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Fusing theory with practice for electronic communications using an on-line simulation tool

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ABSTRACT: *Smart education* has been coined to represent a global movement towards technology-enhanced education or the use of educational technologies to improve student learning. It helps to support the needs and learning styles of students in higher education, offering opportunities for adaptive, personalised, collaborative and self-learning processes. The purpose of this article is to highlight how an on-line simulation tool was used in a practical assignment to foster ubiquitous learning on the importance of low-pass filters, thereby fusing theory and practice. Both quantitative and qualitative data are presented in the form of student academic results and student feedback. Results indicate that 87% of the students could successfully design and add a low-pass filter to the output of a square wave generator, so as to produce a pure sine wave. A recommendation is made to use on-line simulation tools, as this enables ubiquitous learning for all students, as they do not need to download specific simulation software to use on a personal computer. Students can therefore learn anytime, anywhere and anyhow using different devices suited to their own particular needs.

INTRODUCTION

> *Technology is nothing. What's important is that you have a faith in people, that they're basically good and smart, and if you give them tools, they'll do wonderful things with them* [1].

These words, by late Steve Jobs, well illustrate that when people are given the right tools, and especially technology tools such as simulation software, they can produce smart results. This is especially so when student access to physical laboratories may be halted due to various reasons, such as student unrest or global pandemics.

Simulation tools enable students to visualise theoretical concepts, giving them a platform for experimentation, where accurate results can be obtained instantaneously [2] and repetitively. This enables students to fuse theory with practice, as they visually observe the effects of manipulating a given system or process in a specific way. This calls for a student to repetitively engage his/her short-term memory, as multiple runs of a simulation would be required. This in turn can enhance long-term memory that can be formed by repeatedly activating short-term memory, which will cause chemical, physical and anatomical changes in the synapses of the brain [3].

Simulation tools have long been used in education to help students with their cognitive development. This refers to how a person thinks and perceives his/her world through the action of genetic and learned factors [4]. These learned factors include practical assignments, where students can investigate and analyse the operation of systems or processes which impact on their daily life. One such system involves the use of radio-frequency (RF) transmitters used in the broadcast of FM radio stations.

Students often listen to radio station broadcasts as they commute between home and campus. They may find themselves in a taxi or bus that has tuned in to a local FM radio station or they may use their cellphones to live stream the audio. A key component in any RF transmitter is a filter that is used to suppress unwanted frequencies. Filters are critical elements in RF systems, as such devices are necessary for limiting the appropriate operating bandwidth of the system, while at the same time stopping undesired signals and harmonics [5]. Better understanding the operation of such filters can enable these students to further enhance their perception of the world in which they live, as they gain insight into what is required for acceptable radio broadcasts.

The purpose of this article is to highlight how an on-line simulation tool was used in a practical assignment to foster ubiquitous learning on the importance of low-pass filters, thereby fusing theory and practice. Harmonics are generated by using a square wave generator in the on-line simulation tool which must be passed through a low-pass filter to acquire a pure sine wave. Falstad is used as the on-line simulation tool, which is elaborated on in the next section as part of smart education. The context of the study is then given with a description of the practical assignment. A brief methodology, results, discussions and conclusions round off the article.

SMART EDUCATION

The acronym SMART (self-monitoring, analysis, reporting technology) is used in various fields of study, including smart cities, smart healthcare, smart civil infrastructure, smart education. In terms of smart education, it is an educational system that allows students to learn by using up-to-date technologies [6]. Some of the topics covered in the widely published research on smart education include smart technologies, such as the Internet of Things (IoT), flipped learning, big data, and gamification, to name a few [7]. Smart education is also the incorporation of cutting-edge technology to enhance student learning, where learners utilise smart devices to access digital resources through wireless communication media. It may be defined as the *effective and coherent use of information and communication technologies to reach a learning outcome using a suitable pedagogical approach* [8]. According to Bajaj and Sharma, smart education is *about providing personalized learning, anywhere and anytime* and is *about taking learning outside the traditional classrooms* [9]. Jang defines smart education as *an educational system that allows students to learn by using up-to-date technology and it enables students to study with various materials based on their aptitudes and intellectual levels* [10]. The term *anywhere and anytime* may be updated to include the word anyhow, when considering the different types of devices that students use to access the Internet and on-line simulation platforms.

Falstad is a virtual on-line circuit simulation package that was developed over several years by Paul Falstad [11]. The simulator can be accessed via a Web browser as a Java applet and it works well on mobile devices, as well as on personal computers [12]. Virtual simulations are used as a method for the student to master new concepts and to develop higher-order thinking skills [13]. Falstad is free with obvious benefits for the students [14]. The simplicity of the simulator makes it easy to use for undergraduate students in electrical engineering [11]. It is an on-line simulation tool that can be assessed from anywhere in the world, at any time with the right type of connectivity and anyhow using either a mobile device or personal computer, irrelevant of the operating system. At times students need to download and install specific software for a required assignment. This can pose challenges to the student if the software is not compatible with the operating system or if the software is not free of charge. Using Falstad negates these challenges and enables each student to engage with the same learning environment despite using different devices.

One of the definitions of ubiquitous learning is that it is an everyday learning environment that is supported by mobile and embedded computers and wireless networks in everyday life [15]. Ubiquitous learning can also be described as context-sensitive anyhow, anytime, anywhere learning method using ubiquitous devices [16]. The purpose of ubiquitous learning is to accommodate students and their learning styles by giving them access and providing adequate information anytime and anywhere based on their needs and desires [17]. While ubiquitous learning may be attractive to students, it may also pose definite challenges for higher education providers [18]. Challenges may include problems regarding network connections, data, access to mobile devices and personal computers, and more [19-20].

The use of Falstad further enables adaptive learning. Adaptive learning is a methodology that allows one to identify the level of students' knowledge and learning styles and transforms the materials, assignments and ways of delivering the content to adapt to what is required by a student [21]. Practical assignments requiring simulation results can thus be adapted to the devices used by students, and then assessed by academics in an on-line environment to determine the level of knowledge and attributes attained by each student within a specific module.

CONTEXT OF THE STUDY

The context of this study is limited to Communications Technology II (CT2), a compulsory second-year module in the B_ETE (Bachelor: Engineering Technology in Electrical Engineering) degree at the Central University of Technology (CUT) in South Africa [22]. It is offered over the course of 13 weeks, with the syllabus covering five main units or sections. Students have to gather 420 credits in this three-year degree, with 14 credits attached to CT2 [22]. The purpose of this qualification is to build the necessary knowledge, understanding and skills required for a student's progression towards becoming a competent practicing engineering technologist. Engineers are typically tasked with the design and manufacture of equipment and systems, while engineering technologists have the technical know-how to install and use these affectively.

CT2 comprises four on-line self-assessments that focuses on the theory that is discussed in the classroom using PowerPoint presentations and group activities focusing on problem-based learning. The self-assessments contribute 25% to the course mark of the students. The remainder of the course mark is made up of all the practical assignments (weighting 35%) and a main venue-based assessment (weighting of 40%). Students need to obtain a minimum course mark of 40% to be allowed access to the final summative examination at the end of the semester.

CT2 introduces electrical engineering students to the field of electronic communications, where a basic RF transmitter and receiver are discussed. Three types of analogue modulation are explained, being FM, AM and SSB. The dipole and Yagi-Uda antenna are introduced, along with relevant coaxial cables (RG6 and RG59) and connectors (F-type and BNC). An important building block of any RF transmitter or receiver is the filter.

Four types of filters are discussed, being the low-pass (LPF), high-pass, band-pass and notch filters. The design and implementation of a LPF is required in one of the four practical assignments that students need to complete in this module. This practical assignment is designed to help students fuse theory with practice, as they visually observe the effect that a LPF has when placed at the output of a square wave generator. The purpose of this generator is to produce a square waveform that is well known for its composition of odd harmonics. This square waveform may be transformed into a pure sine waveform by the addition of a correctly designed LPF.

PRACTICAL ASSIGNMENT

The first of four practical assignments in the CT2 module requires students to make use of an on-line simulation tool to generate 2 x time domains and 2 x frequency domains that illustrate the transformation of a square wave into a sine wave. Falstad is used as the on-line simulation tool, due to the benefits listed above. The learning outcomes of Practical 1 are stated as follows in the study guide of the students:

Students are expected to be able to:

1. Modify an existing oscillator to produce a specific output frequency;
2. Design a low pass filter to attenuate specific harmonics; and
3. Contrast the number of harmonics between a square and sine wave.

A template is provided on eThuto (learning management system of the University built on Blackboard^{TM}) to the students, where the first three headings are termed *learning outcomes*, *apparatus* (equipment or software used) and *practical setup* (simulation circuit with time and frequency domains). The next heading in the template provides the *method* or guideline, which students need to follow in order to complete the assignment. The student must then provide specific numerical *results* from the different domains, relevant *calculations* and appropriate *conclusions*. The final heading in the template is termed *figures*, where a screenshot of the design of the LPF from an on-line Web site is required.

The completed template needs to be converted to a PDF which must then be uploaded to eThuto.

An on-line rubric is used to manually grade the first three headings and the last heading (called *figures*) of each student's submission. When this grade is posted, eThuto releases an on-line self-assessment where the student needs to enter the numerical results of the assignment, which are graded automatically (this forms a quantitative assessment). This lightens the workload of the academic tasked with marking the assignments, which can number more than 200.

Three specific labels are required in the practical setup, being the square wave, sine wave and cut-off frequency value for the LPF. The student's name and number must also be included. A time domain graph should illustrate a square waveform, which comprises at least three frequencies in a frequency domain graph that needs to be placed next to it. The second time domain graph must illustrate a sine waveform, which comprises only 1 frequency in a frequency domain graph that needs to be placed next to it. A T-type LPF must be designed by the student to suppress frequencies above 710 Hz, being the output frequency of the generator that is built around a 555 timer.

METHODOLOGY

A time-lag study is used covering three years from 2020 to 2022. Three different cohort of students completed the module CT2 during the second semester of each year (August through October). The sample size is 379. Quantitative data in terms of the student's grade for the practical assignment is used to determine if the students could successfully achieve the learning outcomes, as stated in the previous section.

Qualitative data are obtained in terms of student feedback on the practical assignments, in order to determine their relevance to the theory and if problem-solving skills were assessed. Two key graduate attributes of the International Engineering Alliance (IEA) are problem analysis and investigation [23], which calls for this skill to be demonstrated by each student. The questions were derived from previous research, which contributes to its validity and to the reliability of the results [24][25]. No ethical clearance was required, as no personal data or questions were asked. All relevant data was extracted from either the on-line self-assessments or the practical assignment, which all students needed to complete as part of the course requirements.

RESULTS AND DISCUSSIONS

Figure 1 presents the age brackets, gender and home languages of the three different cohorts of students. The dominant age is 20-24 years, which is to be expected as these students are in their second year of study at the University [26]. Their first year, at the age of 19, would follow on from their high school career, which would have ended at the age of 18. Male students outnumber female students by 1.65:1. This is a lower ratio as compared to previous electronic communication modules that were offered at CUT between 2014 and 2019 as part of a different qualification that was phased out (previous ratio of 4:1) [27]. This tends to suggest that more female students are entering engineering, as a global drive to achieve this has been ongoing for the past decade. The dominant home language of the students is Sesotho, which is indicative of the Free State province in South Africa, where CUT is located. This indicates that CUT is providing a critical service to local communities, as students from these communities are selecting CUT to further their academic qualifications.

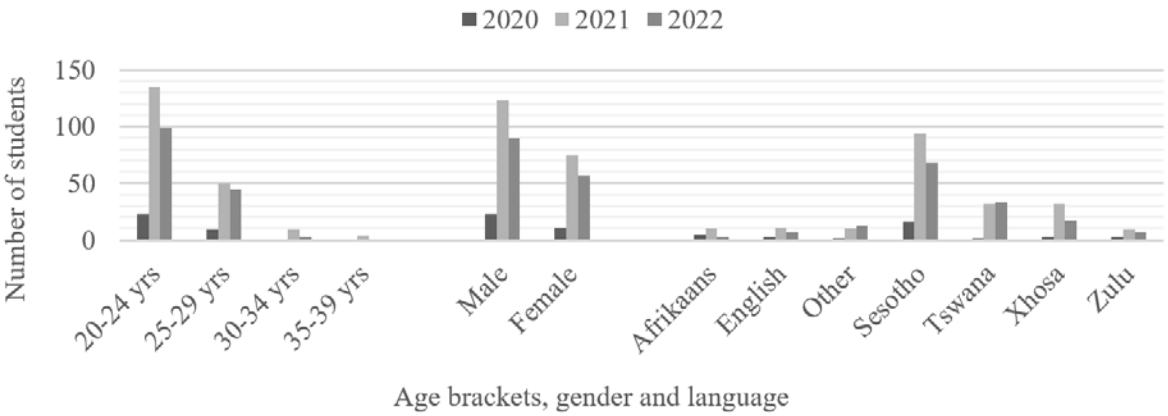

Figure 1: Student profile.

Figure 2 illustrates the grade distribution among students for Practical 1. Of the 379 students, only 33 (13%) were not able to achieve the required outcomes. This indicates that 87% of the students were able to engage in problem-solving skills, as they successfully designed and implemented a LPF in an on-line simulation tool. They were thus also able to demonstrate two further graduate attributes of the IEA, being design or development of solutions and modern tool usage. Noteworthy is the number of distinctions in this assignment, which equals 42.7% (105 + 57/379).

Nine bars are shown on the x-axis representing grade ranges. The number of students who obtained a mark between 1 and 2 (out of a possible 10 marks) equals 5, while the number of students who achieved more than 8 (which is a distinction) equals 162 (105 + 57). Students need to obtain more than 5 marks to successfully complete this practical assignment.

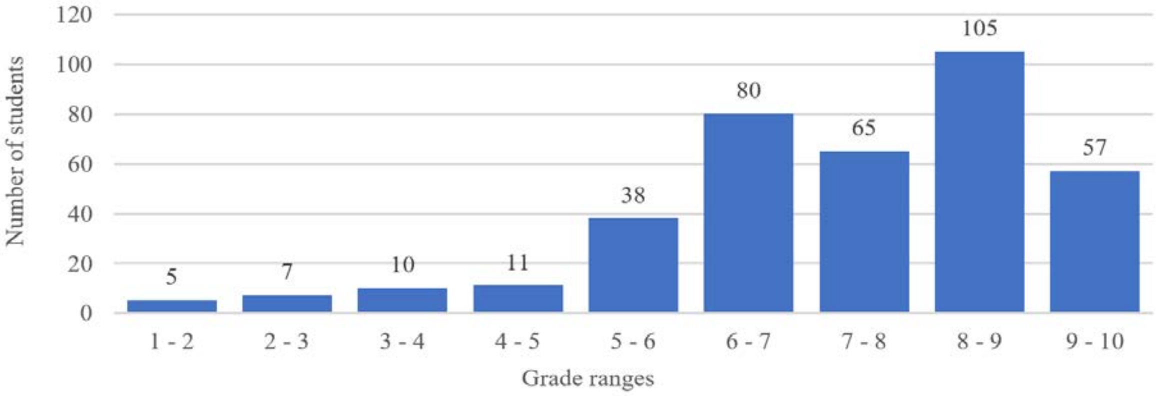

Figure 2: Histogram of the grades awarded to students for Practical 1.

Figure 3 and Figure 4 show the qualitative feedback for Practical 1, as experienced by the registered students. In this case, only 83 of the 379 students voluntarily answered the feedback questions, which were part of a final on-line self-assessment which called on students to reflect on the importance of both the theory and practical in ECT2. The majority of students (42 + 33/83 = 90.3%) indicated that they enjoyed the practical assignments, although 66% (21 + 34/83) did find them challenging to complete. Again, the majority felt that the practical assignments were relevant to the theory provided in the course content (46 + 27/83 = 87.9%) and that they required problem-solving skills on the part of the students (40 + 30/83 = 84% reported this).

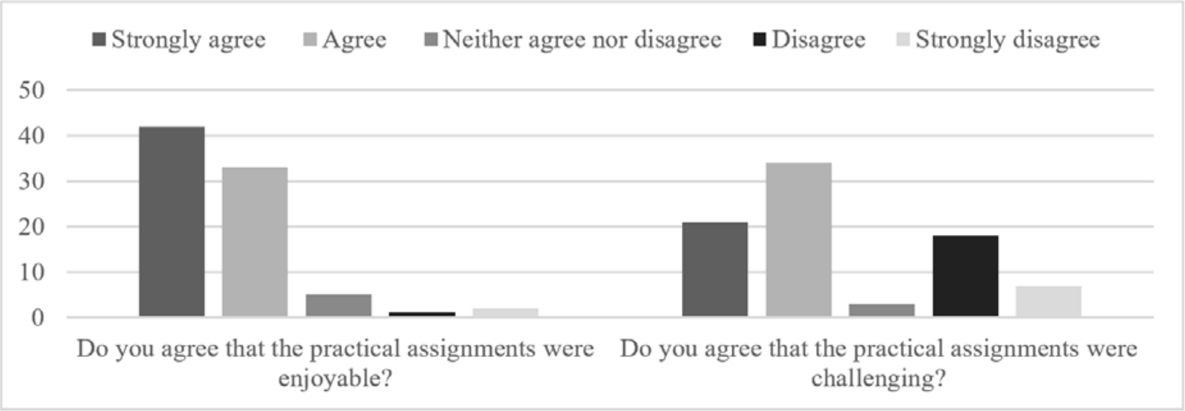

Figure 3: Student feedback on the practical assignments in terms of them being challenging and enjoyable.

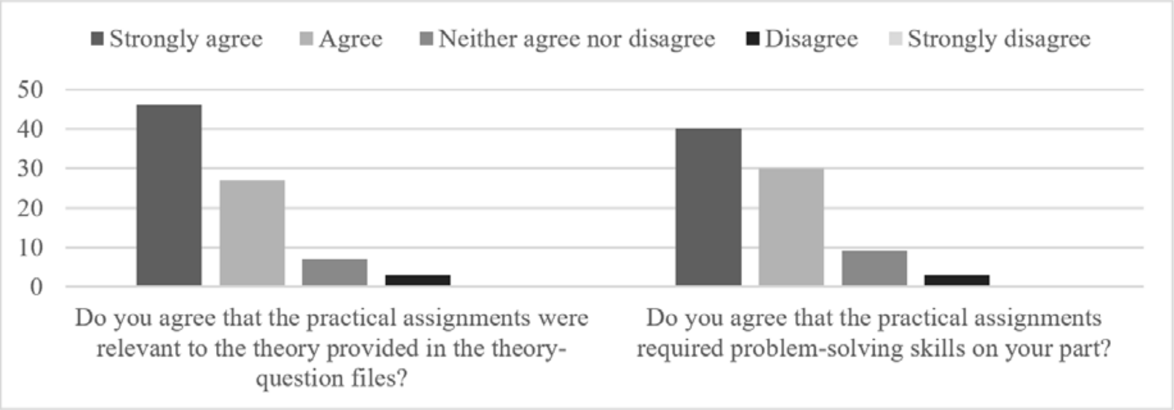

Figure 4: Student feedback on the practical assignments in terms of them being relevant to the theory and requiring problem-solving skills.

Table 1 depicts selective descriptive statistics for Practical 1. The mean value increased steadily from 6.73 in 2020 to 8.37 in 2022. This may be attributed to the improvement of the rubric, which was refined each year by the academic who reflected on its strengths and weaknesses in accord with the submissions of the students. The big improvement in 2022 may further be attributed to student presence on campus after the Covid-19 pandemic. CUT students are primarily socially engaged students who enjoy teamwork and collaboration [28], which may, at times, be more easily facilitated by on-campus activities. The kurtosis values of around 2 (2.16 and 2.33) indicate that the data follow the normal distribution perfectly [29]. A normal distribution indicates that the probability of data is the largest around the mean value, and that the distribution is almost within three standard deviations. The negative skewness value supports Figure 2, indicating that the distribution is tilted to the right with a long tail to the left.

Table 1: Selective descriptive statistics of the grades awarded for Practical 1.

Year	No.	*p* value	Mean	Median	Kurtosis	Skewness
2020	37	0.12	6.73	7	2.33	-1.15
2021	198	0.48	7.44	7.9	0.82	-0.93
2022	143	0.65	8.37	9	2.16	-1.49

CONCLUSIONS

The purpose of this article was to highlight how an on-line simulation tool was used in a practical assignment to foster ubiquitous learning on the importance of low-pass filters, thereby fusing theory and practice. Falstad was used as the on-line simulation tool, where students in CT2 had to generate 2 x time domains and 2 x frequency domains that illustrate the transformation of a square wave into a sine wave. All the students submitted the required practical assignment indicating that they had no trouble or challenges in accessing the on-line simulation tool.

From the results, it was seen that 87% of the students were able to engage in problem-solving skills by successfully designing and implementing a LPF with the use of Falstad. By this, they indicated competence in the graduate attributes of design or development of solutions and modern tool usage (graduates should be able to use information and communication technologies effectively). It is also noted that 42.7% of the 379 students obtained distinctions for the assignment. A post-assignment questionnaire revealed that 90.3% of the students enjoyed the practical assignment, while 66% found it challenging to complete (this suggests that it was not a simple exercise, but one that required thinking ability and problem-solving skills). The majority (87.9%) felt that the practical assignments were relevant to the theory provided in the course content, and 84% indicated that they required problem-solving skills to complete the assignment.

This study is limited to only one module and one practical assignment offered over a three-year period. However, the large sample size of 379 students does contribute to the validity of this approach, as none of the students indicated challenges in accessing or using the on-line simulation tool. The reliability of the approach is also seen in the consistent academic performance of students completing this assignment over the three-year period.

It can thus be stated that this practical assignment was a valuable learning experience, as it was enjoyable and relevant to the course content. Students could engage with this assignment anywhere, anytime and anyhow using various available technologies. Given the right tools, these students did wonderful things in completing their assignment on time and in achieving academic success.

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