BUILDING CIRCUITS FROM SCRATCH

C. de Trazegnies Otero[1], J. M. Vargas Domínguez[2],

[1]Department of Electronics, University of Malaga (SPAIN)
[2]Department of Applied Physics II, University of Malaga (SPAIN)

Abstract

This work presents a teaching experience developed at the grade level on Sound and Image Engineering at the University of Málaga. Students face their first contact with the Electronics Laboratory on the second semester of the grade. Although they use to fulfill the theoretical aspects of this matter, they also use to encounter difficulties to bring their knowledge to the real world, i.e., to fulfill their laboratory tasks.

In order to develop these important experimental skills, we performed an educational experience that combines the construction of basic analogic circuits from normal household materials, with the support of short video tutorials to be used under teachers' supervision.

As a result, students perceived the proposed experience as a challenge. It was perceived as both motivating and harder to fulfill than usual laboratory tasks.

From the teacher's perspective, we found that students who participated in this experience, gained autonomy in subsequent laboratory tasks along the semester.

Keywords: Active learning, learning by doing, electronics, laboratory experimental skills

1 INTRODUCTION

Experimental skills are one of the most important learning goals. It is explicitly included at the Grade list of competences to acquire, labeled as general competence G13 [1]:

> *G 13: Knowledge to carry out measurements, calculations, assessments, appraisals, expert reports, studies, reports, task planning and other similar work in their specific field of telecommunications*

This goal implies not only knowledge about all the measurement procedures, but also the interpretation of results. At a very basic level, students should be able to judge if their laboratory results make sense, i.e., are valid.

The main problem is that, at this introductory level, students still focus on replicating a priori known results, rather than understanding the experimental setup[2], [3]. This behavior affects the way they understand simple electronics concepts, leading to mistakes and misinterpretations on further (and more complex) laboratory sessions[4]. Breaking this dynamic is a necessary teaching initiative to provide the students with basic laboratory skills.

The usual approach is the proposal of some test circuits of increasing complexity for the students to put them together with standard electronic components. Circuits are checked by gathering a series of typical measurements and comparing them with the corresponding predicted values[5]. As the setup is highly predictable, students soon fall into trying to obtain a priori known results, even though some of their calculations might be based in misconceptions and, therefore, wrong. As soon as they get the aimed result, be right or wrong, most of those students fill up their laboratory notes and focus on their next task without a second thought. Thus, they need to be continuously reminded by the teachers that a measurement without its interpretation has no learning value.

We propose an alternative method to achieve the goal of breaking the aforementioned dynamic. Our proposal aims on:

i) Provide an experimental setup with a high statistical variability, so that each student needs to work with his/her own set of measurements.

ii) Slow down the laboratory process by making the students handcraft their own components, so that they need to give thought about their circuits' behavior.

iii) Provide the necessary support to facilitate the students to work autonomously.

2 METHODOLOGY

The laboratory assignment that we present to our students consists of building their first basic RC circuits from self-made components, instead of using standard commercial electronic components. Students were guided to build surface resistors by painting graphite rectangles of different sizes with a soft pencil on a sheet of paper. To build capacitors, the paper was used as dielectric and the plates are graphite layers colored on both paper sides. This assignment was divided into the following tasks:

1. Building resistors. During this experience, students were first guided to build superficial resistors by drawing and coloring graphite rectangles of different sizes on a sheet of paper (Fig. 1). The corresponding resistance was measured with the laboratory equipment. This way, students can get a feeling of the experimental variability of such process, and they are invited to make deductions about different factors that might affect their results, such us rectangle size, pencil softness, number of colored layers, etc. Each student was asked to annotate their resistance values and use the same pieces for further tests.

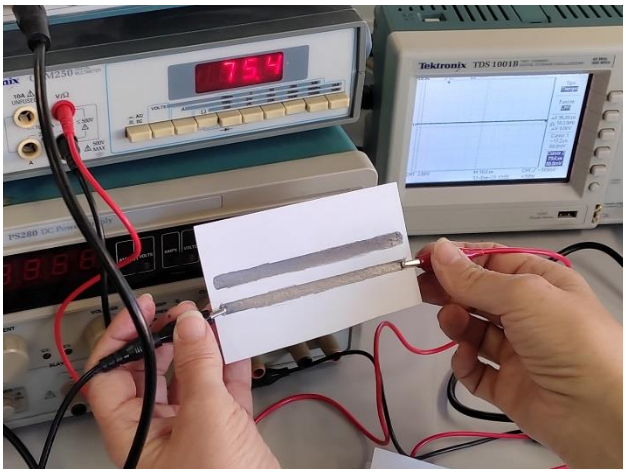

Figure 1 An example of resistance measurement over a self-build resistor

2. Testing the validity of basic laws on series and parallel resistor combination with handcrafted resistors. Students were invited to observe that, although their resistor building method may give very different resistance values, once these values are known, series or parallel combination laws are fulfilled with a high reliability.
3. Testing the Ohm's Law with handcrafted resistors. At this step, students were required to perform Voltage and Current measurements with a multimeter on a tension divider circuit. For this task, they used a single resistor with a sliding third terminal as a potentiometer. Again, students were invited to observe that, even though the total resistance value may differ from one another, the obtained outcoming tension is accurately linked to the ratio between the output resistor length and the total potentiometer length.
4. Testing a capacitor charge/discharge time through a series resistor. For this task, students were required to build a new circuit, including a resistor and a capacitor connected in series on the same sheet of paper (Fig. 2). Students charged their RC circuits by means of a square signal generator and visualized the voltage across the capacitor with an oscilloscope. As the values of both resistance and capacitance may vary a lot due to different construction factors, each student needed to adjust his/her own setup to measure very different charging times and relate this measure to the actual resistance and capacitance values.

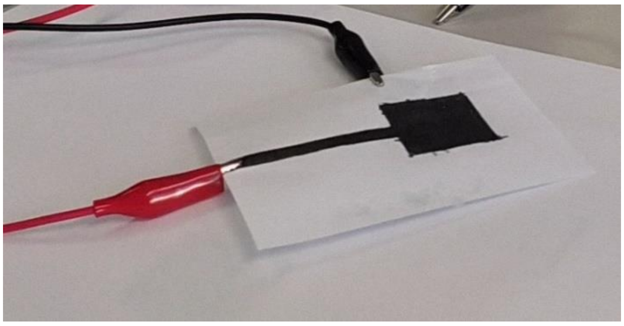

Figure 2 An example of RC circuit

The laboratory tasks were presented as research and discovery problems. Every student achieved slightly different results: there aren´t any ideal measured values to achieve and there is no point on trying to mimic the teacher's or some other student's results. Thus, everyone needed to think about his/her own results, understand them and decide if they make sense according to the electronic principles.

As a further help, a collection of short demonstrative video-clips, one per task, had been recorded in advanced. In previous approaches, the authors had discussed the use of simplified self-produced videos as the main teaching material in their classes, especially under the need of online remote teaching [6], [7]. In this occasion, videos were reduced to a minimal duration. The laboratory session did not stop to allow the students watching the videos simultaneously. Instead, each video was projected in loop-mode on the classroom screen while students were working. Additionally, the video collection was uploaded to our YouTube channel [8] and was available to be consulted on student's PCs or cellar phones during the session so that students could relate what they see with their own implementation.

3 RESULTS

The experience was evaluated both from a student's satisfaction survey and from the teacher's evaluation of students' performance and skills in subsequent laboratory assignments along the semester.

The satisfaction survey consisted of eight questions, four about the tasks themselves and four about the use of video tutorials. Two additional redundant questions were introduced, scattered along the test, to check the consistency of results. These questions are presented on table 1, gathered by groups. Students were asked to answer to what level they agree with the proposed assertions. Additionally, students had some space to express their impressions on the experience in a free and anonymous way.

Table 1. Students' satisfaction survey questions

Group	Code	Question
About practise	Q1	When drawing resistors on paper, I had to think about how the size of the resistor and the resistivity of the material affect the final value of the resistance, and I found it interesting
	Q2	When drawing the capacitors by coloring both sides of the paper, I've had to think about how the area of overlap affects the final value of the capacitance, and I found it interesting
	Q3	When building an RC circuit with the resistor and the capacitor colored on paper, I had to think on how the contact resistances affect the final result of the experiment, and I found it interesting
	Q4	The fact that the basic circuits are built at home has forced me to think carefully about where I should put the external connectors, both for power and measurement, and I think it has helped me to better understand the experiment.

About videos	Q1	I found it useful to have demonstration videos on hand
	Q2	I especially appreciate that the videos are very short so that I can consult the essentials
	Q3	The videos have been played on loop on the laboratory screen, according to each phase of the work that I was doing. In this way, I have often consulted what was happening on the screen as an orientation to carry out my own work
	Q4	I hardly noticed that the videos have played continuously on the laboratory screen, when I needed to consult them, I did it from my own mobile phone
Redundant	R1	Having to build the electronic components has helped me better understand how an electronic circuit works
	R2	I have the impression of having learned new things or of having better understood some basic concepts of the subject

A total of 39 students (28 male and 11 female) regularly attended the laboratory sessions, but only 17 answered the survey. While the total number of participants is low, it is encouraging that the redundant questions present a high level of coherence (Fig. 3)

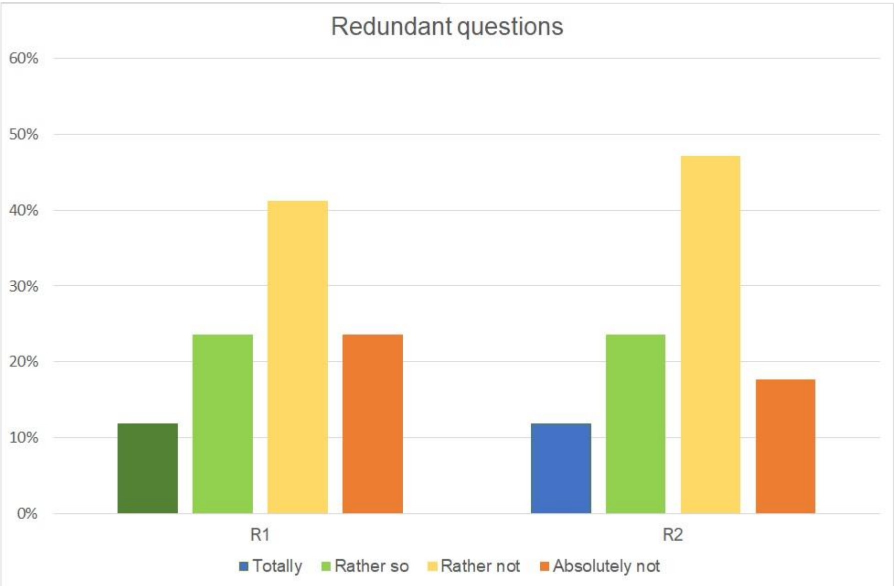

Figure 3. Students' survey results on redundant questions

In general, students express slightly more negative than positive responses to the experience of building and testing their own electronic components (Fig. 4).

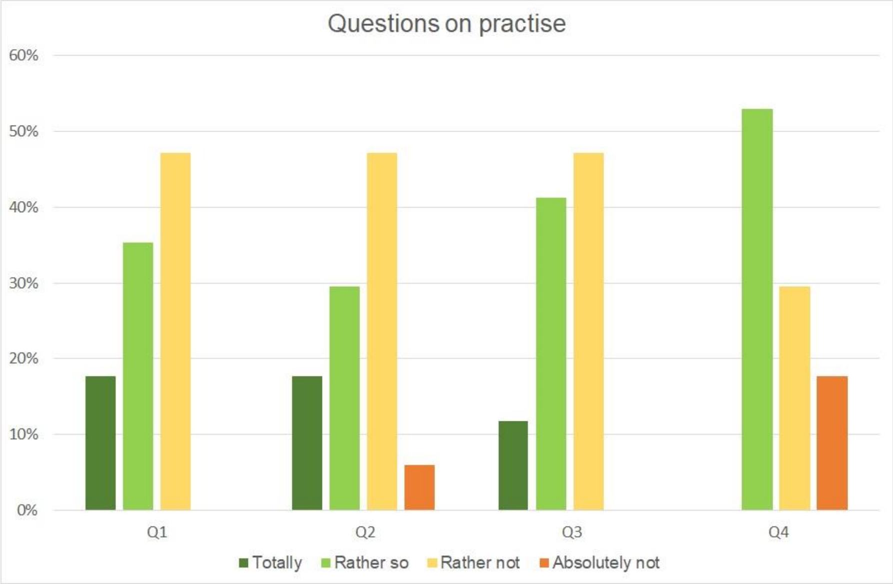

Figure 4. Students' survey results on questions about building circuits with paper and pencil

Some of the students opted to express their opinion on this matter, most of them complaining about having to rethink too much in order to go on forward on their tasks. Nevertheless, they point out, in general, that the proposed tasks were compelling and interesting. As documentation, just two of the students' opinions, expressed in their own words are included here:

Student 1: In my opinion, it seemed a bit complicated for the first laboratory task of the course. Since resistors cannot be painted homogeneously, we obtained unstable results. This way you end up messing up a bit with the results of some things and others. Otherwise, everything perfect on the part of the teachers.

Student 2: I have found this assignment confusing, since it was more of a home-made experiment, I have not been able to consolidate concepts with the help of it. Although the idea seems attractive to me and at first it has been entertaining, when it came to learning time, I could not understand it. […] I have felt that it has run very fast and that we have not been able to keep up with the pace that was requested from us.

We were also interested on using video tutorials as a side help to the laboratory work. A series of short videoclips (between 2 and 10 minutes) were prepared. These videoclips just showed quick examples on how to manage components and laboratory equipment to fulfil the assignments. The videoclips weren't meant to be extensive tutorials, thus, in order to deeply understand the electronic principles behind their tasks, students should consult the course documentation, analyse their own experimental set up and debate their conclusions among them and with the teachers.

Figure 5 presents the results of student's survey on video tutorial support. It can be observed that students are prone to receive information in video format, and that they appreciate the fact that the information is condensed in small clips. Students also report having consulted these videoclips while performing their assigned tasks, on the Lab. projection screen, as well as on their own mobile phones.

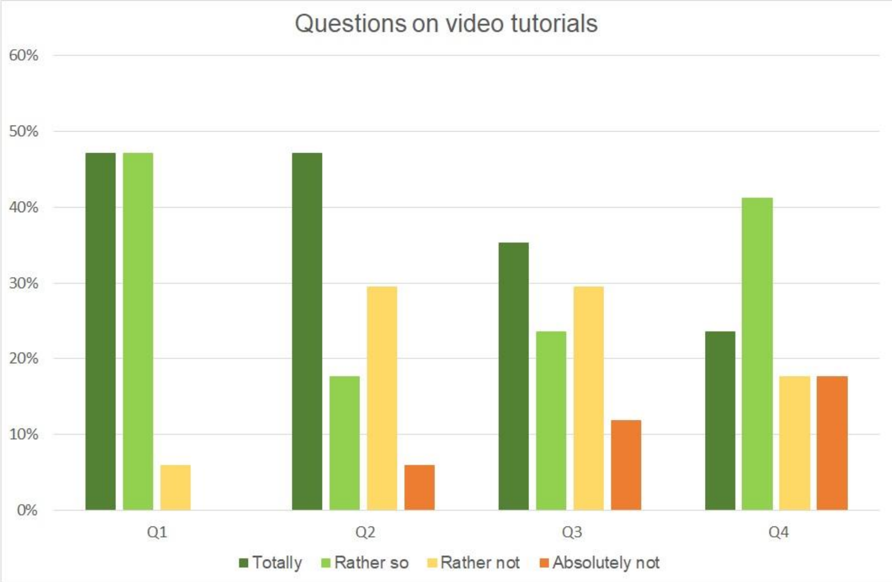

Figure 5. Students' survey results on questions the use of video tutorials during Lab. sessions

The experience presented in this work took place as a first laboratory assignment from a series of four. The remaining three assignments were formulated in a more traditional way, proposing a series of specifications to be fulfilled by building small analogue or digital modules from commercial components.

From the teacher's point of view, we think that the proposed experience has helped the students to better fulfil subsequent assignments. In comparison with students from former academic years, students participating in this experience have shown more autonomy to perform their laboratory tasks by themselves. Thus, the need for repeating or reminding basic knowledge that they should have acquired during the first laboratory sessions has been significantly reduced. Furthermore, we have observed a positive change in the students' attitude towards a more thoughtful and attentive development of the laboratory tasks. However, as this might just be our subjective impression, we look forward to comparing final semester evaluation from this group to that from former years.

4 CONCLUSIONS

We present an innovative experience on the first-time introduction to the laboratory of Electrotechnics for first year grade students of Telecommunication Engineering. Instead of using commercial electronic components, we asked them to build their own electronic components by painting graphite layers on paper sheets. As a result, students were forced to pay attention to every little detail on their circuits, giving themselves the opportunity to mindfully analyze each and every step of the process.

On the downside, students have reported the impression of being overloaded with more work and more attention to details than they had expected. As a positive outcome, they have reported a high motivation to fulfill the proposed tasks, even though they sometimes needed to struggle more than expected to complete them.

Overall, this experience has fulfilled our teaching objectives, as long as it has helped our students to better acquire the required competences on basic laboratory skills, as shown in their progression at subsequent laboratory assignments.

ACKNOWLEDGEMENTS

This work was funded by the Servicio de Formación e Innovación, University of Malaga under Project PIE 22-210. This is contribution number 1 of INNVENTA[2], permanent group on Educational Research and Innovation.

REFERENCES

[1] U. Málaga, “Memoria de Verificación del Título de Grado en Ingeniería de Sonido e Imagen.” Escuela Superior de Ingeniería de Telecomunicación, 2022.

[2] J. Jordana and F. Josep Robert, “A Course on Digital Electronics Based on Solving Design-Oriented Exercises by Means of a PBL Strategy*,” 2015, [Online]. Available: http://www.upc.edu/ice/

[3] C. de Trazegnies Otero, M. Ruiz García, C. Téllez Labao, and C. García Berdonés, “Retos en el laboratorio. Gamificar una prueba de autoevaluación,” in *6th Virtual International Conference on Education, Innovation and ICT*, Adaya Press, Dec. 2021, pp. 637–642.

[4] N. P. Pitterson and R. A. Strevele, “Teaching and Learning Complex Circuit Concepts: An Investigation of the Intersection of Prior Knowledge, Learning Activities, and Design of Learn-ing Environments Teaching and learning complex circuit concepts: An investigation of the intersection of prior knowledge, learning activities and design of learning environments,” 2016.

[5] K. Yelamarthi and E. Drake, “A Flipped First-Year Digital Circuits Course for Engineering and Technology Students,” *IEEE Transactions on Education*, vol. 58, no. 3, pp. 179–186, Aug. 2015, doi: 10.1109/TE.2014.2356174.

[6] C. de Trazegnies Otero and J. M. Vargas Domínguez, “A Minimalistic Approach to Emergency Remote Learning in Higher Education,” in *ICERI2020 Proceedings*, Online Conference: IATED, Nov. 2020, pp. 8370–8374. doi: 10.21125/iceri.2020.1865.

[7] J. M. Vargas *et al.*, “Live Lecture Screencast Recording: A Proposal to Simplify the Tasks Associated with Content Production for Video-Teaching,” in *11th International Conference on Education and New Learning Technologies*, Palma, Spain: IATED, Jul. 2019, pp. 9997–10004. doi: 10.21125/edulearn.2019.2491.

[8] C. de Trazegnies, “Circuitos hechos de papel”, YouTube Playlist, last updated on April 24th, 2023: https://youtube.com/playlist?list=PLYhNGwtnHPdNCwTVYPRRLuxhh88XHJiEO