MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2024, 20(10), em2510
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/15176

From simulation to experiment: Using KiCad to design electric circuits in the physics classroom

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Received 12 June 2024 ▪ Accepted 28 August 2024

Abstract

Secondary school students encounter a wide range of electronic devices in their everyday lives that are not usually covered in physics classes. Examples include mobile phone power adapters that convert high-voltage alternating current to low-voltage direct current. However, such examples are often not used sufficiently in the classroom to provide students with insights into (a) the specific applications of the electronic components used and (b) the underlying electronic design process. To fill this gap, we have designed a new context-based, easy-to-implement teaching-learning sequence that guides students to how to use the electronic design and simulation program KiCad which is being widely used by professionals in the field, (2) build their own analog experimental setup of a mobile phone power supply, and thus (3) understand how a mobile phone power supply works. The presented part of the teaching-learning sequence focuses on the use of KiCad and is designed to allow students to work individually and in groups to learn according to the think-pair-share principle based on a set of tasks we created. This paper examines the pedagogical potential of KiCad and provides a detailed description of the teaching-learning sequence and reports on initial classroom experiences: A total of N = 28 students aged 16 to 17 years participated in the unit as part of an extracurricular course and completed a questionnaire based on the Technology Acceptance Model to investigate the perceived ease of use and usability of the KiCad software. We found that despite the fact that the students had not used KiCad before, they were quite positive about the educational material as a whole and the KiCad software in particular.

Keywords: transformer, simulation, Spice, KiCad, think-pair-share

INTRODUCTION

Transformers are integral to students' daily routines, even if they are not aware of it. A prime example is the mobile phone power adapter, which students use every day to charge their devices. This adapter relies on a transformer to reduce the voltage, ensuring the electronic device receives the correct power level. In particular, in everyday use, students are often unaware that the development of such electrical components and circuits is quite demanding and the result of an often extensive design process. In addition to the benefit of developing students' practical approach, there can also be a pedagogical purpose in using real-life problems in physics education. Context-based learning (i.e., classroom discourse of real-life problems) can be used to stimulate student interest and thus increase motivation by creating a learning pathway through appropriate design (Whitelegg & Parry, 1999). However, it is important that the problems brought from real life are usually much more complex and often difficult to understand, so when designing learning paths, special attention should be paid to ensuring that students encounter as few learning difficulties as possible during the learning path.

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Contribution to the literature

- The study presents an easy-to-implement, context-based teaching-learning sequence for using the expert electronic design automation tool KiCad in secondary school physics classes on electricity.
- The study describes difficulties students face when using the KiCad tool to design and simulate electrical circuits.
- Through students' responses to a questionnaire based on the Technology Acceptance Model, we provide initial evidence in favor of KiCad's perceived usability.

Several papers have been published on the teaching of transformers at the secondary school level, involving, among other things, hands-on approaches, demonstration experiments or simulations (Aguilar, 2016; Caplan, 2009; Hamamous & Benjelloun, 2022; Malik et al., 2017; Roy et al., 2024, Sitkey, 2018). For example, regarding the learning effectiveness of teaching-learning sequences about electricity, the results of a recently published comparative study indicate that "a combined strategy was more effective in enhancing conceptual understanding of electric circuit concepts in comparison to the use of simulation and hands-on strategies" (Tenzin et al., 2023, p. 1). Hence, an integrative approach that makes use of both hands-on experimentation and theory-driven design and simulation of electrical circuits in a context-based setting might be of particular value for learners.

In this article, we build on these findings by presenting a new context-based easy-to-implement instructional sequence that combines students' learning about transformers in general and the functionality of power adapters in particular - namely, using the real-world context of mobile phone power adapters - with students' learning and understanding of the importance of simulating and designing electrical circuits in solving electrical problems. In the following section, we provide the reader with the *theoretical background* for

(a) the physics of power adapters,

(b) the modelling and simulation of electrical circuits required for the design of the teaching-learning sequence, and

(c) the Technology Acceptance Model.

Thereafter our new *teaching-learning sequence* is presented in detail, which is followed by the *research questions* and an overview of *research methods*. Finally, we report general experiences from the implementation of the teaching concept and provide insights into students' perceptions of the KiCad software, as assessed by a usability questionnaire based on the principles of the Technology Acceptance Model.

THEORETICAL BACKGROUND

The Physics of Power Adapters: A Brief Overview

Mobile phone power adapters are AC adapters that "convert a higher-voltage alternating current to a lower-voltage direct current for use with devices that require a relatively constant voltage" (Energy Education, 2024). An important component of AC adapters are transformers; a transformer is the essential component that "initially converts a relatively high-voltage alternating current that is supplied by an electrical outlet to a lower voltage suitable for the device being powered" (Energy Education, 2024). A transformer consists of a primary and a secondary coil. When an alternating current passes through the primary coil, it creates a fluctuating magnetic field in time. This time-varying magnetic field induces a voltage in the secondary coil. The ratio of the number of turns in the coils directly determines the ratio of the voltages (Minkner & Schmid, 2022). Then, a rectifier is used to convert alternating current into direct current. This device – in case of a full - wave bridge rectifier–consists of four diodes arranged in a specific configuration to ensure that the voltage remains positive at all times (Zhao et al., 2013). However, the rectified voltage still has significant fluctuations. To overcome this, a smoothing capacitor is added to the circuit to smooth out the voltage fluctuations. The capacitor charges and discharges as the voltage rises above or falls below the average value, effectively reducing the ripple in the output voltage (Zhao et al., 2013). Today, the switched mode power supply is the most commonly used power supply (Coates, 2024). In the educational pathway presented in this article, the students are guided to design the electric circuit of an AC adapter. On their way, they get to know how experts in the field model and simulate electric circuits for solving a given problem by the use of KiCad.

Modelling Electric Circuits

To keep development costs down, engineers model and simulate electrical circuits. Using software, they test different configurations and prototype their design. One of the most commonly used software tools for this purpose is Spice, which allows users to create schematics and set parameters for each component. The software is "a general purpose simulation program for integrated circuits" (Nagel & Pederson, 1973, p. 4). A well-implemented version of Spice is the simulation function in KiCad Schematic Editor,[1] "a popular suite for electronic design automation, which provides a schematic editor and basic interaction with the simulator" (Faina, 2022, p. 3). KiCad is one of many electronic circuit simulators available (Knörig et al., 2009) and focuses on a schematic view rather than a breadboard view. The latter is the view typically used in simulators designed for students. KiCad is used instead of the more widely used LTSpice because it has a wider range of functions, such as printed circuit board design, that can be used in other contexts, such as extra-curricular projects or robotics courses. If one aims for a more reduced software solution, LTSpice[2] can be used in this teaching-learning sequence.

KiCad offers a wide range of components of electrical circuits such as resistors, capacitors, coils and transistors that can be used but it also allows to create own components. Once the components have been placed, they can be connected using the wire tool. In the *inspect* drop down menu there is the simulation function. It opens a separate window where the simulation can be launched. After a complete run the console should say "no. of data rows". Signals can be added using the menu provided or by clicking on a wire with the probe tool. The tune tool can be used to change the parameters regarding the respective components via a slider control.

In the educational pathway presented in this article, we integrate KiCad software in order to explicitly guide the students through the transition from modelling and simulation to the implementation of a real electrical circuit of a power adapter useful for charging a smartphone in the sense of context-based teaching. However, the effectiveness of the teaching-learning sequence presented in this article, obviously depends on how well this new software is integrated into the learning environment and to what extent learners

(a) accept it and

(b) are able to use it.

The Technology Acceptance Model describes this process of gaining acceptance of new technology and thus serves as the theoretical framework for this study.

The Technology Acceptance Model

To gain insight into the way in which learners perceive the KiCad software, we draw upon the Technology Acceptance Model, originally introduced by Davis (1989), which is "a theoretical model that predicts how a user comes to accept and use a given information technology" (Holden & Rada, 2011, p. 344). In particular, the Technology Acceptance Model reflects the role of perceived usefulness and perceived ease of use for learners' "decision of how and when they will use the technology" (Holden & Rada, 2011, p. 344). A study has identified four main categories that may indirectly or directly impact the adoption of technologies (Granić, 2022; Rap & Blonder, 2024):

1. **User-related factors:** These include elements such as the user's self-efficacy in using technology, their apprehension about using computers, and their confidence in technology use.
2. **Enjoyment and usefulness:** This involves the user's perception of enjoyment during the activity, as well as the playability and accessibility of the system.
3. **Task and technology-related factors:** These cover the technological complexity, the technology required for the task, and internet access considerations.
4. **Social factors:** This category includes subjective norms, social influence, and motivational support.

As science educators, it is essential to address the barriers that teachers may face when implementing programs. These obstacles could be related to the content, pedagogy, or the technological tools required. The present study focuses on the necessity of applying and integrating technological tools that provide up-to-date data for learning through our new teaching-learning sequence based on the KiCad.

MATERIALS

The fundamental premise of the educational program presented here is to utilize the context of charging mobile phones using power adapters to educate students about transformers and the other electrical components required, such as rectifier and smoothing capacitor (see *Theoretical Background–The physics of power adapters: A brief overview* section). This is achieved by providing learners with insights into electrical circuit design, from simulation to hands-on experimentation. In order to ensure the safety of personnel and equipment, mains power is avoided and an extra-low voltage transformer with a maximum voltage of 25 V is employed. It is crucial to highlight that the self-made transformer designed in this sequence is configured as a step-down transformer to prevent the generation of potentially hazardous voltages. It is theoretically possible for students to utilize the final product to charge their own mobile phones. However, it is proposed that the device be used for the purpose of charging a power bank, rather than a mobile phone, in order to minimize costs in the event of an accident.

The teaching-learning sequence comprises four phases, with the initial phase serving as an introduction to the KiCad tool and three subsequent main phases (described in detail in **Table 1**), which are conducted

[1] Available under a General Public License via https://www.kicad.org

[2] Available under https://www.analog.com/en/resources/design-tools-and-calculators/ltspice-simulator.html

Table 1. Overview of the structure of the teaching-learning sequence. An in-depth description of the different phases is provided in the body text

Phase	Setting	Media	Description
Think	Simulation using KiCad	KiCad	Students recreate a linear power supply step by step using KiCad. Each step is simulated, and the outputs are compared to those of the previous steps.
Pair	Real experiment	Simulation results & experimental materials	Students work in groups and compare their simulation results. They rebuild the power supply as they did in the simulation and then compare the real experiment with the simulation results.
Share	Group discussion	Experimental results	The class discusses both the simulation and the experiment together. At least one experimental setup is analyzed using an oscilloscope.

according to the think-pair-share (TPS) method because "the TPS strategy makes the learning environment interactive, lively, collaborative and democratic" (Alsmadi et al., 2023, p. 1123):

1. **Introductory phase:** First, the topic of transformers is introduced using the example of power adapters and raising the question as to how a high AC voltage can be converted into a low DC voltage. Therefore, we suggest teachers to disassemble a charging adapter of a smartphone and to introduce its components transformer, electrolytic capacitor and rectifier. The students are then introduced to the task to model the electric functioning of AD power adapters and are guided by a worksheet. This worksheet and all further working materials can be obtained by readers from the webpage accompanying this paper.[3] It is recommended to conduct a short introductory session to familiarize students with KiCad before entering the TPS phase. For example, students can be guided through building and analyzing simple circuits with some resistors, which may help them to grasp the principles of the Spice interface while reviewing key physical aspects of electrical circuits. In order to facilitate the utilization of KiCad by students, it may be advisable to provide them with a cheat sheet.[4]
2. **Think phase:** Each student independently uses the digital tool to model their own electrical circuit.
3. **Pair phase:** In groups, the developed circuits are compared, and the real circuits are constructed, implemented with electrical components before, finally, they are compared with their digital counterparts.
4. **Share phase:** The results are reflected in a class discussion.

Taken together the learning objectives underlying the teaching-learning sequence are as follows: The students are able to ...

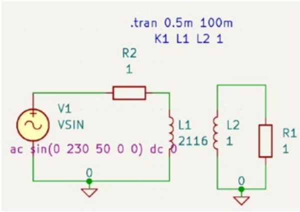
- explain the functioning of the components of power adapters using transformer, rectifier and smoothing capacitor.
- model and simulate electric circuits using simulation software.
- set-up an electric circuit underlying power adapters based on a schematic representation.

Think-Phase

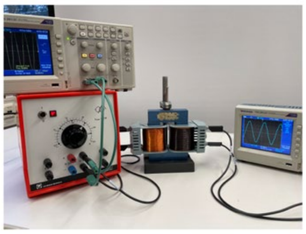
In this phase, students will disassemble a mobile phone charger to study its components, which include a transformer, an electrolytic capacitor and a rectifier. It should also be mentioned that most power supplies use a voltage regulator to provide a constant and fixed output voltage regardless of the load. These solid-state components should be mentioned for the sake of completeness but are beyond the scope of this teaching-learning unit.

The students are then guided to reconstruct the underlying electrical circuit of the charger. A worksheet (available for interested readers via the website accompanying this paper[3]) guides the students through simulating the electrical circuit in three steps (voltage transformation, rectification and smoothing) using KiCad and – in the later pair-phase – building the corresponding circuit using real electrical components available in the physics classroom. Therefore, in the beginning, students need to be introduced to the main features of KiCad, supported by the cheat sheet mentioned above. In the thinking phase, they will first model a transformer with two coils connected to a virtual power supply. These coils must be coupled using a Spice function named [K1 L1 L2 1] (see **Figure 1**). Here, K1 is the coupling coefficient, L1 and L2 are the inductances of the coils. A coupling coefficient of 1 indicates ideal coupling, meaning no magnetic flux is leaking out of the transformer, and all the energy is transferred between the primary and secondary coils. A coupling coefficient of 0 would mean that the coils are not magnetically linked at all, and there is no energy transfer between the two. The coupling coefficient is affected by the following factors:

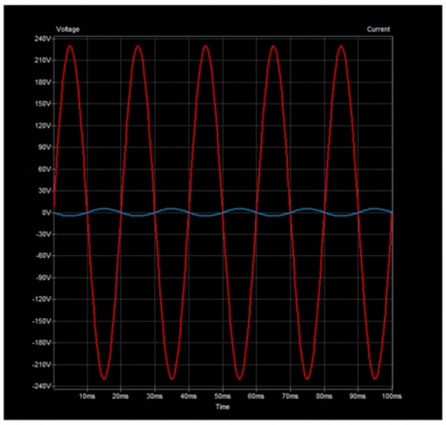
[3] https://fiztan.phd.elte.hu/letolt/supp-from-simulation-to-experiment
[4] For example, available at https://silica.io/wp-content/uploads/2018/06/kicad-cheatsheet.pdf



(a) Circuit diagram implemented via KiCad



(b) Experiment



(c) Result of the simulation of the electric circuit shown in a) via KiCad:Voltage at the primary (red) and secondary (blue) coils

Figure 1. Transformer set-up with two coils (Source: Authors' own elaboration)

- **Core material and design:** High permeability materials, such as iron, enhance coupling.
- **Winding placement and geometry:** Closely spaced coaxial windings improve coupling.
- **Leakage flux:** Flux that does not link both windings reduces the coefficient.
- **Operating frequency:** Higher frequencies can increase losses due to eddy currents and skin effects.

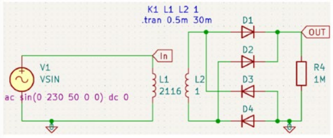
For a more realistic simulation this value can be adjusted for the given transformer.

Given that the circuit operates at 230 V AC, students must specify a power supply with these characteristics. The simulation parameters should be set to a time step of 1 ms and a total duration between 20 ms and 100 ms to observe voltage fluctuations.

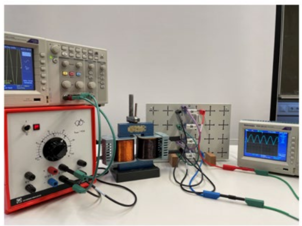
It is important to note that Spice and KiCad use the inductance (L) rather than the number of turns (N) of a coil. Inductance is proportional to the square of the number of turns, so for simplicity we can use L. Inductance can be calculated using the equation (Minkner & Schmid, 2022):

$$\frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{L_1}{L_2}. \tag{1}$$

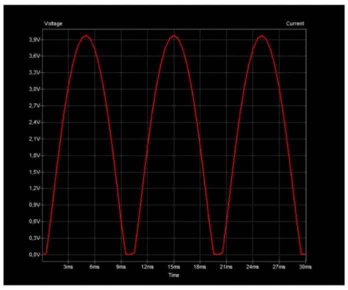
For simplicity, we set the inductance of the secondary coil to 1 H. To ensure correct simulation, a common ground potential must be established. This way the voltages on both sides can be compared. Students should place a '0V reference potential for simulation' flag on both sides of the transformer (see part a in **Figure 1**). Next, students calculate the inductance ratio to produce a secondary voltage (U_2) of 5 V using the equation (1) and test these values in the simulation. The set-up is shown in part a) in **Figure 1** and the expected voltage curve is shown in part c) in **Figure 1**. The output and input voltages are shifted by 180° because the coils in part a) in **Figure 1** are wound in opposite directions.



(a) Circuit diagram implemented via KiCad



(b) Experiment



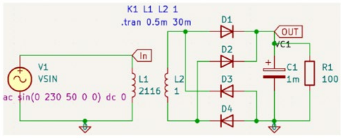
(c) Result of the simulation of the electric circuit shown in a) via KiCad: Rectified voltage

Figure 2. Circuit with 4-diode rectifier (Source: Authors' own elaboration)

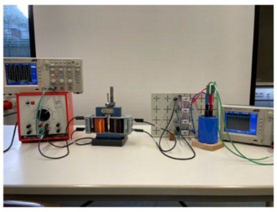
Students are then guided to implement a full bridge rectifier to ensure positive output voltages at all times. This requires four diodes arranged as shown in part a) in **Figure 2**. Students can either be given the configuration details or be instructed to research them, thereby enhancing their simulation software proficiency and research skills. To test the set-up, students are guided to run a simulation and observe the rectified output voltage as shown in part c) in **Figure 2**.

Comparing the input and output voltages of the transformer, the students may note that the output voltage varies as a function of the coil ratio but maintains a |sin(·)|-like waveform. To smooth out these variations, an electrolytic capacitor is used, as shown in part a) in **Figure 3**. Simulation of the circuit shows that the capacitor is indeed charging and as shown in part c) in **Figure 3**. The students should try different capacitances and load resistances and analyze the fluctuation of the output voltage.

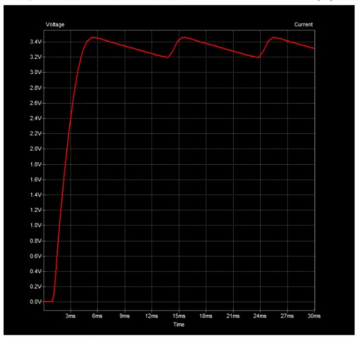
But the voltage does not reach 5 V because the coil ratio was calculated using AC voltages, and for DC the root-mean-square (RMS) voltage must be considered. Recalculating with the RMS value gives $L_2 = 1{,}058$ H: $\frac{230}{5\sqrt{2}} = \frac{\sqrt{1{,}058}}{\sqrt{1}}$. The voltage diagram is shown in **Figure 4**. To bypass capacitor charging time, set the start voltage to 5 V with ".ic V(/VC1) = 5" and adjust the simulation time frame with ".tran 0.5 m 1,050 m 1,000 m".



(a) Circuit diagram implemented via KiCad



(b) Experiment



(c) Result of the simulation of the electric circuit shown in a) via KiCad: Voltage at the capacitor while charging with remaining fluctuation

Figure 3. Circuit with smoothing capacitor (Source: Authors' own elaboration)

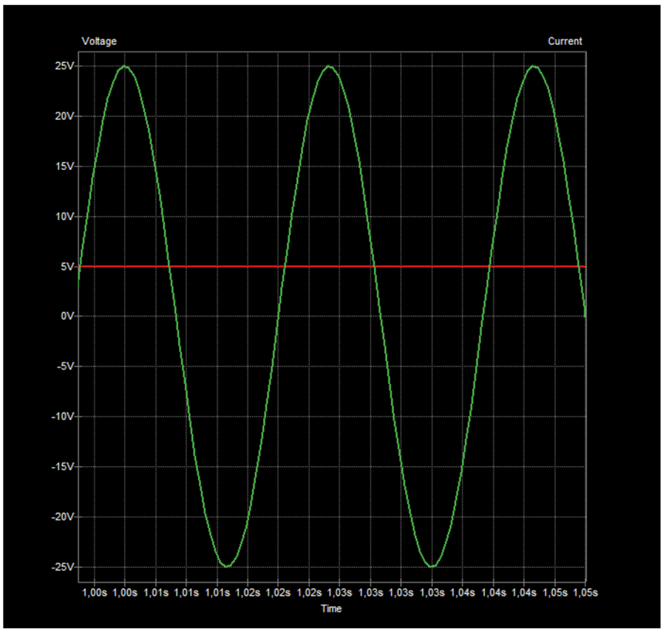


Figure 4. Input and output voltage diagram with 1058:1 coil ratio (Source: Authors' own elaboration)

In KiCad, component parameters can be changed in real time. This tool is very useful for students as they can experiment with the values and quickly observe the effects of the changes. This hands-on experience helps them to understand the factors that influence the output voltage and allows them to fine-tune the circuit to meet the desired specifications.

Suppose the input signal is a 50 Hz sinusoidal voltage at 230 V and the desired output is 5 V DC. Adjustments are made until the correct voltage is achieved. Students can change component values using the screwdriver icon in the simulation window. Students can also use this feature to simulate a variable load and test the circuit with different output configurations. For safety reasons,

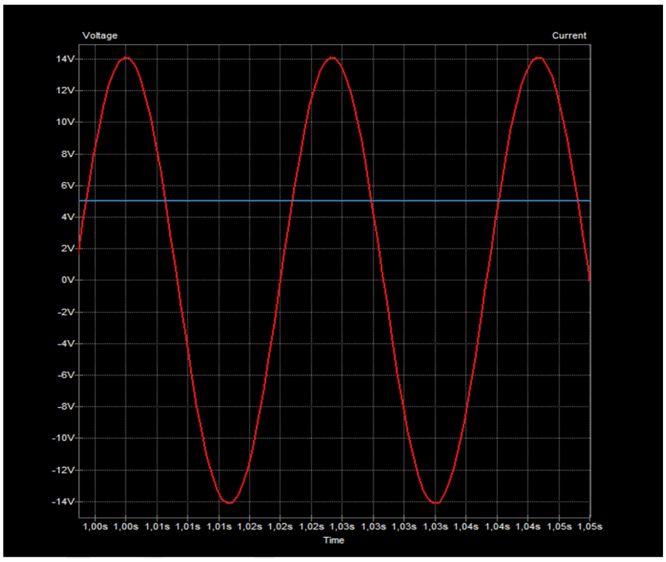


Figure 5. Input and output voltage with 16:1 coils (Source: Authors' own elaboration)

the students' initial tests are conducted with a voltage of no more than 25 V, in particular when setting up the real experiment in the pair-phase. Students must determine suitable coil combinations for these conditions. Adjusting the power supply to give a 5 V DC output may be more practical. For example, with a coil ratio of 16:1, the voltage must be 14.1 V, as shown in **Figure 5**. This approach allows students to systematically reconstruct the charger adapter and understand the individual components and their functions.

Pair Phase

The aim of the pairing phase is to move from theoretical models of electrical circuits to their experimental implementation. Students are paired and guided to discuss their models and simulation results in order to agree on a common experimental approach. Students should follow a systematic procedure similar to the simulation, consisting of three main steps:

(a) voltage transformation,

(b) rectification and

(c) smoothing.

They should compare the measured voltages with those obtained from the simulation. The materials needed for this experiment are a low-voltage transformer, a power bank, a USB cable (cut open), an electrolytic capacitor, a multimeter, a rectifier or four diodes, two coils, a transformer-grade iron core, and standard connectors. Students should first construct the transformer using the core and two coils. The supply voltage should be set according to the value calculated using equation (1) and tested in KiCad with the coil parameters. The final set-up should resemble part b) in **Figure 1**. Next, the rectifier should be assembled, using either a complete rectifier component or four diodes, as shown in **Figure 6**.

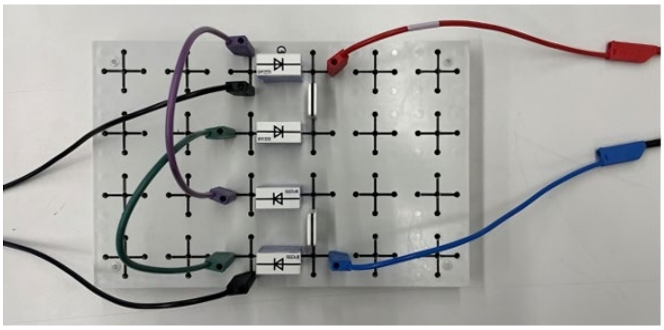


Figure 6. Rectifier set-up (Source: Authors' own elaboration)

To achieve sufficient smoothing, an electrolytic capacitor with a capacitance of at least 1 mF should be introduced. Once this step is completed, the circuit is finished as shown in part b) in **Figure 3**, producing a 5 V DC output. The successful connection of the power bank sets an important milestone for the students.

Share Phase

Due to the limited availability of oscilloscopes in most educational institutions, the share phase involves connecting an experimental set-up to an oscilloscope for the whole class to observe. Using an oscilloscope, the class can also analyze the stability of the DC voltage, compare different capacitances and discuss their advantages and disadvantages. In addition, students can use a virtual oscilloscope[5] to familiarize themselves with an oscilloscope on their digital devices if there are not enough oscilloscopes available in the classroom during the pair phase.

The results are then discussed in a plenary session, giving students an opportunity to reflect on the lesson and their learning. In addition, the links between the low voltage transformers used in the physics experiments and the subject matter are explained. This facilitates a discussion on the functionality of transformers and how they achieve different voltages.

In this lesson, we discuss a linear power supply. The pros and cons of these supplies should be explored, along with a discussion of the more modern switched-mode power supply, as most wall adapters use this setup. It is important to highlight when and where each type of power supply is more advantageous.

Research Question

Since it is well known that any software (especially if it seems a bit difficult to use at first glance) can be a barrier to student use, initially, we aimed at an exploration of students' perceptions of KiCad software which is at the core of the teaching-learning sequence presented here. Hence, the research question reads as follows: *How do secondary school students rate the usability of the KiCad software?*

In addition to evaluating the usability of KiCad, we were also interested in the workflow during the teaching-learning sequence in order to make suggestions for future implementations. We report these general observations as well as common difficulties.

METHODS

Sample and Setting

The unit presented in this article was implemented as part of an extracurricular course involving N = 28 secondary school students (aged 16-17 years).

Instrument

As outlined by Holden and Rada (2011), the perceived ease of use and usability are operationalized through a scale comprising nine 7-point rating scale items (where 0 equals 'strongly disagree' and 6 equals 'strongly agree') which has been shown to have sufficient internal consistency in earlier works (Krug & Huwer, 2023). These items were adapted to fit the context in loco in the research framework of the Technology Acceptance Model, and the participants were asked to complete them after the implementation of the teaching-learning sequence. The English version of the adapted item formulations can be found in **Figure 7**.

Data Analysis

To answer the research question, we conducted a frequency analysis and determined the distribution of student responses to the questionnaire items. We refrained from in-depth statistical analysis due to the small sample size and exploratory nature of this study.

RESULTS AND DISCUSSION

General Observations

In general, the students demonstrated a high level of engagement in modelling and simulating the electric circuit underlying AC power adapters using KiCad software in the think phase and in implementing the corresponding real experimental set-up in the pair phase. In particular, the context of smartphone adapters seemed to increase students' situational interest in the topic. This is not surprising, given that involving students in observing, performing and explaining hands-on experiments has been shown to increase students' situational interest (Palmer, 2009). Further research with larger samples is planned to investigate more specifically the extent to which the teaching-

[5] For example, see https://ap.iqo.uni-hannover.de/doku.php?id=c_elehre:oszilloskop#sidebar-site-tools

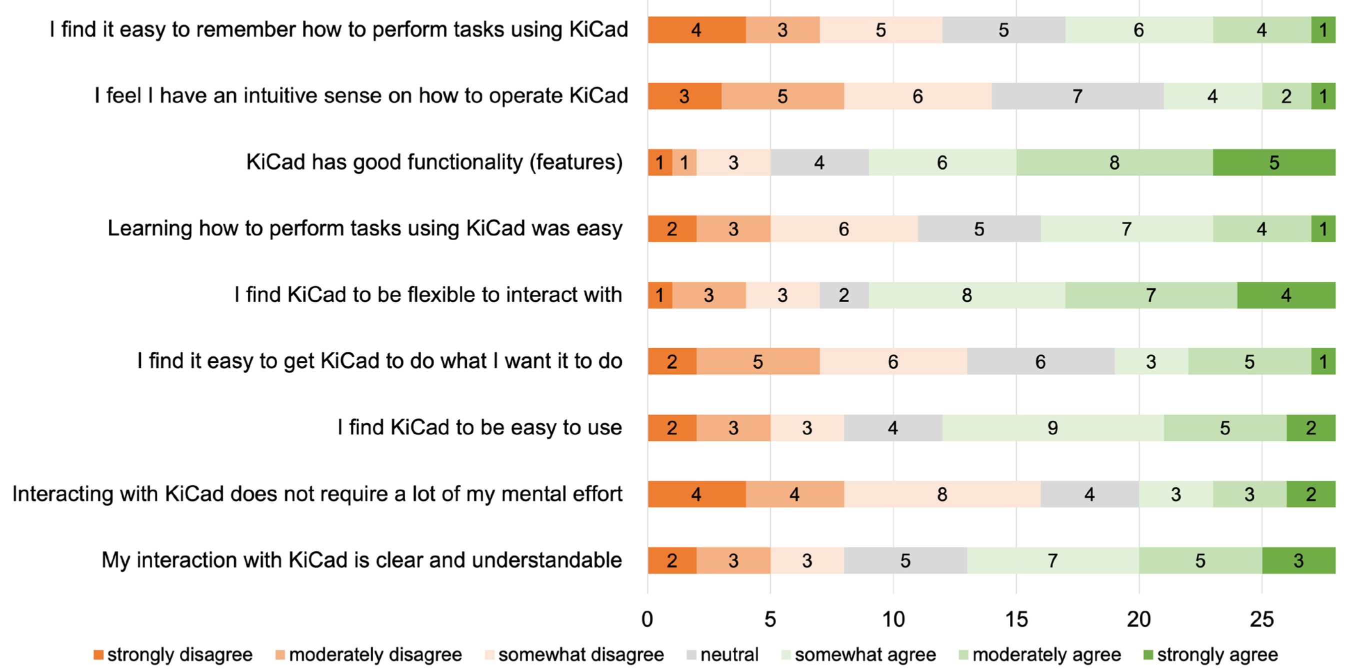


Figure 7. The absolute frequencies of the ratings of the nine items of the Technology Acceptance Model questionnaire (Holden & Rada, 2011; Krug & Huwer, 2023) as provided by the 28 participating students (the items were translated into the German language for the purposes of this study) (Source: Authors' own elaboration)

learning sequence presented here can indeed trigger students' situational interest in AC adapters in particular and transformers in general.

In practical terms, it should be noted that some minor errors occurred during the think phase, when students worked individually on designing and simulating the electrical circuits using the KiCad software. Most of these can be solved by restarting the program. In the event of runtime errors, the addition of a 0 Ω resistor to separate two voltage levels has proven to be a useful solution.

In order to ensure the workflow, to avoid errors and to support the students in troubleshooting, it has proved useful to issue a KiCad cheat sheet.[6] Such a document contains a list of all the essential commands for KiCad, thereby facilitating the use of the software, particularly during the initial stages of its utilization.

KiCad's Perceived Usefulness

The distribution of students' ratings (also see **Figure 7**) indicates that perceptions were rather positive, which supports the above impressions. Notably, students responded favorably to statements related to the software's functionality and clarity of interaction, with a substantial proportion either moderately or strongly agreeing with these items. For instance, over half of the students agreed that KiCad had good functionality and that their interaction with the software was clear and understandable. This aligns with previous findings by Holden and Rada (2011), which emphasize the importance of clear functionality in determining a software's usability. Moreover, while the majority of students found KiCad flexible (19 students agreed) and easy to interact with (16 students agreed). However, a subset of students experienced challenges: For example, there were notable percentages of students who expressed disagreement or neutrality regarding

(a) the ease of learning to use KiCad (11 students expressed difficulties in this regard) and

(b) remembering how to perform tasks using KiCad (12 students expressed difficulties in this regard).

These results point to the potential need for a more structured and comprehensive introduction to the software, as suggested by the fact that students might not have had sufficient guidance during the teaching-learning sequence. Furthermore, about 30% of the participants either disagreed or remained neutral on the statement regarding KiCad's flexibility. Similar reservations were reflected in their ratings on how easy it was to get KiCad to do what they wanted (13 students expressed difficulties in this regard). These findings may imply that while KiCad has strong functionality, certain aspects of the interface may require improvements to make it more intuitive for novice users, which is a recurrent challenge in the implementation of new technology in education (Holden & Rada, 2011).

The findings from the initial trial will inform future refinements of the teaching-learning sequence.

[6] For example, see https://silica.io/wp-content/uploads/2018/06/kicad-cheatsheet.pdf

Limitations

In terms of limitations, it is important to note that the small sample size (N = 28) and the exploratory nature of this study limit the generalizability of the findings. In addition, the participants' extracurricular status may have influenced their motivation and engagement levels, which may be different in a mainstream classroom setting. Future research should address these limitations by incorporating larger and more diverse samples, along with more rigorous statistical analyses, to confirm and extend these initial findings.

CONCLUSION AND OUTLOOK

Real-life problems are often complicated, and it is also well known that any software (especially if it seems a bit difficult to use at first glance) can be a barrier to teacher's classroom implementation. However, from the student responses on the questionnaire items regarding the use of the KiCad software based on the Technology Acceptance Model, we found initial evidence that students feel able to use the KiCad software in our new context-based teaching-learning sequence which we hope to support the teachers' acceptance and implementation of the material and suggestions provided in this paper. KiCad software can help overcome resource constraints. Different circuit configurations can be implemented and analyzed in detail in a timely manner. Dangerous voltages and currents, such as mains voltage, can be simulated without endangering students or students or using expensive equipment. Students also gain experience in reading oscilloscope graphs as KiCad displays voltages in this format. Students also gain first-hand experience of working with simulations in a context-based learning method. In the teaching-learning sequence presented in this article, they are encouraged to learn about the physical properties of a transformer and how voltage can be rectified and smoothed. By experimenting in groups, students learn to work together and discuss physical problems. The classroom discourse at the end can help to consolidate the physical knowledge in their everyday lives. Finally, the integration of KiCad in a variety of curriculum content and extracurricular activities appears promising with regard to stimulating students' situational interest in designing and setting up electric circuits, thus paving the way for more efficient teaching of electricity.

Our initial evaluation of the teaching-learning sequence presented in this article suggests that incorporating additional guidance and practice sessions could enhance students' proficiency and comfort with the KiCad tool, thereby improving the overall workflow. Regarding the usability of KiCad, the results of our pilot study suggest that secondary school students generally evaluate the usability of KiCad positively. The majority of students expressed satisfaction with the software's functionality and its potential to enhance learning, as evidenced by the distribution of responses favoring ease of use and interaction. However, the results also highlighted areas for improvement, particularly in terms of ease of learning and memory retention when performing tasks in KiCad. This points to the need for more comprehensive introductions and user support to mitigate initial challenges.

Author contributions: KD: conceptualization, methodology, software, investigation, data curation, formal analysis, writing - original draft; **KT:** writing - review & editing, visualization; **PB:** writing - review & editing, supervision. All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Acknowledgements: The authors are grateful to Ferenc Urbán for publishing the website that accompanies this article.

Ethical statement: The authors stated that the study was in accordance with the local legislation and institutional requirements. Informed consent was obtained from the participants involved in the study.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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