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TLIC PAPER

A Characteristic Curve Remote Laboratory for School and University

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ABSTRACT

Remote laboratories play a pivotal role in facilitating teaching and learning experiences, offering unique opportunities beyond traditional classroom settings. The project OnLabEdu (Online Laboratories for School Education) aims the development of remote laboratories for both, school and university-level students, completed with the development of appropriate accompanying educational resources. This paper introduces a characteristic curve remote laboratory featuring a first-developed learning arrangement on RGB LEDs and the interplay of energy, forward voltage, and wavelength of light. Drawing from the model of educational reconstruction, the learning arrangement is based on a profound clarification of the scientific content and considering students' perspectives. Against the background of a design-based research approach, the learning arrangement was evaluated with high school students through probing acceptance interviews. Now, we are interested if the learning arrangement is also suitable for tertiary level students. Therefore, we conducted six probing acceptance interviews with pre-service teachers, hailing from physics ($n = 3$) and non-physics ($n = 3$) backgrounds. The primary objective of the evaluation was to identify potential learning barriers and elements that promote a stimulating learning environment along with the operation of the remote laboratory for the tertiary level. The findings revealed similar challenges for tertiary-level students and high school students. We detected that students are challenged with technical terminology as well as explaining the term forward voltage and its connection to the concept of energy. These results give initial ideas for a re-design of the learning arrangement to address the identified issues and make the learning arrangement suitable for tertiary level students.

KEYWORDS

remote laboratory, development of learning arrangements, probing acceptance, tertiary education

1 INTRODUCTION

Remote laboratories, often called remote labs, represent a vital augmentation of teaching and learning settings, particularly within the context of schools. The extensive

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prospects offered by remote labs are instrumental in alleviating certain constraints related to the feasibility of experiments within conventional educational settings. This is especially pertinent, as carrying out experiments in authentic settings is frequently hindered by the formidable demands placed on educators regarding experiment design and safety considerations that may be challenging to uphold in school environments [1]. In such scenarios, remote labs emerge as indispensable tools for integrating complex experiments into the school curriculum, enriching teaching and learning experiences [2].

The OnLabEdu (Online Laboratories for School Education) project, supported by the Austrian Innovation Foundation for Education, addresses the need to develop remote labs tailored to the specific needs of school education. Developing well-designed teaching and learning materials that align with these technological resources is crucial to the widespread use of remote labs. Three prototype remote labs are currently being developed as part of the project, marking the start of the initial pilot phase. Alongside developing the software and hardware components of these remote labs, a parallel effort is to create educational resources that will enhance the utility of these labs in the classroom. The development of these learning arrangements is based on current educational research paradigms. In addition, these learning arrangements and the remote labs will be subject to iterative refinement, informed by empirical evidence gathered through the accompanying educational research. This approach facilitates the incorporation of contemporary insights from educational research, covering areas such as student conceptions, basic subject-related concepts, and competency-based orientation, into the development of teaching materials. In addition, the project will foster educational research concerning learning processes.

The learning environment and associated educational materials forged within this project are first optimized for students at the secondary level [3], representing the primary target group. Nevertheless, the widespread use of the remote lab is one pillar of the project, therefore, its use is tested in both schools and universities.

This paper will provide an overview of one of the developed remote labs, specifically, the characteristic curve lab. Attention will be devoted to the ongoing development of the learning arrangement and the empirical findings derived from tertiary-level students working on the lab's tasks of the developed learning arrangement. More precisely, the empirical data collected on tertiary-level students concerning factors hindering the learning process and elements that foster educational advancement will be focused. This expands our knowledge of improvements for re-designing the learning arrangement at university level and makes the characteristic curve remote lab and the developed learning arrangement available to a broader audience.

2 THE CHARACTERISTIC CURVE REMOTE LAB

2.1 Overview of the laboratory

The characteristic curve remote laboratory is intended to detect the current-voltage characteristics of different electronic components, including resistors and diodes. The hardware infrastructure is made up of one circuit board that has 16 measurement ports. The labs design can be seen in Figure 1. The laboratory can be used through a web-based client interface. This interface allows you to measure the current-voltage characteristics of various electronic components. There is also the possibility to set voltage-ranges as shown in Figure 1. One useful feature is the webcam functionality, which lets you monitor your measurements in real time. This is a convenient way to observe when the forward voltage is reached due to the illuminating LED—one of the components that can be measured (see Figure 2). As a result of those features, the laboratory can be used broadly and serve different levels of education with alternating learning objectives in various disciplines (e.g., physics, technology, electrical engineering). In the next section, we present a few examples of its application on several levels.

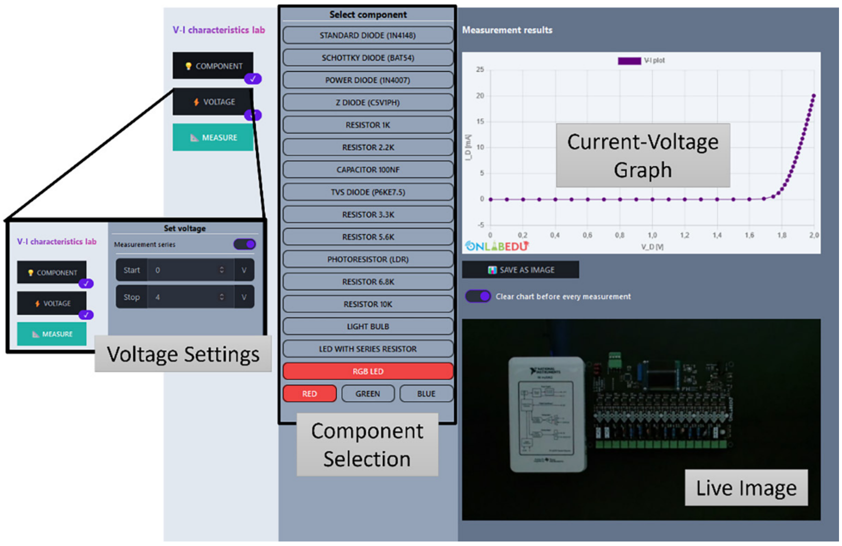

Fig. 1. Characteristic curve web client

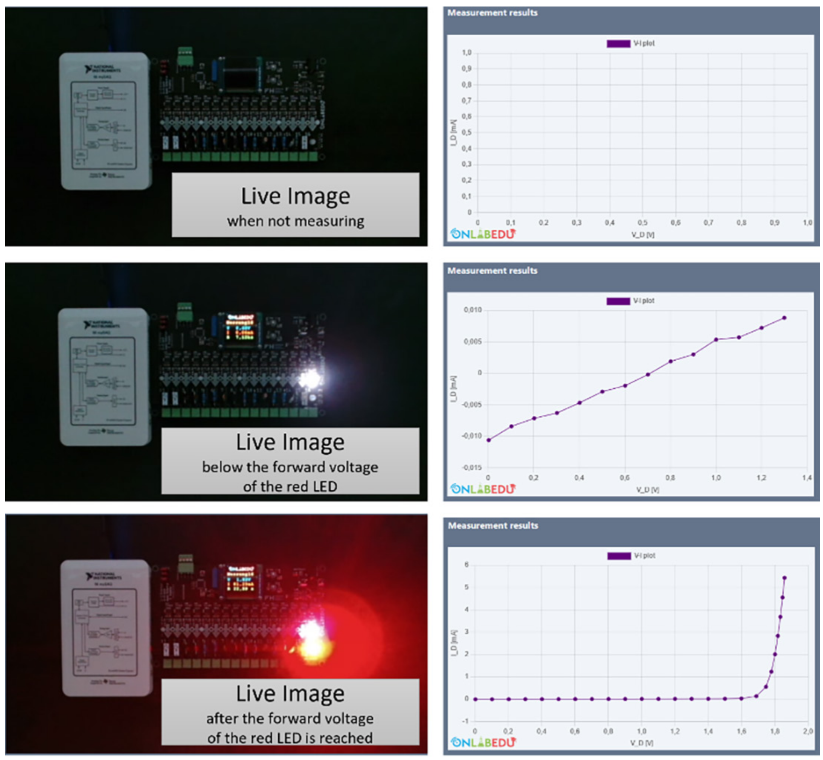

Fig. 2. Live image while measuring the characteristic curve of a red LED

2.2 Applicability at different educational levels

A major advantage of the characteristic curve remote laboratory is that exercise tasks can be set at different levels of knowledge; from lower secondary level up to tertiary education, and at both Bachelor and Master level. For instance:

- Lower secondary level: A pencil is measured at the graphite lead and the wooden handle; two measurements must be taken: “Perform the voltage and current measurement on the pencil lead and pencil handle. Describe your observations concerning the measurements. Draw assumptions that support your observation based on electric properties of the materials.”
- Higher secondary level: Different colored LEDs are measured: “Describe your observations. Focus on the energy (voltage) applied and the wavelength of the measured LED and find a relation. Support your assumptions with further measurements.” (See also the learning arrangement in [3] and later in this paper).
- Bachelor level: Characteristics of semiconductor diodes are measured: “Measure the characteristic curves of a standard diode, a Schottky diode, and a power diode. Find and explain the differences between the curves using the theoretical background.”
- Master level: The characteristic of a TVS (transient voltage suppression) diode is measured: “Record the characteristic and calculate the operating point (voltage and current) of the TVS diode, where the differential resistance of the diode gets less than 1 kΩ.”

The mentioned examples must be viewed under the assumption of an ideal situation. Moreover, the effort required to conceive, set up, commission, and develop the exercises should not be underestimated. The aim should always be to offer many different exercises on the one hand, and to offer these exercises to a multitude of different levels of knowledge. Only in this way, the initial effort of the remote lab can pay off long term.

2.3 The learning arrangement

The presented learning arrangement (a detailed description of the development can be found in ref. [3]) was developed contradicting the background of a design-based research approach [4]. Therefore, iterative cycles of design, evaluation, theory impact, and re-design are done (see Figure 3). The initial iteration of the learning arrangement relies on design principles based on the existing body of literature on research in science education. In addition, the model of educational reconstruction serves as a basis for developing the learning arrangement [5]. Hence, when designing learning arrangements, it is important to consider both the clarity of the science content and the perspectives of the learners. Central to the overarching guiding principle in developing these learning arrangements is the adherence to a constructivist paradigm, wherein students’ learning processes unfold [6].

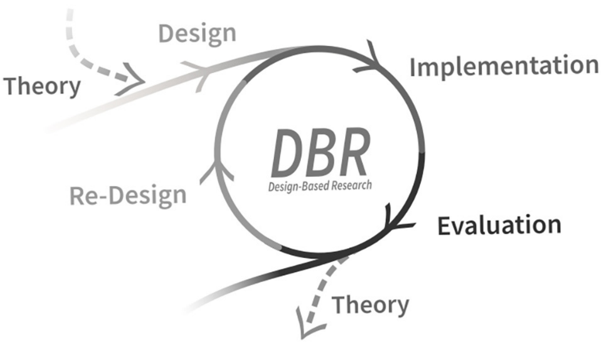

Fig. 3. Design-based research cycle (Design-based research approach, Sarah Zloklikovits CC BY 4.0, https://commons.wikimedia.org/wiki/File:DBR_english_greyscaler.svg)

The topic of the learning arrangement is RGB LEDs and their forward voltage. Therefore, it aims to focus on the basic concept of energy and its relationship to the forward voltage of RGB LEDs. This context was chosen because energy is a basic concept built upon in science and technology. Resultingly, it serves as a perfect topic for several educational levels. In addition, the visibility of RGB LEDs' glow creates an effect that can be perceived directly with the students' eyes while measuring the characteristic curve. This effect can be compared with the measured curve.

The first version of the presented learning arrangement accompanying the characteristic curve remote lab was originally developed for high school students (11th–12th grade) in Austria. The current version of the learning arrangement is in the second design cycle at the moment and will be adjusted for university level.

Main relevant parts of the learning arrangement are the scientific key ideas derived from literature [7, 8] and students' conceptions of energy (e.g. [9, 10]), electric current [e.g. 11, 12], and the electromagnetic spectrum and radiation (e.g. [13, 14]). The main aspects of the learning arrangement considered in this paper will be briefly covered in the following sections.

The scientific key idea we focus on in this paper is:

> *"The forward voltage indicates the energy level which must be reached to turn on a LED"* [3, p. 318]

The learning objectives focused on are:

> *"The learners can connect the wavelength of different light colors to its energy"* [3, p. 318]
>
> *"The learners can explain how the different forward voltages are related to the colors of the LED"* [3, p. 318]

2.4 Overview of the learning arrangement[1]

Students begin with a three-page introductory document covering key terms and concepts as the electromagnetic spectrum, conduction bands, valence bands, insulators, semiconductors, conductors, and forward voltage. The document also briefly introduces LEDs and defines Fermi energy. It ends with a brief overview of the remote lab. Subsequently, students complete three assignments, which involve:

1. Creating a hypothesis about the forward voltages of different LED colors and providing a rationale.
2. Testing their hypothesis using the characteristic curve lab and documenting their approach.
3. Using the LED datasheet to determine color wavelengths and to explain why the forward voltages follow the order: red, green, and blue, with images from the remote lab's measurement series.

3 ACCOMPANYING EDUCATIONAL RESEARCH

One objective of the OnLabEdu project is to implement remote laboratories that can be used on several levels of education. Therefore, providing teaching and learning

[1] For more details concerning the learning arrangement, see ref. [3].

materials plays an important role. Hence, an already developed learning arrangement for high school students should be tested at higher education levels to get hints for the adaption of these materials concerning their application on tertiary levels.

The already developed learning arrangement [3] provides a valuable basis for higher educational levels. First, it covers one basic scientific concept that connects several scientific ideas and the topic is situated on all levels of education—the concept of energy. Second, we focus on the connection of energy (voltage) which must be applied to illuminate a red, green and blue LED which is relevant for students of physics and technology.

The current study forms the next iteration step of the development process of the learning arrangement. Facilitating conceptual change [6] on several levels of education is one objective of our project. Therefore, we need to test our learning materials on several levels of education.

3.1 Research question

The main goal of this evaluation of the learning arrangement is to test the learning arrangement among students at higher academic levels, encompassing more than just high school students [3]. Our objective is to optimize the learning materials to support the unique requirements of students at various educational stages. To accomplish this, we have devised the following research question: What elements of the learning arrangement promote or hinder pre-service physics teachers' learning process at the tertiary level of education?

3.2 Design of the study

In addressing the research question above, we employ the method of probing acceptance [15]. This method enables us to uncover obstacles and elements that facilitate learning within the learning arrangement. All probing acceptance interviews follow the same procedure used in the first iteration [3]: Students will receive a sheet with scientific terms and explanations. They will complete assigned tasks and answer questions about their approach, information used, and challenges faced. They will also provide feedback on the website's usability and suggest improvements.

Three pre-service physics teachers (1 female, 2 male) and three non-physics pre-service teachers (2 female, 1 male) were interviewed in the second half of their bachelor studies. Data collection was carried out in June and July 2023. The audio data was transcribed, pseudonymized and analyzed using qualitative content analysis [16]. The data was analyzed by two authors and communicatively validated.

4 RESULTS

In this section, we will begin with results found in the data of non-physics students, followed by physics teacher students. Finally, we will compare the results of both groups and discuss them in awareness of previous studies.

4.1 Non-physics pre-service teacher

All non-physics pre-service teachers struggled with scientific language. This can be derived from difficulties concerning connections of the concept of energy, forward voltage and other scientific terms. For instance, when explaining forward voltage, Anne stated: *"In their ground state, semiconductors do not conduct. When voltage/energy is applied, they become conductors, therefore semiconductors, and this energy needs a certain forward voltage."* (Anne, paragraph 16 of the transcript: content-translated from German) Anne's statement shows fruitful approaches in her thinking. Nevertheless, it is unclear what exactly she means by the phrase *"need for a certain forward voltage."*

Furthermore, Carlos interchanged the terms current and voltage, and he explicitly stated his problems with the demand of scientific language: *"So, I didn't quite get along with the technical terms because I also don't understand the physics of what photon diode valence band means, I don't have the prior knowledge. If I had read it five more times, I would have come to a similar result"* (Carlos, paragraph 36: content-translated from German). In consequence, technical language seems to be a huge challenge for the students.

Moreover, forward voltage can present a difficulty in both explanation and comprehension (see Anne's statement above). Alice explained forward voltage by pointing at the voltage-axis where the graph began to rise. This would be correct, however, she did not specify what the term means. Carlos inadequately explained forward voltage as: *"Okay, so until an electron reaches the conduction state, that's how much voltage you need."* (Carlos, paragraph 24—content-translated from German). All these results point to difficulties in understanding the term forward voltage.

Finally, setting the voltage-range is a problem for the students. All three non-physics pre-service teachers were not able to set the appropriate voltage-range in the first place. Therefore, the first measurement produced no applicable result. When the interviewer showed them how to change the range, they all had a lightbulb moment.

4.2 Physics teacher students

Choosing the appropriate voltage-range for the measurement was also a challenge for the physics teacher students. Only one participant managed accomplishing the task at first attempt. The other two pre-service physics teachers had a light bulb moment as well, when the interviewer showed them the voltage-range options.

Concerning the term forward voltage physics teacher students also showed similar problems as non-physics pre-service teachers. For instance, Will pointed at the y-axis and asked if this was the forward voltage (the y-axis displayed current and the x-axis voltage). Helena stated her hypothesis: *"The higher the forward voltage of the semiconductor, the more energy is available."* [Helena, answer to phrase a hypothesis on the worksheet—translated from German]. Therefore, the understanding of the term forward voltage is also challenging for physics teacher students.

In addition, the density of information given within the learning materials seems to be overwhelming. Will and Helena both stated that there is a multitude of information presented in the learning materials and the number of electronic components they can use within the laboratory. In concrete, Will said that he had never seen a data sheet of a diode before: *"I've never seen a data sheet like that before. So wow, what does it say? And then the physicist came out. Then I was unhooked by the fact that it said type because I thought type was the diode and that confused me. And then I was confused that it said maximum voltage and not normal."* [Will, paragraph 83—translated from German]. As visible above, the physics teacher students expressed the existence of a huge quantity of information.

One pre-service physics teacher managed the tasks very well. Jan described the solving process as follows: *"After you have familiarized yourself with the lab, it's just a bit* *of trial and error, because the interface is very clear and intuitively easy to use, and then I selected red, green and blue in order, after I found the RGB LED at the very bottom, and focused on the moment when my current starts to rise. That is, when the current starts to flow, which I said is the forward voltage"* [Jan, paragraph 60—translated from German]. This shows that the task could be successfully processed without considerable difficulties.

4.3 Summary

Pre-service physics teachers and non-physics pre-service teachers show difficulties when solving the tasks of the learning arrangement and working with the characteristic curve laboratory. The main differences between non-physics and physics pre-service teachers were shown in their use of scientific language. While non-physics student teachers struggled with using and understanding scientific terms correctly to a high degree, physics student teachers only partially faced obstacles in using scientific language appropriately but showed understanding of the given terms. Nevertheless, physics teacher students also show obstacles in using scientific language appropriately.

Moreover, the setting of the voltage-range has shown to be an obstacle to both groups as well. Only one pre-service physics teacher showed competencies in setting an appropriate voltage-range. All other students felt a lightbulb moment. This shows that those students do not possess knowledge or ideas about the scale used for the voltage-range.

Finally, the term forward voltage in connection with the concept of energy seems to be problematic for both groups non-physics and physics pre-service teachers.

5 DISCUSSION

This study evaluates a learning environment developed in a characteristic curve laboratory already used by high school students. The far-reaching goal of the OnLabEdu project, in which the remote laboratory was developed, is the widespread use of remote laboratories. Thus, the use of a learning arrangement (originally designed for high school level) in the tertiary education sector was tested by means of acceptance surveys. Specifically, three pre-service physics teachers and three non-physics pre-service teachers were interviewed. The aim was to find out to what extent the learning arrangement needs to be adapted to fulfill the needs of these target groups in tertiary education.

Theoretically, one could assume that the required level of the already developed learning arrangement for high school level is possibly too low, especially for pre-service physics teachers. In addition, there should be hardly any differences for non-physics teacher training students compared to acceptance interviews, already conducted with high school students, as secondary-level students and non-physics students at university level can be considered to have similar prerequisites to accomplish the learning arrangement. The results of this study have proven to be similar to the results shown in the previous study [3]. In accordance with those results, we detected obstacles with the term forward voltage and the setting of the voltage-range in this study as well. Additionally, we found that pre-service teachers face challenges regarding the appropriate usage of technical language. In contrast, one obstacle we found with high school students, phrasing hypotheses [3], could not be detected in this study. Therefore, bachelor students seem to be able to phrase hypotheses appropriately.

Additionally, the relationship between energy and forward voltage of LEDs appears to be a new concept for nearly all students. As a result, properly integrating the acquired knowledge into their existing knowledge framework may be a significant challenge. Furthermore, the failures to set the right voltage-range of almost all students in all three target groups (high school students, physics and non-physics pre-service teachers) hint to a knowledge gap regarding electronic components and their characteristics.

Moreover, the comparison of results of physics and non-physics pre-service teachers and high school students show consistent manifestation of similar trends within all three cohorts. This implies that the considered subject matter is conspicuously absent from the Austrian curricula. Additionally, it can be implied that they do not consciously face the topic in their daily lives.

The presented study is of exploratory nature. Therefore, it is important to interpret the results with caution. Drawing definitive conclusions about other learning environments or curricula is crucial because the data and results of the presented study are based on the limited sample size of only six acceptance interviews within a very special setting–the developed learning arrangement.

In conclusion, we observed that students in tertiary education face similar obstacles as encountered by high school students [3]. Consequently, we suggest that the learning arrangement should be revised in the next re-design cycle by introducing additional support for using the remote lab. Specifically, we recommend incorporating hints directly into the interface of the remote lab, particularly concerning the setting of the voltage-range. Furthermore, we recommend supporting material to connect the term “forward voltage” with “energy” and “wavelength/frequency.” Nevertheless, we did discover that the learning arrangement we evaluated is also highly applicable for higher education. Further studies must be carried out to evaluate the usage of the learning arrangement in other tertiary educational groups.

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