Combining Theory and Experimentation to Develop Inductive Learning Skills in an Electric Circuits Course.

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Abstract

Since 2004 major curriculum changes have been made to the first year Electric Circuits course presented by the School of Electrical and Information Engineering, University of the Witwatersrand to both Electrical and Biomedical students. These changes were designed to reduce the failure rate in later years by better preparation of the students and also to filter out, in the first year, students with no prospects of completing the degree programme. In 2007 the course was changed to make the learning experience global, combining both the theoretical and practical aspects of the course with special emphasise on the best teaching practice of inductive learning. Two laboratory tasks were added, containing operational amplifiers and a resonant circuit, with the "tools" to model and understand these circuits being presented in the formal lectures. Analysis of the students' response indicate an improved learning environment for the students and a 30% improvement in the pass rate, from 60% to 80%, for the course in 2007.

I. Introduction

Curriculum changes are an integral and ongoing function of any degree programme. The School of Electrical and Information Engineering at the University of the Witwatersrand has structures in place to ensure that these changes are coordinated and are in line with outcomes required by the school and the courses presented in following years. Line committees ensure that courses within defined areas, such as power systems, control, electronics, etc., contribute to the outcomes of that area and an annual curriculum meeting (for all teaching staff) ensures that all the courses contribute to the outcomes of the degree programme. Many of the changes that have been made were in response to changes in accreditation requirements [1], [2] and the analysis of the changing skills of the students entering the degree programme [3], [4].

Electric circuits is an introductory course presented to all electrical, information and biomedical engineering students in the first year of study and is one of only two "engineering" courses the students undertake in their first year of study. The other course is an engineering design course comprised of English literature and a "build" project. Electric Circuits was identified in 2003 as the course where the students entering first year could start the transformation from their rote learning secondary school background to critically thinking engineering students. Many of the changes that were made were reported in Innovations 2006 [5]. These changes were also designed to reduce the failure rate in later years by better preparation of the students and also to filter out, in the first year, students with no prospects of completing the degree programme.

Each year the course has been evaluated both in terms of the feedback from the students and the final marks obtained by them in terms of the target outcomes [5]. These outcomes are the development of imagination, self-confidence, intrinsic motivation, critical thinking and problem solving. The analysis of these outcomes at the end of 2006 indicated that the students were having trouble relating the theoretical and practical aspects of the course and as a result were having problems visualising the concepts of voltage and current in both dc and ac circuits. The skills of exploration and experimentation were also at a low level amongst some of the students. The comments "Nobody showed me how." and "Nobody told me." were universal responses when the students were trying something new.

As a result of this analysis, changes were made in 2007 to further integrate the laboratory tasks with the material being presented in lectures. Course presentation in terms of the student intake, learning styles, the changes made to both lectures and laboratory tasks and preliminary results are discussed in this paper.

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II. The Students Entering the Degree Programme

Since 1994 the secondary school system in South Africa has undergone major, and ongoing, changes in an attempt to meet the social responsibilities and educational requirements of a new democracy. Analysis of the students entering the School of Electrical Engineering [3], [4] indicated an increased tendency for the secondary schools to "coach" students for the final exam, to improve both the individual student's marks and overall pass rates. Schools are rewarded by attracting more students and not attracting the attention of the National Department of Education. This concentration on high marks and pass rates for the final exam has resulted in the increase use of rote learning in all subjects and the dropping of the "difficult to teach" subjects such as Mathematics and Science. A report by the Centre for Development and Enterprise [6] shows that only 5% of the matriculants in 2004 passed higher grade Mathematics, a prerequisite for entering an engineering degree programme.

A number of the curriculum changes were made by the School of Electrical and Information Engineering to specifically introduce students to the rewards of self-discovery and self-motivation, sadly lacking in their secondary school education [5]. These included more laboratories with a self-learning approach. Some of our intake, just because they did reasonably well in higher grade Mathematics and Science, are "forced", by bursars and marketing pressure, to embark on an Engineering career. The practical aspects of the laboratories help these students decide whether engineering is really a career for them, or not, which also consequently helps to reduce the increasing drop outs we were experiencing in the third and fourth years of study.

A new National Senior Certificate has been introduced in South Africa to try and improve the problems of rote learning by introducing an outcomes based system which will reward understanding rather than just knowing. Time will tell whether we find an improvement in our intake, although the number of students with Mathematics and Science subjects is unlikely to increase.

III. Inductive Learning

In their paper Felder and Silverman [7] discuss the different learning and teaching styles in Engineering education. The paper describes the possible mismatch of a student's learning style and that of the teaching style of the lecturer. As this is his most cited paper Felder has added a preface [8] to the paper describing two significant changes he has subsequently made to his model. These are the changing of the visual/auditory category to visual/verbal and dropping of the inductive/deductive dimension. Although he still believes induction and deduction are different learning and teaching styles he states: "*the "best" method of teaching, at least below the graduate school level, is induction, whether it be called problem-based learning, discovery learning, inquiry learning, or some variation on those themes. On the other hand, the traditional college teaching method is deduction, starting with 'fundamentals' and proceeding to applications*".

Inductive learning is really how all the theories we teach were originally developed. Firstly observations, then experiments, more observation and eventually the development of theories and models to explain the observations. Traditionally courses present the theory and models and have some experimentation which actually says "I told you so". Students know this and and treat laboratory tasks as just an "I told you so" exercise without the understanding how the model would have been developed from their own observations. As is pointed out in our Electric Circuits course: "There are no Laws of Physics, just Observations and subsequent Models of Physics".

Although the the laboratories for the Electric Circuits course were changed in 2004 and appeared, to the lecturers, to be directly related to the theory being presented, most of the students still saw the lectures and laboratories as two unrelated tasks. This resulted in changes in the course in 2007 and 2008 to further emphasise the "observations first, model/theory next" process of inductive learning.

IV. Changes in 2007/8

Electrical Engineering is one of the more difficult subjects to teach as electricity cannot actually be seen and only the results of its work can be measured i.e. heat, motion, sound etc. One of the goals in presenting the circuits course is to enable the students to visualise what is happening in an electric circuit. It is not good enough just to memorise the equations of the models we use to visualise and explain the behaviour of electricity. It is also essential that the students understand how these models are derived, assumptions included, as this understanding is crucial for future success in the degree programme and a career in engineering.

In 2007, with a few minor modifications in 2008, the course structure was changed to make the learning experience global by combining both the theoretical and practical aspects of the course. The changes included the addition of two laboratory tasks containing operational amplifiers and a resonant circuit. These circuits were presented at the first lecture and the components to build the circuit given to the students at the first laboratory. The formal lectures were then presented the "tools" to model and understand these circuits. In informal lectures the students (and lecturers) tried to explain why the circuits often did not follow the theory and new models were created to explain these differences.

The seven laboratory tasks, built on "breadboard" and powered by 9 Volt batteries, that need to be completed by the students during the course of the year are:

1) Build and demonstrate an audio amplifier with a microphone input using a LM386 amplifier:
   This task is to introduce the students to the laboratory, electrical components, building and testing of circuits and the fun of creativity. This is the first time most of our students have ever built anything vaguely related to electric circuits and they can also "show it off" at home, as no laboratory equipment is required to build or test the circuit.
2) The students are given all the components to build the operational amplifier circuit shown in figure 1. They have to then model the circuit in terms of the models presented in the lectures, build and measure

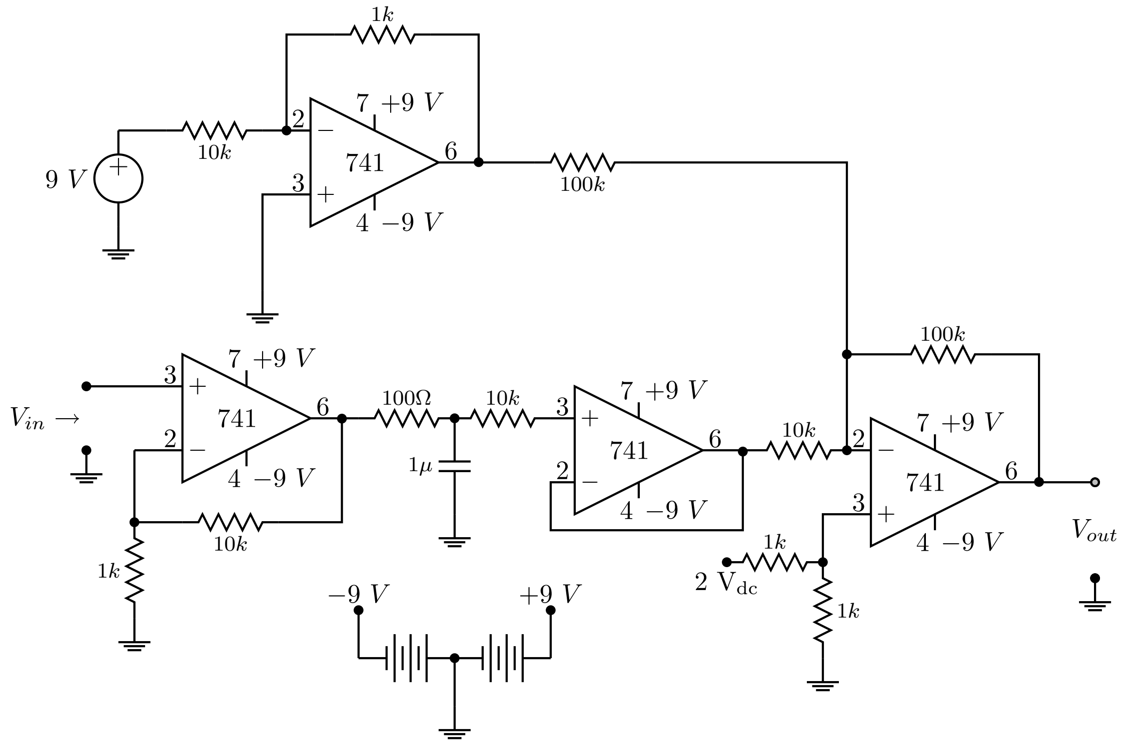

Fig. 1. An operational amplifier circuit

   the output with both ac and dc input signals and demonstrate these outputs to a tutor on an oscilloscope with inputs from a signal generator:
   There are no formal laboratories to "teach" the students how to use the laboratory equipment. They are expected to find the information on how to use the equipment from the handouts, their formal electric circuit notes and the library.
   These two tasks are expected to be completed by the end of the first semester with the lecture content just completing basic circuit analysis and the introduction of ac theories and phase shifts in signals. The students can actually "see" with their circuits what is being discussed in class.
3) For the third task students are required to build the circuit containing a resonant circuit (see figure 2) and demonstrate and explain their measurements:
   There is nothing like measuring 190 Volts across components supplied with a 9 Volt battery to bring the concepts of resonance to reality!
4) Two further tasks are the determination of the theoretical models of the circuit shown in figure 1 and that of South Africa's power grid: These tasks are used to combine, in the students minds, the measurements on the actual circuits and the theory presented during the lectures.
5) For the final two tasks the students revisit the audio amplifier. Individually they must, using measurements, determine the frequency response and the Thévenin equivalent circuit of the amplifier circuit.

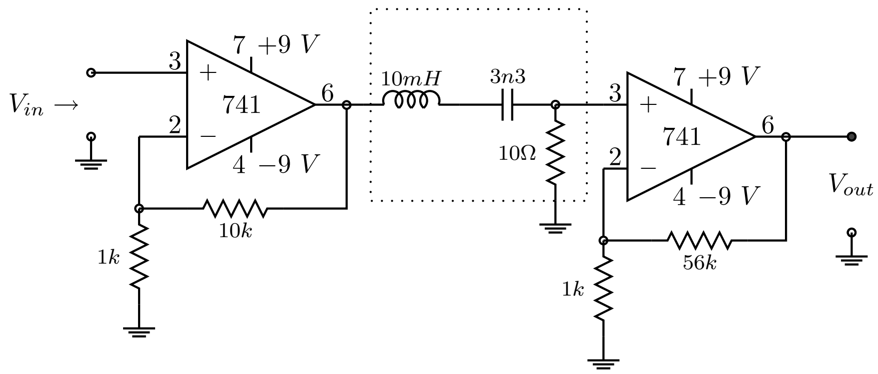

Fig. 2. Another operational amplifier circuit

They are then required in groups of four to build and demonstrate, over a distance of 50 metres, the two wire communication system shown in figure 3:

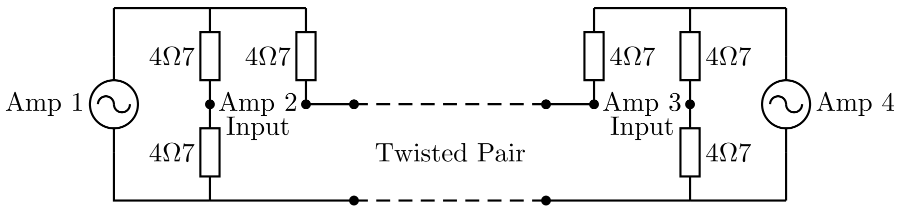

Fig. 3. A resistor bridge two-wire communication system.

These tasks tie the end of the course back to the beginning, giving the students a feeling that they have accomplished and learnt something during the year and also have some fun talking to each other using a system they have built and analysed.

The laboratories are also run quite differently from the traditional well controlled one experiment, and only that experiment, at a time method. The students are encouraged to experiment and are only guided, not directed, by the under-graduate student demonstrators and the post-graduate student tutors. The demonstrators and tutors have been instructed not to help students with specific solutions until all else has failed, with the standard answers of “What do you think” and “Go and try it” as the most common responses to almost all questions. Interestingly the interaction in the Electric Circuit’s laboratories is quite different from other laboratories with an almost collegiate atmosphere between the students and the tutors and demonstrators. The Electric Circuit’s laboratories have also become the most popular laboratories to tutor and demonstrate.

The laboratory tasks do not attract any marks but are “Satisfactory Performance” requirements for the course and non-participating students are deregistered from the course, allowing the staff and tutors more time for the students actually participating in the learning process.

V. Results

Preliminary analysis of the results from course changes, such as those discussed in this paper, are largely subjective with a long time lag (at least four years) before the students graduate and a complete objective analysis can be undertaken.

From the lecturers point of view there was a big change in the attitude of the class, as a group, in 2007 when compared with previous years (2004-2006). Debates were vigorous, when differences in opinion arose, and the students were more prepared to challenge the theory being presented in the formal lectures, based on their observations. A course evaluation by the students indicated the the laboratory tasks, although challenging, were enjoyable and did add to the theory being presented. These debates are continuing in the same manner with this year’s student group with even more freedom of expression and the lecturers very seldom completing a lecture as planned.

Personal communication, mostly unsolicited, with repeating students indicated that seeing the reason for the theory made it easier to understand and analyse.

The final marks for the course in 2007 also indicated an improvement, with a pass rate of 80% compared with a pass rate of 58% and 61% in 2005 and 2006 respectively. Although not quantified, the lecturers marking the exams felt that the students seemed to have more insight when answering the questions, with a big improvement in the understanding of ac theory.

VI. Conclusion

A secondary school system based on rote learning has resulted in the students being totally underprepared for an engineering degree programme. As a result of this underprepared student intake changes have been made to a basic electric circuits course to introduce, formally, the best teaching practice of inductive learning while also introducing the concept of critical thought, the fun of exploration and the enjoyment of engineering.

Laboratory tasks have been introduced to enable students to relate their observations and measurements of the electric circuits to the material being presented during lectures. This has also facilitated the easier visualisation of the models and theories being developed to explain the behaviour of electric circuits. Timing of both the laboratory tasks and the material being presented in lectures have also been synchronised to optimise the inductive learning process.

The results, although largely subjective, indicate an improved learning environment for the students with an increased pass rate of 80% for the course in 2007 from about 60% in 2005 and 2006.

References

[1] ECSA, *Engineering Council of South Africa: Standards for Accredited University Engineering Bachelors Degrees. PE-61, Rev. 1*, Johannesburg, 20 July 2000.

[2] *Washington Accord*. (2005) Washington accord: A multinational agreement signed in 1989. Revised August 17, 2005. [Online]. Available: http://www.washingtonaccord.org

[3] G. J. Gibbon, "Changes in course presentation to accommodate the 'information age' and outcomes based requirements," *Transactions of the SAIEE*, vol. 94, no. 3, pp. 10–16, Sept 2003.

[4] G. J. Gibbon, K. Nixon, and M. Nixon, "Analysing the raw material: Who are our first years?" in *Engineering Education for Sustainable Development*. Pretoria: 3rd African Regional Conference on Engineering Education, Sept 2006, pp. 399–407.

[5] G. J. Gibbon, I. R. Jandrell, and D. Rubin, *Innovations 2006: World Innovations in Engineering Education and Research*. Arlington: iNEER, 2006, ch. 4: Shifting the Responsibility of Learning in First-Year Electrical Engineering Students, pp. 27–38, 2006.

[6] Centre for Development and Enterprise, "Doubling for Growth: Addressing the maths and science challenge in South Africa's schools," Centre for Development and Enterprise, Johannesburg, CDE Research Report no 15, Oct. 2007.

[7] R. M. Felder and L. K. Silverman, "Learning and teaching styles in engineering education," *Engineering Education*, vol. 78, no. 7, 1988.

[8] R M Felder. Learning and Teaching Styles in Engineering Education: Author's Preface. [Online]. Available: http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/LS-1988.pdf