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Research Article

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Reconstructing A 3rd Year Power Electronics Course

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Abstract
Electrical Engineering and technology evolve at a very fast pace. However, undergraduate courses, especially those who build fundamental knowledge in Electrical Engineering, do not change so fast. In this article, we describe a major redesign of a 3rd year power electronics course (first course to introduce power electronics in the degree) incorporating new educational technologies and an improved pedagogical approach: the net effect was better student experience and satisfaction, and better learning.

Keywords: Undergraduate Education, Power Electronics, Electrical Engineering

Significance and Rationale: In the current work, we have added different educational activities such as quizzes, group discussions, questions during lectures to increase student engagement. It is known that increasing engagement with students lead to improved learning.

Methodology
Students responded to survey questions in different years: in particular, students were surveyed before and after the changes were introduced to assess the efficacy of changes. We have also run statistics for test results.

Research Findings
• Students better engage with the course material if they can relate their learning to practical examples.
• New technologies can provide better access to learning resources and improve assessment, but also pose new challenges to integrity of assessments.
• Well prepared experiments can help students to better solidify the theory learned in class, identify the limitations of existing theory and better connect theory with reality.

1. Introduction

Teaching is the art of facilitating learning. Although the main task of the lecturer is to convey information to students, the educator must provide different opportunities for the students to learn the course material, trying to engage them as much as possible. As technology evolves, we need to change not only the course contents but also employ new technologies that enable a better teaching experience for students. At the same time, any course aims to make our students technically competent in what they are learning and, overall, in their profession. Whenever a new course is being designed, it is recommended to consider Brookfield's four lenses [1]. (a) our own experience as learner of that course, (b) feedback from students, (c) our colleagues' suggestions and feedback and (d) guidance from the theoretical literature. The first lens allows to reflect on how we learned the course material, the strengths, and weaknesses of how the contents were presented to us, while the second lens allows us to assess the difficulties of the students with respect to the course material, what needs to be improved in terms of lectures and experiments and how they experience learning [2]. The third lens allows us to get new ideas on how to deliver the course material and to discuss our problems when delivering the course. Finally, literature provides resources to better scaffold our course, assess our students and organize the contents.

In the course, power electronics is the application of electronics for the control and conversion of electric power [3]. A traditional application of power electronics is to drive motor drive systems and control industrial processes. In recent years, the advent of renewable energy sources (e.g., solar, wind, hydropower sources), boosted the necessity of transforming the generated electric energy from one form into another (e.g., from DC current generated by a solar cell into AC voltage used by household appliances), reinvigorating power electronics together with advances in solid-state electronics. The core course comprises of 3 hours lectures, 1-hour tutorial and 3 hours laboratory. It is the first power electronics course for Electrical Engineering degree, and they generally take the course in the 3rd year. The course runs for six weeks, with topics comprising general semiconductor power devices, rectifiers, DC-DC converters, and inverters. In this article, we initially describe how the course ran before the changes and then describe the changes to the course based upon the four lenses described before: the result is that the lectures became more engaging, the laboratory experiments more related to renewable energy and students were periodically assessed allowing them to better assess their level of learning.

2. Literature Review and Background

Electrical engineering is a very rapidly evolving field of study, always putting pressure on a degree that needs to be delivered in a four-years' timeframe. In addition, the degree is subject to different constraints and regulations such as accreditation by a professional body (e.g., Engineers Australia [4]. Job market, student background and motivation, university quality frameworks and industry needs. Finally, artificial intelligence is impacting society, including higher education: for example, the advent of Artificial Intelligence (AI) changes the way we teach and assess our students [5]. In any educational course, we are told that lecturers need to engage students for active learning: as argued by Freeman [6]. Active learning improves the performance of students. In fact, Chi has shown that the lowest learning gain occurs when there is no active engagement in the lectures, such as passively listening to the lecture [7]. Active learning looks like a simple task, but the essential question on how to engage students is fuzzy and becomes more complicated when learning activities need to engage students in hard topics. Moreover, successful engagement requires a proactive response from students: some students feel threatened when his/her responses are needed, and others need more time to absorb new knowledge. Finally, as stated by Streveler and Meneke active learning will not solve all instructional problems and require extensive design, implementation, and assessment [8].

A good example of active learning is peer learning in this method, a brief lecture is followed by questions [9]. If the students provide the incorrect answer (>70% incorrect answer), the concept is revisited; if they provide the correct answer (>70%), then a short explanation is provided, and the lecturer moves to the next topic. However, if the correct answer is between 30-70%, then there is a discussion amongst students, and they revote the correct answer. Peer learning has led to lower course dropping, a reduction of students' attrition and encouragement to group work, all leading to an increase of the final exam scores [9]. It is even argued that peer instruction leads to knowledge gain to students with lower background knowledge. Collaborative learning was also studied by van Helden and co-authors [10]: they concluded that collaborative learning, if well implemented, can lead to the achievement of learning objectives. It is useful in designing project courses where students work in small groups to solve complex problems. However, it is necessary to clearly specify the objectives, rules, division of labour and provide adequate tools. Conflicts can arise when students have different motivations and backgrounds or personal differences, which can lead to non-productive learning.

In addition to teaching technical content, lecturers need to consider many other factors when teaching a subject: previous knowledge of the students, level of numeracy, diversity (e.g., age, gender, ethnicity) of the classroom and their perceptions of their future careers. Also, engineers now need to be prepared to be good global citizens in fact, engineers can contribute to addressing the main challenges of the 21st century including climate change, poverty, war, and illness [11]. In addition to acquiring technical skills, engineers also need to learn soft skills such as interpersonal skills, teamwork, communication skills, leadership, self-management, and adaptability [12]. The emergence of new technologies also creates many new opportunities for classroom interaction lectures can be recorded, students can be assessed online, lecture notes are widely available to students, formative and summative feedback can be given in real-time, students can peer-assess each other, students can discuss different topics amongst themselves and with the teacher online and there are many sources of information about any topic online [13]. There is even the possibility of running experiments online nowadays.

Mathematics is an essential skill for engineers, but different students have different mathematical abilities: some can use mathematics in a skilled manner, some can do calculations but cannot clearly explain what they are doing, while others cannot even do calculations in a basic way. Hadley and Oyetunji have listed 10 core math skills for engineers such as describing differentials as differences, limiting cases, integrals have embedded meaning, perceptions of magnitude, algorithmic reasoning, and graphical numeracy [14]. In the power electronics course, students should be proficient in solving ordinary differential equations, conduct circuit analyses, calculate Fourier series and integration: some students have difficulties to conduct these tasks, creating the necessity of providing remedial support for struggling students. In another technical course (Signals and Systems), Crockett et al [15]. Have reported similar findings such as "many students arrive at correct answers despite incorrect or incomplete understanding", while other students had difficulties even to perform simple mathematical operations.

In addition, some of the students in the course are military students who are either studying at university many years after they have completed high school. As reported by R. Shariat and co-authors [16]. Students who had previous military training can have better performance than young students since they tend to be more mature and more focused. However, they also need to deal with the fact that they will need to refresh many mathematical concepts. Teaching should also be inclusive and respect differences in terms of gender, ethnicity, cultural background, and age.

Laboratory exercises help students to acquire hands-on experience on technical equipment such as power drivers, inverters, DC-to-DC converters, and power systems. Hands-on-skills are important in many industrial jobs where graduates are expected to be competent in designing circuits, use equipment and analyse data. Also, laboratory exercises help students to better understand and consolidate concepts learned during the lectures. However, as stated by Santos et al, no matter how much we train our graduates, their competences do not always match the market expectations and the difference can be as high as 30% [17].

Assessment is an important component of any course: we need to assess the level of learning of the students on the course. There are many levels of learning as described by Bloom knowledge, understanding, application, analysis, synthesis, and evaluation [18]. Higher grades are often associated with higher levels of learning including the ability to analyse, evaluate and create knowledge. Although assessment is necessary to assess learning, it can also lead to anxiety, stress, and frustration to students: to minimize the feelings, assessment needs to provide enough time to tasks to be completed by different students, the instructions and information need to be accessible, consistent, and clear and accommodations should be provided to students with disabilities [19]. We need also to combine formative and summative assessment with rich feedback used in an efficient way, it can lead to a better learning experience [20,21].

Digital technologies can also be used for assessments, leading to outcomes such as knowledge improvement, improved digital literacy and a way to develop credentials [22]. In fact, computer technology is being used to detect plagiarism, predicting students at-risk of failing, which is quite useful for essays and reports. It is tempting to also use modern technology to run class tests and final exams, instead of using old-fashioned in-class paper tests. However, its use comes with caution: security breaches can occur, illegal collaboration can occur, and modern artificial intelligence programs (e.g., ChatGPT) can be used to solve online questions. For example, in one study, Newton and Xirometi [23] concluded that, in a multiple-choice test, ChatGPT performed better than random choice of answers but could allow students to pass the course.

3. Description of Courses and Changes

The power electronics course is a core course within the Electrical Engineering degree: it was initially offered in the 4th year of the degree program, but now is being offered in the 3rd year. The course builds on past mathematics courses in the first 2 years plus basic circuit analyses. Most of the students are military students with a small cohort of civilian students (around 15 % of the class). Although we have mature students, most students are in their twenties. The course comprises of 3 hours of lectures, 1 hour of tutorial and 3 hours of laboratory experiments per week – the whole course runs for six weeks. This is the first course in power electronics which is followed by more advanced elective courses in the 4th year. The lecture contents are shown in Table I, week by week: most of the course covers conversion of one type of voltage into another.

Week	Topic
1	Introduction to power electronics
2	Rectifiers- AC/DC converters
3	DC/DC converters
4	DC/DC converters- Inverters
5	Inverters
6	Introduction to motor drives

Table 1: Weekly Distribution of Lectures

As advised by Streveler and Menekse all lectures are available on the Moodle website as are the solutions of tutorial questions [8]. All lectures are pre-recorded so students can revise the lectures or watch them online. Note that the changes were implemented over a few years, based on the four lenses of Brookfield my own experience, students' feedback, peer review teaching and the literature [1]. In terms of peer review teaching, some of the lectures have been attended by university academics who provided constructive feedback on the lectures. I have also discussed with my colleagues how to improve the course and the lectures. Remembering the lectures a few years ago, it was teacher centric with students listening to the lectures in sessions of 50 minutes. The first major change was in the structure of the lectures: the title of each lecture is now followed by the learning outcomes of the lectures, then a short introduction why the topic is being learned, followed by the lecture contents with several examples and the summary of the main points. The learning outcomes in the beginning of each lecture guide the learner to what he needs to concentrate his/her learning efforts – although it might seem obvious to the professional what the main points are, it is not so obvious for the beginner. Previous knowledge is also highlighted to guide students on what they need to remember before reading the lecture notes and content. The introduction to the lecture is generally either an educational video or the lecturer highlighting the main applications of the topic. Observing students watching the videos, I had a mixed response from students: some students watched the videos with attention while videos others turned off – a similar response was observed by Amashi et al. [24]. Nevertheless, videos offer diversity in teaching. In addition, we have used software to reduce writing on a whiteboard since it could be illegible for students sitting in the back rows.

As aforementioned, the lectures were teacher centric and have been modified over the years: questions were introduced in the lectures to assess students' learning of topics, similarly to Mazur's group [9]. If an answer was incorrect by most students the topic was revisited and re-explained. Secondly, the lecture was broken into blocks as suggested by Brookfield [2]. The main topic discussion was discussed after the introduction with a presentation of a main circuit: students had 5-10 minutes to study the main circuit (e.g., a step-up DC-DC converter) and try to understand how it worked. The main operation was then described to exploit the physics of the devices. Finally, the main equations describing the operation of the circuit with highlights of how the equation was derived were explained. In general, the details of each mathematics derivation are only fully understood if the student derives the equation by himself/herself – however, an explanation of the steps in which the equation was derived helps even weak students. Questions are also asked during the lectures to increase the interaction with students and find their difficulties: as stated by Chi asking comprehensive questions during lectures leads to greater learning gains [7].

After the main topic is presented, it is followed by examples and a summary of the lecture. I add many examples in the lectures since many students learn by example. Although we generally do not have enough time to go through all examples, students can go through the examples to verify their learning, if they still have questions concerning the lecture notes, they can contact the lecturers to correct their mistakes, fill gaps of knowledge, clarify their misunderstandings and, sometimes, correct the lecturer's mistakes.

In the first week, we introduce power electronics and a revision of mathematics and circuit theory. Although there are only a few review lectures, we provide help and personal assistance in case they still do not remember what they have learned before. In the worst-case scenario, the university provides peer support from other students and remedial support from other academic staff. Tables and textbooks are also available for consultation: the variety of problems faced by students is quite diverse, but the most difficult mathematical tool faced by students is Fourier series. The concept is abstract but is highly important in the study of inverters, since DC voltages are switched on-off creating square-like waveforms that are only understood through the application of Fourier series. Although students have learned these concepts in previous courses, misconceptions remain, or they still lack the ability to properly apply mathematical concepts – misconceptions have been identified in a variety of courses at different universities. For example, in a semiconductor course taught by Nelson and co-authors [25]. He observed that students had difficulties connecting mathematical concepts with the physics of the devices. Also, in week 1, students work in groups to discuss different applications of power electronics – the exercise allows them to understand why they are learning power electronics.

Tutorials offer students a chance to test what they have learned during the lectures and receive formative feedback. We ask students to work in groups to solve the questions in the tutorial: collaborative and peer learning help students to learn. When we feel that students are facing difficulties in solving problems, we generally try to solve one problem as a starting point in the tutorial. They can also ask questions during the tutorial, and I try to help them as much as possible. In the end of the tutorial session, we ask one group to present the solution of 1 question. The laboratory experiments are divided into two parts: initial simulations followed by experiments. Simulation software such as LT Spice helps students to visualize waveforms, experiment with circuits and better understand how they work by observing waveforms at different points of the circuit. As argued by Nelson and co-workers, simulations can help students to overcome their misconceptions about the theory [25]. Assess the limitations of the theory and reinforce learning. Having said that, although simulations are considerably cheaper than real circuits, the experience of analysing real-world circuits provides precious hands-on skills to students. There were four experiments in the course: one on rectifiers, the second on DC-DC step-up converter, the third on inverters and the last one on motor drives. We have added learning outcomes to each lab script since students wanted more guidance of what they had to focus on their reports. In addition, marking rubrics was given to students to better clarify how they were being assessed. Also, the first lab report on rectifiers is formative, allowing students to receive feedback and prepare better reports that will be assessed at the end of the course. Given the limited time that students spent in the laboratory each week, they were provided with specially fabricated circuit boards, avoiding spending time debugging circuits. Assessment is essential to determine the level of learning, I generally assess students based on Bloom's taxonomy. However, assessment is always a bone of contention between the lecturers and students: although the lecturer has the power to assess the students, students can strike back by writing bad comments on course surveys and complaining to department heads. To keep students engaged with the course materials, students had to take multiple-choice online fortnightly quizzes that were automatically graded. Since online quizzes are subjected to illicit collaboration between peers, use of unauthorized notes or web information, unauthorized use of equipment and impersonation the total weight of quizzes was kept to 5% [25]. Students even had the opportunity to increase their grades by submitting written answers for the wrong answers. We believe that the quizzes kept students engaged with the course material without significant stress. The addition of a formative report led to better lab reports, with some students completing the cycle suggested by Houston and Thompson the end goal of formative assessment is to lead to better results in summative assessments [20].

The class test aimed to assess different levels of learning, with questions with different degrees of difficulty. The most difficult question in the class test was beyond the course material and required a certain degree of creativity. Finally, the final exam was like the class test but more focused on inverters to reduce stress in students. From time to time, some students need to repeat the course. As stated by Emberley and co-workers, students have different responses to failure: unresponsive (do not change past behaviour's), avoidant (he/she is discouraged by failure and reacts with self-sabotaging behaviour's), floundering (student tries to overcome his/her failure but the efforts are unproductive) and rebounding (changes his/her strategy to achieve success) [26]. In case of unresponsive and avoidant students, many of them end up abandoning the degree. An avoidant student is generally given counselling and private tutoring, in addition to taking home tasks, ending up passing the course. Floundering students are provided extra support with further explanations after class and ended up passing the course. Finally, not much support was necessary for rebounding students, except for extra encouragement.

The study tried to address the efficacy of the changes with respect to previous runs of the course: it will address both the students' feedback (both formal and informal), and class test results. In addition to formal feedback provided by the university students' surveys, I ran weekly critical incident questionnaires (CIQ) to get informal feedback about how the course was going. Basically, CIQ asks simple questions about what mostly engaged the student and what topic made him/her confused [2].

A. Nature of The Student Cohort

The study involved 45 undergraduate Electrical Engineering students. The course has been running for 10 years, but the major changes have been implemented in the last 2 years. Most students are serving the military (around 80%) but we also have civilian students (the remaining 20%). Most students are in their twenties (around 80-85% of the cohort, including some military cadets), but we also have matured or advanced age students with ages between 30 and 60 years old. In general, a university degree offers the possibility of being promoted. In terms of gender, most participants are men (approximately 75%) and the remaining women.

B. Students' Surveys

UNSW runs a student survey called *My Experience*: students are asked to answer several questions about the lecturers as shown in Table II. For each question, the options are: Strongly disagree (SD- 1 point), disagree (D- 2 points), moderately disagree (MD-3 points), moderately agree (MA-4 points), agree (A- 5 points) and strongly agree (SA- 6 points). The statistics of the responses are generated by computer software and compared amongst results from the faculty and the broad university.

Questions
1. The lecturer encouraged student participation
2. The lecturer provided helpful feedback
3. The assessment tasks were appropriate
4. Overall, I was satisfied with the lecturer's teaching

Table 2: Questions in The Student Survey

In addition to the student survey rating, students are also encouraged to provide informative feedback on the teaching. Although student surveys are indicative of success and failures when teaching a course, it should be noted that many of the responses are emotional rather than analytical [2]. Also, the relevance of learning may not be appreciated immediately but many years after graduation. Finally, it should be mentioned that students' surveys are influenced by cultural and gender biases [28]. We still remember this factor being pointed out to the dean of education in a discussion of students' surveys. In fact, the authors of the article are non-native English speakers, with different accents from most students, which influences the survey responses [28]. A general perception amongst many academics from diverse backgrounds is that 'it is very hard to compete with white and native speakers in teaching', but active engagement with them is still possible. In addition, as stated by Brookfield [2]. We always need to separate destructive from constructive feedback: racist and offensive comments will never help to improve our teaching.

C. Class Test Results

Another metric is class test results. Students' surveys are valid to find problems in a course, but class test and final exam results provide a more quantitative evaluation of learning. As aforementioned, whenever an assessment is constructed, the aim is to assess different levels of learning: from pre-structural to deep learning. The easiest questions examine the ability of students to solve simple problems based on direct application of formulae, then the difficulty increases as students must analyse the questions to create solutions for a question beyond the course material. Although we try to keep the difficulty of class tests and final exams at a similar level, their results are affected by the student's previous knowledge: although we provide some remedial support for struggling students, the support is not a good replacement for years of mathematics and science courses at university and high school. In addition, different students have different math abilities.

A major restriction on the class test/final exam results is imposed by university standards: we need to abide to limits higher grades and failures. As a rule, the university requires that no more than 10% of the class either fails or ends up with marks above 85%, while the total number of marks above 75% must be below 50%. If there are too many failures or high marks, then the faculty has the right to moderate the marks.

D. Lab Reports Results

Students are required to submit online lab reports at the end of the semester. They are provided with formative and summative feedback after submission. They are not only assessed by their correct responses, but also by their ability to analyse and explain the results in both qualitative and quantitative ways. Although online submissions are subjected to illegal collaboration, plagiarism, and cheating most students will not spend time copying a very well written and comprehensive report [26]. In fact, based upon the analysis contained in a report, it is possible to quantify how much a student has learned from the lecture notes. The measurement is affected, however, by the students' writing skills and the amount of effort that they spend writing the report. It should be noted that, some international students have high scores in class tests/final exams, but not as good scores in lab reports – which can be explained by their difficulties in expressing their ideas in a second language (e.g., English).

4. Results and Discussion

The first analysis is about the students' survey: the weight of the responses is: SD (strongly disagree- 1 point), D (disagree- 2 points), MD (moderately disagree- 3 points), MA (moderately agree- 4 points), A (agree-5 points) and SA (strongly agree- 6 points). The results for question 4 are shown in Fig.1 for the worst result before changes (blue), the best result before changes (orange) and results after the changes were implemented (grey). The mean and variance for different questions are summarized in table II for the worst case before changes (w), the best case before changes (bb) and after the changes (a).

The first impression is that student engagement (Q1) is correlated with the quality of teaching (Q4) and they have similar patterns. It seems that when students are satisfied with the course and teaching methods, the variance is lower than when they are dissatisfied (exceptions evidently exist whenever students are quite angry with the course, some survey results in the university show averages between 1.0 and 2.0). When the average is below 4.0, the university starts conversations with the lecturer(s) of the course and requests an action plan to improve students' satisfaction. The responses for question 4 are summarized in Fig. 1: the red bars represent the worst response; the orange bars the best responses before changes and the blue bars represent the responses after changes: the students were overall satisfied with the teaching, with no disagreement.

Question	Average	Variance (σ)
Q1w	3.63	2.10
Q1bb	4.89	1.45
Q1a	5.23	1.45
Q2w	3.62	2.11
Q2bb	4.78	1.45
Q2a	5.3	1.44
Q3w	3.7	2.06
Q3bb	4.45	2.18
Q3a	5.07	2.27
Q4w	3.63	2.11
Q4bb	4.78	1.45
Q4a	5.30	1.45

Table 3: Responses to The Student Survey

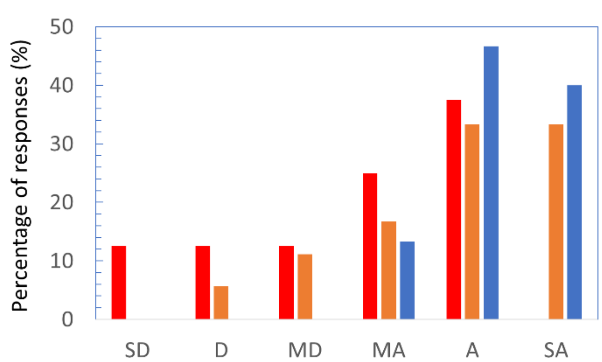

Figure 1: Survey responses to question 4: red (worst response before changes), orange (best response before changes) and blue (response after changes).

Student satisfaction is one of the methods to analyse the efficacy of changes in a course but is always subject to different biases such as gender, race, and country of origin [28]. In the current study, about 85% of the students were born in Australia, with only 15% being born overseas. One more quantitative result are the results from the class test, with a grain of salt: the university has several constraints on marks such as low percentage of marks above 85% (percentage p less than 10%) and percentage of marks above 75% should be less than 50%. In general, if the overall marks are high, the final exam needs to be more difficult than usual to reach the statistics targets. If, after the final exam, the distribution of marks is still too high or too low, the faculty has the right to moderate the marks. It is also expected that the marks will have a Gaussian distribution, but this is not strictly enforced. Since the class test marks are discrete and spread over 100 numbers, we will gather the marks into UNSW defined categories: F (fail) for marks below 50%, P (pass) for marks between 50% and 64%, Cr (credit) for marks between 65% and 74%, D (distinction) for marks between 75% and 84%, HD (High Distinction) for marks between 85% and 100%.

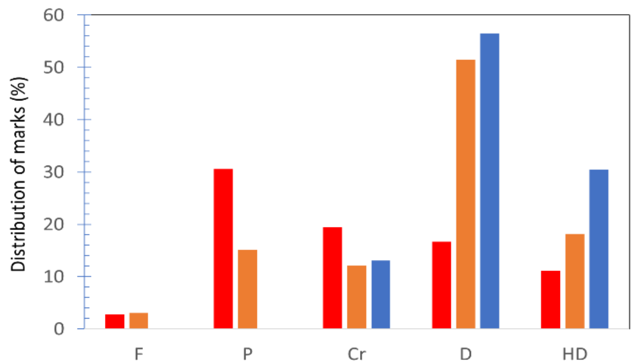

Figure 2: Distribution of marks for the class test: red (worst response before changes), orange (best response before changes) and blue (response after changes).

Fig. 2 shows the distribution of marks for the 3 cases discussed in Fig. 1: although we attempt to make class tests with similar levels of difficulty, the results also depend on factors such as background of the students, motivation, mathematical skills, and number of course they are taking in that semester. In the worst case, the class tests also presented the worst results, and the results were better after changes when students really tried to engage with the course material albeit with their own limitations. In fact, the marks after the changes were so high (even after a hard-final exam) that we had to moderate down all marks twice to abide with the university policies.

Before attempting to run a statistical analysis of the class test results, a few variables are defined through the equations below:

a) The average of N_r marks [m_{1r},m_{2r}, m_{3r} ..m_{Nr}] is defined as,

$$m_{avg,r} = \sum_{p=1}^{N} \frac{m_{p,r}}{N_r} \qquad (1)$$

where r=w for the worst results before the changes, r=bb for the best results before the changes and r=a for the results after the changes.

b) The corrected standard sample deviation is calculated as,

$$\sigma_r = \sqrt{\frac{\sum_{p=1}^{N}\left(m_{p.r}-m_{avg,r}\right)^2}{N_r-1}} \qquad (2)$$

Since the average, corrected standard sample deviation and number of samples are different, we have decided to calculate the Welch's test parameters [29,31]. The statistics parameter for Welch's test are given as,

c) Given two collections of marks r and q, the t-parameter between the two samples is calculated as [29-31],

$$t_{r,q} = \frac{m_{r,avg}-m_{q,avg}}{\sqrt{\frac{\sigma_r^2}{N_r}+\frac{\sigma_q^2}{N_q}}} \qquad (3)$$

d) The Welch's degree of freedom between two collections of marks r and q, is calculated as

$$v_{r,q} = \frac{\left(\frac{\sigma_r^2}{N_r}+\frac{\sigma_q^2}{N_q}\right)^2}{\frac{\sigma_r^4}{N_r^2(N_r-1)}+\frac{\sigma_q^4}{N_q^2(N_q-1)}} \qquad (4)$$

We compare the 3 cases (w, bb, and a) in pairs with Welch's statistics.

The results are summarized in Table IV. The average is worst for the worst result (w) which can be correlated to the worst student satisfaction as shown in Fig. 1. Although class test results are correlated to students' satisfaction, other factors such as cultural background and biases, empathy of the lecturers and students' relations with the lecturers are also important in students' evaluations (there were cases in which the average of the class test was like the best case, but the students' satisfaction wasn't high). After the changes, the average increased and the marks were higher: students' motivation led to better learning and, consequently, higher marks.

Sample	Average	Corrected standard sample deviation	t-parameter	Degree of freedom
Worst results before changes (w)	66.5	16.1	$t_{w,bb}$ =-2.71 $t_{w,a}$ =-4.84	$v_{w,bb}$ =55.89 $v_{w,a}$ =43.16
Best results before changes (bb)	77.7	16.2	$t_{bb,a}$ =-0.78 $t_{w,bb}$ =- 2.71	$v_{w,bb}$ =55.89 $v_{bb,a}$ =30.52
Results after changes (a)	80.2	6.2	$t_{w,a}$ =-4.84 $t_{bb,a}$ =-0.78	$v_{w,a}$ =43.16 $v_{bb,a}$ =30.52

Table 4: Statistics of The Class Test

When analyzing Welch's test, the t-parameter calculations show that the results have quite different averages, with a larger difference between the results after changes and the worst results before changes, as expected. In addition, the introduction of quizzes gave students a better idea of what to expect in the class test. In terms of the lab reports, the general expectation is that the student will get higher marks (D, HD) if his/her results are correct, and he/she explains and analyzes the results. Just presenting the results leads to a maximum mark of Credit. Students also work in small groups in the lab and generally write the report at home: it means that students can share information amongst themselves, discuss their results and analyze the data in groups. Table V summarizes the average and standard deviation of the results for different years: there is not much difference between their mean values and deviation.

Sample	Average	Corrected standard sample deviation
Worst results before changes (w)	76.7	17.3
Best results before changes (bb)	73	21.1
Results after changes (a)	76.7	17.3

Table 5: Statistics of The Lab Reports

Figure 3 shows the distribution of the marks for the lab reports: they do not have a considerable difference for the 3 cases studied here. However, since the lab reports are submitted after the end of the lectures and class test, it can be observed that given that the class test results were lower in the worst case, students spend more time writing the lab reports, leading to higher marks. It is hard to fail a lab report, and, in most cases, this happens when the student does not submit any report. Students are given rubrics about what is expected in their lab reports, but it does not necessarily increase their marks. Finally, the formative assessment for the first lab report (submission was optional) led to better lab reports for about 60% of those students who requested formative feedback (less than 15% of the class).

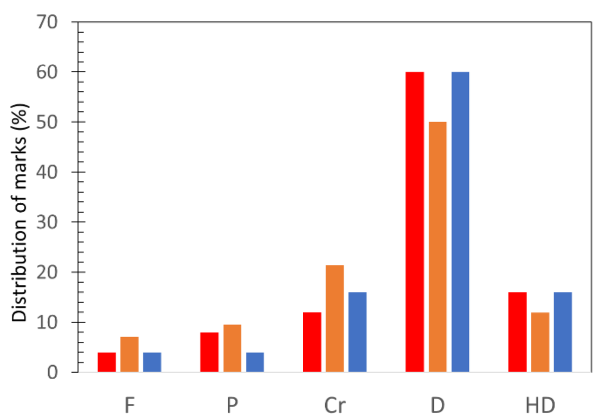

Figure 3: Distribution of marks for the class test: red (worst response before changes), orange (best response before changes) and blue (response after changes).

Engineering Education, 106(2), 299-325.

5. Conclusions

This article reports a series of changes introduced to a power electronics course: a) better structuring each lecture by adding learning outcomes, introduction, main idea, discussion and examples, b) adding fortnight online quizzes to the course, c) spending the first week of the course on revision of mathematics and circuit theory, also creating group discussion on why the topics of the course are important, c) constantly adding questions to the students to verify their learning, d) allow tutorials to be peer learning, with students working together to solve tutorial questions, e) adding more information on lab scripts of what is expected from students in terms of learning outcomes and giving them rubrics, f) relating laboratory experiments with renewable energy such as exploiting the use of inverters with solar cells. Also, allowing students to work in groups in the lab experiments improves their teamwork skills.The net result was transformational: not only did we achieve better student satisfaction, much more engagement with the lecturer during the class and tutorial but also better test results.

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