THE EFFECTIVENESS OF DIRECT APPLICATION OF THEORY ON STUDENTS' PROGRESS AND UNDERSTANDING.

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ABSTRACT

This paper presents the evaluation of Electrical and Electronics Engineering bachelor students' response to a power electronics laboratory. Our intention is to examine the effectiveness of direct application of theory on student's practical simulation and measurement skills. The course design consists of weekly theoretical courses and lab practicals. The first weeks are introductory courses where basic theoretical concepts regarding linear power supplies, buck, boost and buck-boost and control engineering are provided. The remaining courses are in-depth and cover design of magnetic components and understanding of semiconductor behavior and some basics on EMI. The laboratory practicals run in parallel and are based on assembling a boost converter. The set-up focuses on improving interaction between theory and practice. Evolvement of how students approach the lab practicals and the interaction between the lab practicals and theoretical courses is presented. Students' interest and motivation was monitored in order to optimize the interaction between theory and practical lab assignments and the influence on progress and understanding. In the ideal situation students follow both the courses and lab practicals according to the given time plan, but in practice the students perform the practicals at their own pace. On average the students' progress was, as expected, lagging a little behind. The overall progress was satisfying to finish the course and lab contents within the given time period, delivering satisfactory results. The outcomes of the study are of importance for further other course development where a closer interaction between theoretical course and lab practicals is to be introduced.

Keywords: *Electrical Engineering, Power Electronics, Laboratory, Course Design, Boost converter, Simulation*

1 INTRODUCTION

Emerging and fast changing technologies require constant changes in teaching power electronics[1][2][3]. Theoretical instructions along with experimental setups and laboratory assignments are common practice in teaching within this discipline [4][5][6][7][8][9]. Previous studies investigated the order and effects of theoretical and practical instruction in engineering programs on pass rates and satisfaction [10][11]. Yet, little is known on individual achievements by the students and the extent to which interaction between theory and practice influences students' perception on their actual progress and skills in a certain course. We present an approach for teaching power electronics to undergraduate bachelor students in electrical engineering. This paper will firstly introduce the structure of the power electronic course. Observed learning results and students' experience is described and finally suggestions for course optimalizations are provided.

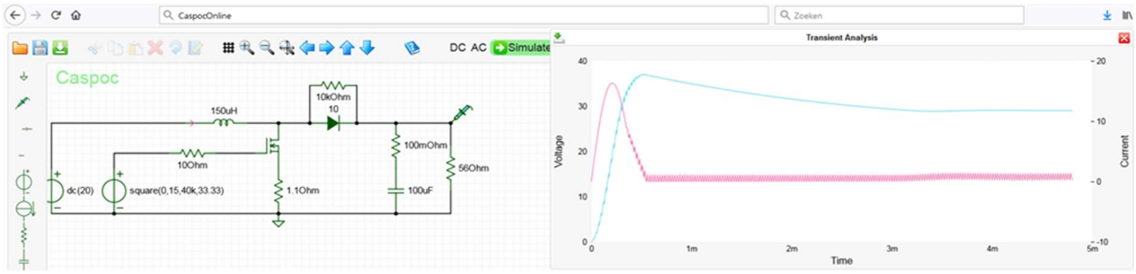


Figure 1. Online simulations using CASPOC Simulatons Online[12]

The goal of the course is to teach the principles of switched mode power supplies. The lectures contain all basic theory and explain in detail the design of circuit, its components and the control. In the laboratory assignment, students learn the practical aspects of the topics explained during the lectures. For example, in explaining the circuit of the common topologies like buck, boost and isolated converters, the switches are represented by ideal models, being either on or off. Students are then implementing this switch, by combining a gate driver, gate resistor, Mosfet and heatsink. Choice of gate resistor and measuring the gating signals is implemented in this laboratory assignment, as shown in figure 1. The actual design of the gating circuit that contains the gate driver, Mosfet and PCB layout, where the gate current loop has to be minimized, is discussed during the oral lecture. However, give the short duration in time of the laboratory assignment, the PCB is already pre-designed and is available during the laboratory assignment. Especially time is one of the limiting factors regarding the laboratory assignment and therefore all time-consuming activities are done in advance for the students, such as pcb design and production and instead of designing the power inductor from scratch and doing the winding manually, an off-the-shelve power inductor is chosen.
The main topic of the lecture is on the design of the power circuit and various topologies. The control of the switched mode power supply is the topic of an advanced lecture. The lectures are spread among seven weeks and contain the following topics:

I. Introduction, smps versus linear power supplies, switching cell
II. Buck and Boost converter
III. Semiconductor
IV. Buck-Boost and Flyback
V. Isolated converters like Forward and Pushpull and Full-bridge
VI. Magnetic components
VII. Control and PWM

For each week the laboratory assignments have to support the lectures. However during the first lecture, being an introduction to linear supplies and the basics of switched mode power supplies, the students do not learn enough to directly apply in practice. Therefore the first lecture contains the basics of the principle of the switching cell consisting of a switch, diode and inductor and gives the example of the buck converter, without going into detail on the design of the components, nor going in detail on the waveforms. During the first practical assignment, the students start with an online design tool, where they can study these aspects by experimenting with a virtual prototype. The design tool is dong the component selection and calculation of the waveforms is such a format, that students directly see the impact of choices regarding input and output relation and the influence of the basic design constraints like switching frequency and size of the power inductor.

1.1 Lecture Layout

The practical assignments are also spread over the same seven weeks as the lectures and the contents of each assignment is complementary to the lecture. During the first practical assignment the theoretical knowledge from the lectures is still limited, so this assignment set up like a trail and error design guidance to perform virtual experiments resulting in the waveforms for a basic switched mode power supply. Goal is to teach the workings of a single switching cell, containing of switch, freewheeling diode and an inductor. The basic property of the switching cell is easily understood by explaining it as a step-down converter. The mathematical relations between input and output are linear relations(1) and the current flow, alternating between the switch and freewheeling diode is clearly visible from the schematic, figure 1.

$$Uout = D \cdot Uin \qquad Iout = D \cdot Iin \qquad Pin = Pout \qquad (1)$$

The required knowledge from the lecture is the fact that the inductor current cannot be interrupted and that the slope of the current through the inductor depends on the voltage across the inductor $VL = L * di/dt$. From these basic mathematical relations the students are able to understand the sizing of the inductor once they select a fixed switching frequency Fs having a constant on-time interval of D/Fs and a constant off-time interval of $(1 - D)/Fs$, where *D* is the duty cycle varying between 0 and 1. By intuition the students understand the relation $Uout = D * Uin$ and from this the other relations can be understood. The virtual experiment the students have to carry out in the first assignment is based on this basic knowledge and gives them a jump start into designing a Boost converter.

In table 1 the lectures are listed per week along with the laboratory assignments topics. The lectures follow the structure of the lecture notes and the sequence of the lab assignments is chosen, because each lab assignment naturally follows the previous assignment. The lab assignments come with a separate lab instruction manual, explaining each step to be carried out during the lab assignment.

Table 1. Original sequence of topics for lecture and lab assignments.

Week	Lecture	Lab Topic	Lab-Assignment
1	Intro, switching Cell	I	**Online design tool: Basic Waveforms** 1) Choice of parameters (Uin, Uout, Iout, Fs, Cout) 2) Influence of the inductor L on the operation and (Uout and IL)
2	Buck and Boost Converter	II	**Online Simulation: Open loop, constant dutycycle** 1) Start-up overshoot 2) Variation of the load resistance
3	Semiconductor	III	**Online Simulation: Mosfet Switching Waveforms** 1) Influence of Rgate and Cgs in the gating circuit 2) Influence of Cgd 'miller' capacitance on the gating circuit 3) Switching loss due to Cds
4	Buck-Boost & Flyback	IV	**Online design tool: Power Inductor Design** 1) Selection of minimum core diameter and material 2) Calulation of the windings 3) Calculation of the losses (Rdc/Rac winding loss and core loss BF)
5	Isolated Converters	V	**PCB Assembly** 1) Placing all components except the the control IC. 2) Measurement of all voltage / current waveforms for constant dutycyle operation
6	Magnetic components	VI	**Ofline Simulation: Closed Loop, Control IC** 1) Simulating the behavior of the closed loop control based on the control IC, Gatedriver, Mosfet and the feedback loop components.
7	Control	VII	**Measurement: Closed loop waveforms** 1) Finalize the PCB with the control IC, measure all v, i and compare with simulation results. Examine the losses in the Mosfet, L and Cout using an infrared thermal camera

2 STUDENTS' LEARNING EXPERIENCE

2.1 Monitoring Progress

Students' progress was monitored throughout the seven week lab practicals (N=31). As described previously, the lab practicals were designed to guide students through three phases: Online simulation, PCB assembly and measurements. Figure 2 shows the students' actual progress. As can been seen, the actual progress of the PCB assembly took more time than scheduled. The result was that a number of students started their measurement activities in week 7, with almost no time to finish this properly. In the end, a few students succeeded in handing in a report by the end of week 7.

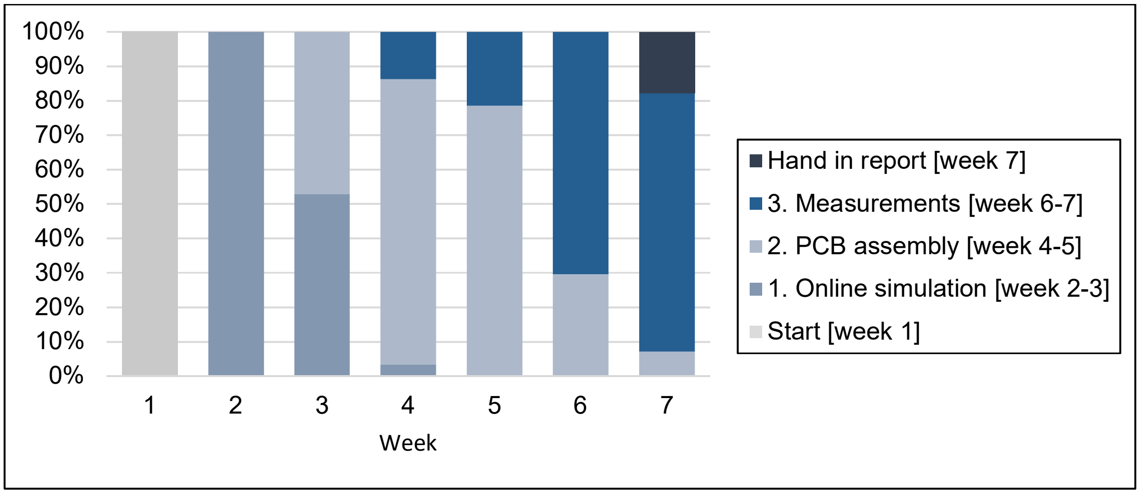
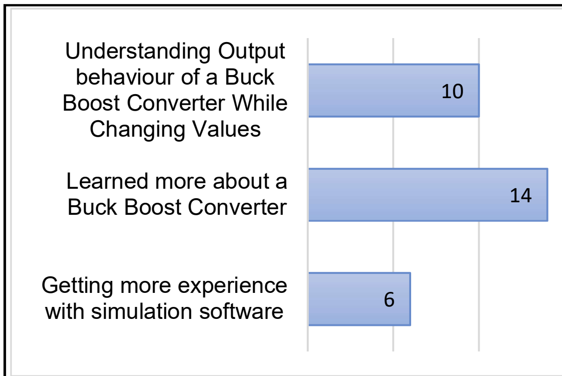


Figure 2. Students' actual progress during the seven week lab practicals (N=31).

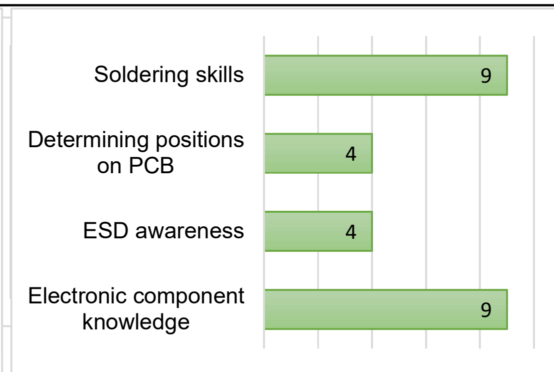
2.2 What did students learn?

Students' feedback was collected after each phase of the lab practicals: online simulation, PCB assembly and measurements. Feedback was collected through an online survey tool on the following topics: The extent to which students were able to apply the relevant theory into practice, what students learned and what was least clear. Students' response to the question to what extent they could apply theory into practice was positive across the three phases. On an ordinal scale (1 = extremely poor, 2 = very poor, 3 = fair, 4 = good, 5 = very good, 6 = excellent) a median score of 4 is measured for each phase. This indicates that students perceived the relevance of the theory for their practical assignment as good. Figure 3 shows the feedback on what students learnt most from the lab practicals. Since the questions were open ended, similarities in responses were analysed and categorized into main categories. The outcomes support the objectives of the lab practicals and indicate that topics from the theoretical lectures were directly applied in practice.

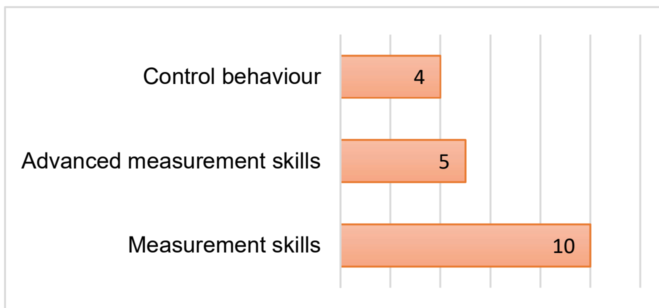
Moreover, out of all the responses, electronic component knowledge (identifying and selecting the components and reading data sheets) and soldering skills were also mentioned as least clear and took most time and effort for the students during the PCB assembly phase. This indicates that students learnt most of what was initially new to them by experimentation. During laboaratory practicals, students are mainly involved in active experimentation stage according to Kolb's experiental learning cycle. In this stage, acquired information and knowledge is required first before new knowledge can be constructed through experimentation [13]. This transformation stage is of importance in educating engineering students in order to become specialized in their discipline. It explains the delay in progress during the PCB assembly and measurements phase.



a. Simulations (n=30)



b. PCB assembly (n=26)



c. Measurements (n=19)[1]

Figure 3. What students learn from the lab practicals.
[1] A distinction between measurement skills (basic skills, measurement equipment use and debugging) and advanced measurement skills (accuracy, analysing voltage and current wave forms and identifying differences based on the simulation) has been made.

2.3 Students' experience of lab practicals

Depending on the practical experience of the students, some lab assignments went well, others took more time and effort. As can be seen in table 1, some topics are already put in practice during the lab assignment, whereas the theory is not yet covered during the lecture. This requires that the students will study the theoretical material already in advance, however, most students postponed their lab assignments until the topic was discussed during the lecture. Another problem with this sequence is that students required more time to finish the PCB assembly than other students, depending on their practical experience. Looking at the feedback results form the students, this was a major concern and the main reason for rearranging the sequence of topics.

From the progress results, we see how much time is needed by students for assembly and for measurement. Based on these results, a schedule must be drawn up that complies with:

1. Practical assignments should be synchronized with the lecture contents
2. The time duration of each practical assignment should be realistic to be completed by the students

Table 2 shows the new sequence, where the topics during the lab assignments are synchronized with the lecture topics.

Table 2. Synchronized sequence of topics for lectures and lab assignments.

Week	Lecture	Lab Topic	Lab-Assignment
1	Intro, switching Cell	I	Online design tool:Basic Wave forms
2	Buck and Boost Converter	II	Online Simulation: Open loop, constant dutycycle
3	Buck-Boost & Flyback	V	PCB Assembly
4	Magnetic components	V IV	PCB Assembly (*see fig 3a*) Online design tool: Power Inductor Design
5	Semiconductor	III V	Online Simulation: Mosfet Switching Waveforms Measurement: Open loop waveforms
6	Control	VI	Ofline Simulation: Closed Loop, Control IC
7	Isolated Converters	VII	Measurement: Closed loop waveforms (*see fig.3b*)

3 VARIATIONS IN ASSIGNMENTS

Validating the laboratory assignments is usually done by examining the final measurement report. However as many students tend to do lab assignments outside of the regular lab assignment time schedule, there is nearly no proof that the students perform the lab assignments themselves. Copying of measurement results is in essence forgery and in many cases hard to prove. Giving out as many different lab assignments as there are students can become very costly. However, variations in parameters is possible. The use of variations in voltage, power and control parameters, gives students different assignments so that they can be tested individually.

Typical variations that can be applied for the practical lab assignment for building a boost converter are:

A. Input voltage Uin: 20V .. 30V in steps:2 volt
B. Output voltage Vout: 20V .. 48V in steps: 2 volt
C. Output current Iout: 1A .. 5A in steps 0.5 Ampere
D. Switching frequency Fs: 50kHz .. 100kHz in steps: 5 kHz
E. Inductor current ripple delta-IL: 0.25A .. 2A in steps: 0.25 Ampere

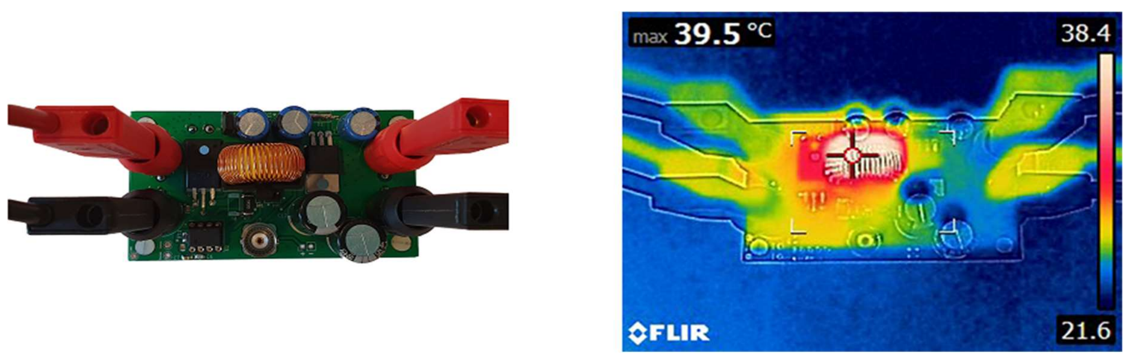


Figure 4. a)Boost PCB[14], b)Thermal image

In practice the variations B and C are related by the available load resistors, unless an electronic load or variable resistor is used. The use of a variable load is to be preferred, as it is safe to use and has lower cost-price compared to an electronic load.
The variations d and e are related to the available inductors. If off-the-shelf power inductors are going to be used, only a limited set of inductor values will be available. The maximum current ripple (variation E) through the inductor is related to the switching frequency (variant D) via the duty cycle and input voltage, gives $L * \Delta I = Uin * d * Fs$. If the power inductor is going to be winded manually around a toroid

core, the value of L can be chosen such that any combination of switching frequency Fs and maximum inductor current ripple is possible.

A more indepth analysis of the converter can be done in simulation. In figure 5 the simulation of a boost converter is presented where paracitic componets are included in the model. The aim for the students is to identify the influence of each parasitic component in the simulation results.

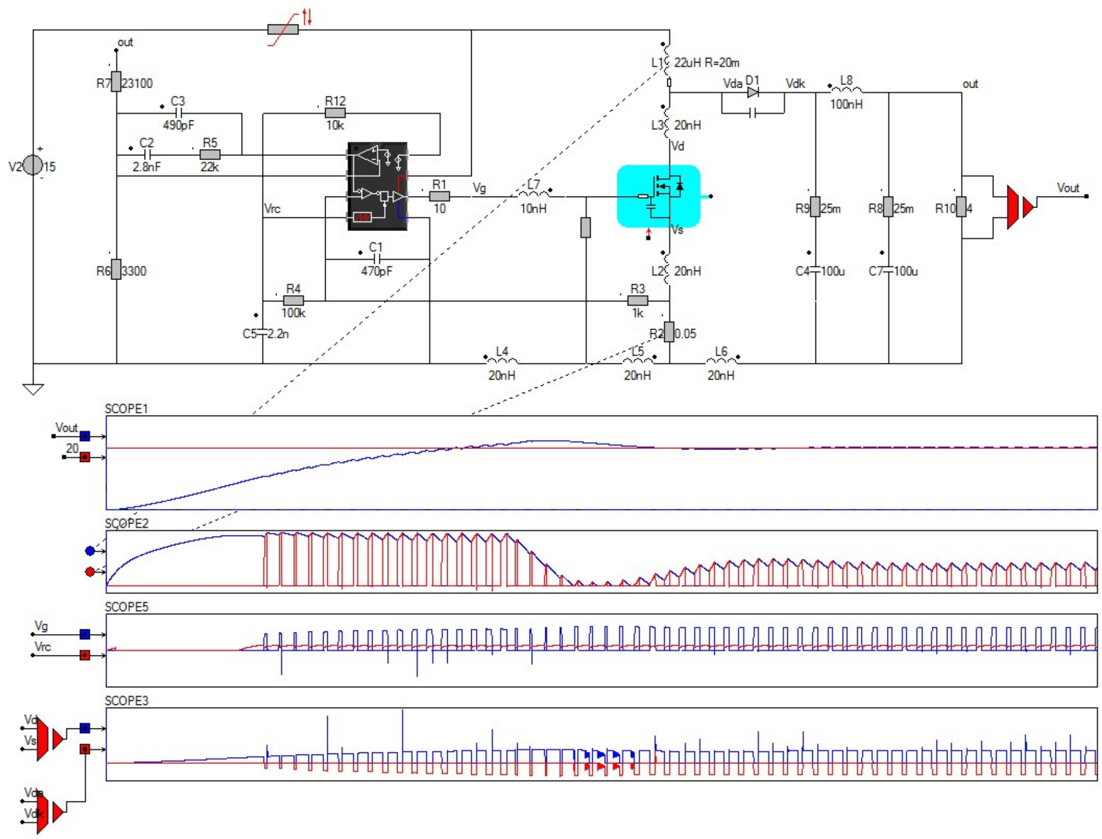


Figure 5. Simulation in Caspoc [12] of a boost converter with parasitic components and current mode control ic. The scopes give from top to bottom, Scope1:Output voltage and reference voltage, Scope2: Inductor and sense resistor current, Scope3:5 Gate and oscillator voltage, Scope3: Mosfet and Diode voltage

4 CONCLUSION

This paper presents the evaluation of Electrical and Electronics Engineering bachelor students' response to a power electronics laboratory set up. Our intention was to examine the effectiveness of direct application of theory on student's practical simulation and measurement skills. Responses indicate that students perceived the oral lectures as useful for practical application in the lab assignments and provides understanding about learning experiences and progress. This supports our approach of incremental increase of knowledge by theory and direct application in laboratory practicals [4] [5]. However, minor adjustments have to be made in our set up in order to optimize students' learning experience.

One considered optimalization is a synchronized topic sequence. If more laboratory lectures are available, extra assignments could be added to the list from Table 2. For example optimizing the efficiency of the boost converter by selecting a better semiconductor or by optimizing the power inductor. Reducing the output voltage ripple, by selecting more output capacitors in parallel to reduce the total series resistance of the output capacitors. As a drawback of the improvement of output voltage ripple, the stability is influenced and students could measure this impact using a variable electronic load. The improvement of the feedback loop by redesigning the feedback loop component s is a topic that should be covered in an advanced course on power electronics, as seven weeks is too short time to cover these topics in detail.

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