of the defining technological transformation of 3IR tenants (Moll, 2021), is the foundation of the drive and commitment to teach 3IR technology skills and the belief in engineering education mission. The program's success is proof that once the students are confident and knowledgeable about the 3IR economy and the engineering dynamics involved, they will be activated to transition into establishing themselves as proficient 4IR professionals. Thus, 4IR is evidently a staggering confluence of emerging technology breakthroughs, as proposed by Schwab (2016) and it blurs the lines between the physical, digital, and biological spheres through artificial intelligence application, as postulated by Marwala (2020).

The mission of engineering technology education is to produce technologists who can work with current technology, and therefore, engineering curricula must be a combination of applied engineering theory and hands-on instruction. This pedagogy strategy has achieved the mission of engineering technology education. T&L of courses on mechanical drawing and design of engineering equipment must be core in the instruction of engineering technologists. These courses must emphasize more on synthesis as opposed to analysis, that is, course content must include design thinking-related courses rather than scientific analysis and mathematical modeling. It is undeniable evidence that the university is able to meet the requirements of ECSA and produce graduates who can successfully transition into new occupations, with relevant graduate attributes required in industry.

It is thus, fitting that engineering curricula must include 3IR technology skills teaching and learning programs, to afford engineering students an opportunity to develop 4IR skills and ability to participate in the development of the 4IR economy. Currently, it must be noted that teaching the 4IR technology skills paradigm is rather complex, since 4IR technologies manifest because of the convergence, confluence, and evolution of the clearly defined technological transformation of 3IR technologies, as indicated by Moll (2021). Therefore, McGinnis's (2018) proposition, that 4IR is a fusion of advances in 3IR technologies, such as robotics, AI, etc, is plausible and core to the strategic beliefs in this 3IR technology skills teaching program. The success of the program is proof that a Skills-Driven pedagogy for Job transition pathways applicable in Engineering Education can successfully transition engineering graduates into new and scarce skills occupations, with relevant graduate attributes required in industry.

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