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Technology enhanced learning in electrical engineering education for African postgraduate students

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ABSTRACT: Technology has become an important tool in higher education to foster student learning by bridging the gap between theory and practice. Fusing theory and practical is vital in all forms of education, as the application of knowledge is more important than simply the accumulation thereof. Therefore, this article highlights how technology enhanced learning has been introduced into two different electrical engineering modules offered at an open distant learning institute to help support this fusion. Technology enhanced learning (or technology education) is defined in this article as the use of computer-based software and electronic circuits to help students fuse theory with practice. Quantitative data relating to student pass rates over a 16-year period are presented which highlight that many students struggle with design-based learning that involves the construction of a working electronic circuit. However, the majority of students tend to succeed with computer-based learning where system simulation is required. It is recommended to maintain a balance between the use of software and hardware in helping students to fuse theory with practice, thereby enhancing their engagement with the course content.

Keywords: Design-based learning, computer-based learning, student engagement

INTRODUCTION

> *Education is the most powerful weapon which you can use to change the world* [1].

These words, by a former president of South Africa Nelson Mandela, well illustrate the influence and potential of education to reform individuals, communities and societies at large. Education can be defined in various ways and be confined to various contexts.

In 1983, Theuns and Rasheed roughly typified education as general, theoretical, discipline-oriented and using a rather high degree of abstraction [2]. Then in 1993, Varey portrayed education as a series of inputs (course content), processes (methods of delivery and selection of *successful* students) and outputs (what the learner knows, understands and can do as a result of learning), making it sound very much like a factory [3]. By 2003, Kay had described education as a field where the general purpose is the transmission of worthwhile knowledge to students by rational and ethical means [4]. Finally in 2013, Juffermans and Van der Aa defined education as an institution that organises learning by bringing together teachers (at least one) and learners (usually more than one) in a given space (e.g. a regular classroom) [5]. Of course these definitions cover various educational contexts, from school to vocational to adult to higher education and cannot be confined to a singular type of education. However, all these definitions have something very important in common; namely, learning.

Learning must take place is arguably the most important statement that may be associated with any type of education. Learning can include understanding and assimilating established knowledge or it can include formulating and evaluating new knowledge. This should be based solidly on achieving learning outcomes that need to be formulated using illustrative verbs drawn from Bloom's taxonomy [6]. Institutions of higher learning are often mandated to provide both aspects; namely, providing theoretical and practical instruction to student masses, while churning out numerous research articles and papers to the international scientific community. The research process …*is often messy, idiosyncratic, and difficult to articulate* [7], while the teaching and learning process faces its own distinct challenges.

One distinct challenge currently facing higher educational institutions in South Africa is the low throughput rates, which was found to be only 15% in recent years [8]. This has a negative impact on government subsidies received from the Department of Higher Education and Training (DHET), and subsequently on the purchasing of new equipment and technologies required specifically in engineering education. Many factors contribute to this low throughput rate, including lack of student motivation, not aligning theory and practical within the curriculum and not exposing students to real world situations [9]. Furthermore, *the undergraduate engineering curriculum shapes and constrains the learning experience for every engineering student* [10]. Subsequently, media-based learning has come to play an important complementary role in supporting teaching and learning for two main reasons. Firstly, changes in society and increasingly media-rich interactive modes of communication require that universities move beyond traditional chalk and talk approaches. Secondly, there is a *need to manage and support individual, self-paced learning in the context of large classes, student diversity and under-preparedness* [10]. Moreover, universities of higher education are increasingly making use of technology-enhanced learning and innovative assessment for academic student support [11].

The purpose of this article is to highlight how media-based learning (in the form of technology education) has been used to integrate theory with practice in an electrical engineering curriculum, leading to success in one module and failure in another. Two modules are presented from a postgraduate programme, where two forms of educational technology were used to reinforce specific theoretical knowledge through practical work; the one being the use of computer simulations and the other the use of project-based learning. Computer simulations are widely used in engineering education to teach techniques of engineering design and manufacture and the underlying principles, which determine the behaviour of engineering systems [12]. Project-based learning has been used in a number of disciplines to provide undergraduate students with the opportunity to simulate professional activities and apply theory to practice [13]. The outline of the electrical engineering course from which the two modules are selected is presented first. Key theoretical principles from both modules are then presented, being integrated into computer simulations or project-based learning. The research methodology follows along with the results.

POSTGRADUATE QUALIFICATION STRUCTURE IN ELECTRICAL ENGINEERING

Electrical engineering students must be in possession of a National Diploma (National Qualification Framework (NQF) level 6 qualification usually requiring a minimum of three years to complete) before they can register for the BTech programme (usually requiring a minimum of two years to complete on a part-time basis). Students have to obtain a minimum of 120 credits at this level (NQF level 7) to be awarded the BTech: engineering: electrical qualification. The majority of modules in this BTech programme have a credit value of 12, with the exception of a capstone module (termed Industrial Projects 4), which has 36 credits attached to it. This means that students need to complete 7 x 12 credit modules along with the compulsory capstone module to achieve the 120 credits. Two of the elective modules in this programme is Process Instrumentation 4 and Radio Engineering 4, which were selected for this study as the authors are the primary lecturers for these modules. These modules comprise both a theory (10 credit weighting) and a practical module (2 credit weighting) in which students must obtain a final grade mark of 50% or more for both modules to successfully complete them. Process Instrumentation 4 focuses on computer simulations, while Radio Engineering 4 encompasses project-based learning.

KEY THEORETICAL ASPECT IN PROCESS INSTRUMENTATION

One of the theoretical aspects in Process Instrumentation 4, which needs to be reinforced by practical work involves programming a logic controller (termed a PLC) for use in the automation of industrial processes in industry. Basic concepts are introduced in the first year of study at the Diploma level, and then built on and expanded through each subsequent level presented over a year period. Students must, therefore, progress to a stage where they are able to complete actual industrial tasks making use of the PLC equipment, software instructions and addresses used in industry. This leads to constructive alignment [14] of the modules in the various levels from the Diploma through to the BTech (Process Instrumentation 1 - 4). One of the theoretical sections requires students to write a PLC program that will control the liquid storage within two separate tanks. The filling process is triggered by means of an empty signal and stopped by a full signal, which is sent to the control units (connected to a PC) by float switches. This process is highlighted in Figure 1. Students are given the following operating instructions, which must form part of their simulation program:

- The motor is started when the float level switch for tank 2 starts pulsing indicating that it requires filling;
- If the emergency stop button is pressed, all operations must cease immediately; and
- If a drive motor fails, then the trip-indicating auxiliary contact must open and a flashing light needs to be activated.

The control circuit must be wired in the following way, so that the lecturer may evaluate the practical task according to a predetermined rubric:

- Input0 = Emergency stop;
- Input1 = START filling tank input;
- Input2 = STOP filling tank input;
- Input3 = Motor tripped input;
- Q1 = Star motor contactor/drive; and
- Q2 = Flashing - indicator light - tripped motor.

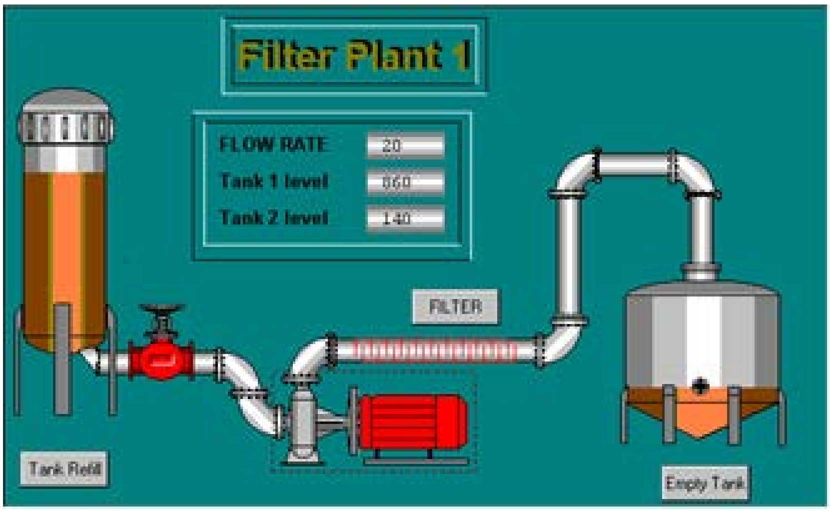

Figure 1: Overview drawing of the task given in Process Instrumentation 4.

Students are supplied with the PLC simulation software so that they can verify the correct operation of their program at their place of residence. The practical part or laboratory work now involves downloading their program to an actual system and seeing its operation in a real life scenario. This laboratory work has become a reality at the Florida Science Campus of the University of South Africa (UNISA) in South Africa, where students are already working with the PLC simulation software in a controlled environment.

KEY THEORETICAL ASPECT IN RADIO ENGINEERING

Radio Engineering 4 students need to comprehend time and frequency domain analysis, where they need to design a number of radio-frequency (RF) circuits. This module builds on previously acquired knowledge in Radio Engineering 3 and Electronics 1, 2 and 3 (offered at the Diploma level). One of the theoretical sections in Radio Engineering 4 involves phase-lock-loops, where students need to understand the operating principles of frequency generation.

Students are required to design and physically build two RF generators (one crystal based (XTAL)), where they may select their own frequency below 4 MHz and the other LC based where students must select a frequency four times higher) on an electronic circuit board, which must be submitted for assessment. Theoretical design procedures and mathematical calculations form the theory, while the construction and fault-finding techniques form the practical which must complement each other. The electronic circuit board must work and is evaluated using an electronic oscilloscope and a frequency counter, forming part of project-based learning.

The practical submission (see Figure 2 for an example) must include the following which is stipulated in the modules tutorial letter sent to students at the start of the course:

- a written report showing:
  - all theory and calculations required to select the required components for the circuit;
  - a fully labelled circuit diagram with a heading identifying the type of oscillator;
  - how the construction proceeded and how the circuit was fine-tuned;
  - oscilloscope traces of at least two different points in the circuit to demonstrate understanding of how the circuit operates;
  - a spectrum analyser trace for the output of this circuit;
  - measured results of frequency stability vs. temperature (table advisable);
  - predictable results of frequency stability vs. time (table advisable); and
- a fully labelled operational circuit (either PCB or Vero board construction).

Students need to apply their fundamental knowledge acquired from the prescribed textbook to decide on a crystal oscillator design; then complete all the calculations to select the correct components; and then build and test the circuit. Figure 2 highlights the two oscillators (LC and XTAL), which have been built by a student on a Vero board. This practical circuit must work when tested in a laboratory, and thus students need to take care of packaging the circuit correctly which must be posted to UNISA. This further tests student’s logical reasoning as they need to realise that foam (or other soft material) is required to package the circuit in order to protect it from damage, while being transported by the local Post Office or courier service. Some students do not package the circuit correctly (should be inserted into an anti-static bag and be placed with foam or bubble plastic into a sturdy cardboard box), while others do not even take the time to label it and even waste material with their submission. It is important to re-iterate that the circuit must be operational for students to pass this module, irrespective of the quality of the submitted written report.

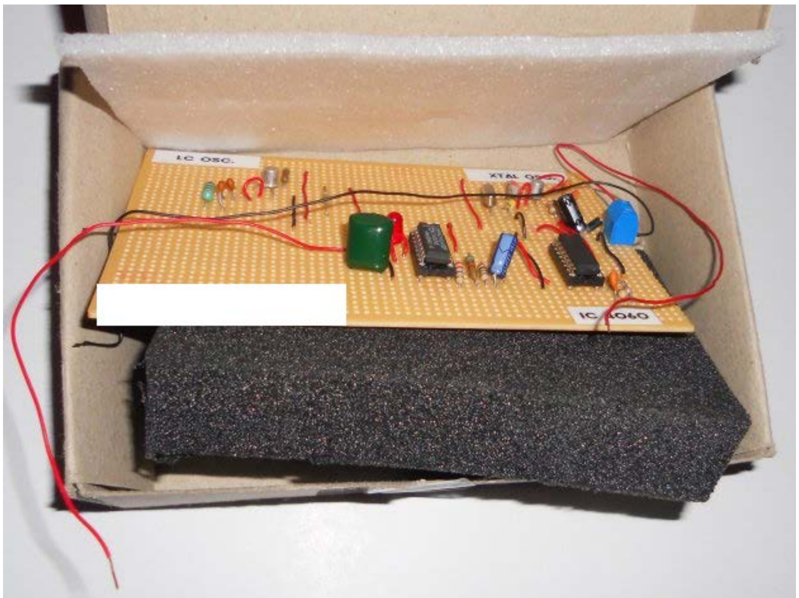

Figure 2: Student submission of the practical electronic circuit required in Radio Engineering 4.

RESEARCH METHODOLOGY

Quantitative analysis is used in a time-lag study. The target population is restricted to all students enrolled for Process Instrumentation 4 (PRS4) and Radio Engineering 4 (RAE4) between 2004 and 2019, and thus involves whole-frame sampling. The data focuses on the pass rates (minimum of 50% required to pass) achieved by these students for both their theoretical and practical work, which is vital in an engineering curriculum [15]. The analysis and publication of this data relates to the scholarship of teaching and learning, where academics investigate their own teaching practice to identify ways to improve student learning [16].

RESULTS

The pass rates for the theory and practical work for PRS4 are shown in Figure 3, which indicates that the pass rate for the theory module fluctuated between 95% (in 2004) and 48% (in 2016). The pass rate for the practical also tends to fluctuate, with a high point in 2004 and a low point in 2008. The overall average pass rate for the theory was 82%, while the practical had an average pass rate of 74%. The majority (83%) of these students were male, with the predominant home language being English and Zulu.

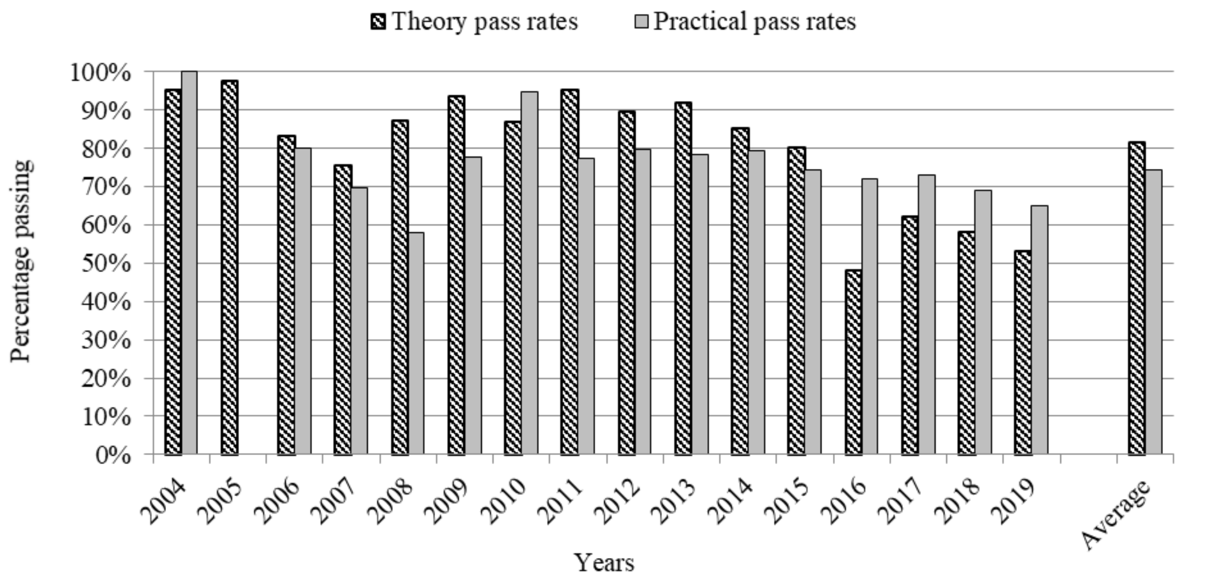

Figure 3: Pass rates for Process Instrumentation 4.

The pass rates for the theory and practical work for RAE4 are shown in Figure 4, where the number of students passing the theory (obtaining more than 50%) fluctuated dramatically from 10% in 2005 to almost 70% in 2009. However, very few students could apply the theory in practice, with only 33% on average submitting a fully labelled operational electronic circuit along with their written report. The majority (82%) of these students were male, with the predominant home language being English, Xhosa and Zulu.

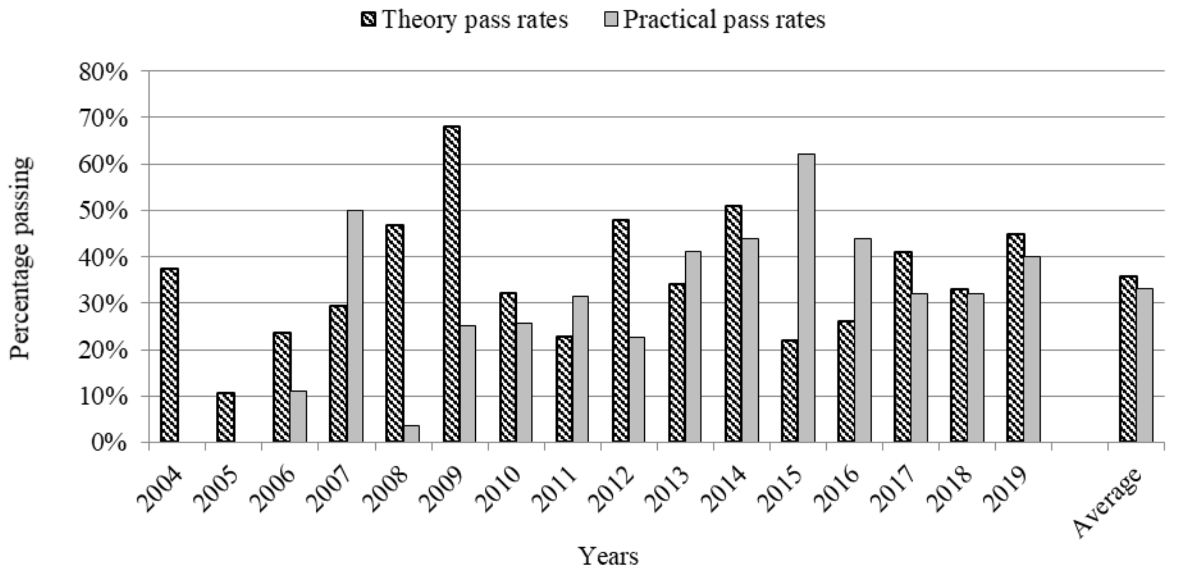

Figure 4: Pass rates for Radio Engineering 4.

CONCLUSIONS

Key benefits in using project-based learning and computer simulations (both inclusive of technology education) include exposing engineering students to numerous fine motor skills and cognitive skills as they engage their hands, thoughts and voice in demonstrating the achievement of specific learning outcomes in these two modules. Another key benefit is that they can be used to successfully integrate theory and practice. However, African engineering students seem more adept at using computer simulation than design-based learning to complete their practical assignments. This is evident from the fact that, on average, 74% completed their simulation work in Process Instrumentation 4, while only 33% could successfully design and construct a working electronic circuit in Radio Engineering 4.

A recommendation in this regard is to balance the use of both software and hardware in engineering education, so as to expose students to both pedagogies in an effort to improve their engagement with the course content. It must though be stated that using technology enhanced learning in engineering education may yet become one of the most powerful weapons to enhance the teaching and learning process in higher education.

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BIOGRAPHIES

Arthur James Swart completed his Master's degree in education in 2007 and his doctoral in electrical engineering in 2011. He is currently an Associate Professor at the Central University of Technology, Bloemfontein, South Africa, where he mentors staff members regarding the scholarship of teaching and learning. His educational research focuses on the effective use of educational technology to help students fuse their theory and practice. His field discipline research focuses on electronic communication and solar energy. His research collaboration network includes the North-West University, the Cape Peninsula University of Technology, the Vaal University of Technology and the University of South Africa. James has published close to 200 conference papers and journal articles within the fields of electrical engineering and engineering education. He has a passion for life-long learning and holds the motto that *consistency is often a mark of quality*.

G. Leslie Nickola obtained a Master's diploma in electrical engineering at the former Vaal Triangle Technikon in 1991, and a MEd in curriculum studies at the Rand Afrikaans University, Johannesburg, South Africa. At the University of South Africa (UNISA), he was responsible for Electronics and Process Instrumentation modules, as well as engineering projects and Work Integrated Learning modules at the time the article was written.