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PAPER

Assessment and Level Modelling in Fundamentals of Electrical Engineering

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ABSTRACT

This paper focuses on the module "Fundamentals of Electrical Engineering," in which students from different engineering disciplines often face difficulties. Despite efforts to enhance the course through digital media, the formation of study groups, and adjusted lecture and exercise materials, there is still a high failure rate in the subject, leading to potential student dropouts. The primary goal is to analyze students' challenges in solving electrical engineering problems to evaluate their grasp of the fundamentals of electrical engineering and identify varying levels of competence. The findings are based on a cross-sectional study conducted at the conclusion of a university course in Germany, involving 196 students. Through item response theory (IRT) analyses, it was determined that the assessment items demonstrated satisfactory fit values. The proficiency model delineates four levels, with only 8.2% of students achieving the highest level. At this stage, students can tackle more intricate problems using circuit analysis techniques. However, a notable portion of students (40.3%) lack a basic understanding of electrical circuits, placing them at the lowest level.

KEYWORDS

fundamentals of electrical engineering, assessment, level-modelling, electrical problem-solving competence

1 INTRODUCTION

When examining the educational process of engineering, it is remarkable that, in recent years, there have been several research studies and advances in the field of engineering education. Some concrete examples of these advances include studies on problem-based learning [1], project-oriented learning [2], makerspaces [3], paired peer learning [4], flipped classrooms [5], and future-fit classrooms [6]. Similarly, on the social aspects and professional competences required in engineering, new competences have become necessary, such as sustainable development [7], teamwork, lifelong learning, open-mindedness, oral communication, written communication, multiculturalism, networking, leadership, ethics, social responsibility, creativity, innovation,

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and so on [8] and [9]. There are numerous incorporations of digital strategies to teach virtually and remotely [2] that contribute to the educational process. In examining these changes, it is clear that much of the study focuses on the latest trends in engineering education. These include the adoption of new educational methods and elements, driven by digitalization and technology; the reformulation of educational objectives; the addition of new competences and curriculum changes; and the incorporation of the latest technological advances currently under development.

Despite the advances mentioned above, there is still a notable gap in study related to the didactics of electrical engineering content and its implications for engineering education as a whole. This lack of study that specifically analyzes the didactic aspects of electrical engineering fundamentals makes it difficult to explore the complexities of transforming technical content into a pedagogical domain.

Despite the efforts made by educational institutions to enhance teaching through various pedagogical approaches, such as the use of digital media, the establishment of learning groups, and the adaptation of lectures and exercises, the failure rate in the Fundamentals of Electrical Engineering module remains persistently high across various engineering programs.

The module "Fundamentals of Electrical Engineering" is the initial electrical specialist module in the undergraduate courses of electrical engineering, information systems engineering, mechatronics, renewable energy systems, economics and engineering, and the teacher training program in vocational schools at Technische Universität Dresden in Germany. This study aims to acquire knowledge about the factors that influence the complexity of learning electrical engineering content and to investigate the technical obstacles encountered by students. The objective is for this investigation to assist students in their learning journey and, as a result, decrease the instances of unsuccessful attempts in this module.

2 LITERATURE REVIEW

The starting point of this section is the broad field of the fundamentals of electrical engineering and the ability to solve electrical engineering problems that students encounter at the start of their educational journey. Therefore, the main objective of this literature review is that professionals in the field of electrical engineering need to develop these professional skills, and the evaluation of their learning progress is centered on their capacity to exhibit proficiency in problem-solving. A list of selected empirical studies is provided at the conclusion of this section.

2.1 Fundamentals of electrical engineering

The fundamentals of electrical engineering cover a wide range of topics and concepts essential to understanding and applying electrical phenomena and principles. They provide the foundation for modules dealing with electromagnetic fields, dynamic networks, and more applied subject areas. The exact definition and meaning of the term "Fundamentals of Electrical Engineering" may vary according to context and curriculum. One way to better understand this area is through a curriculum analysis of German universities that belong to the renowned alliance of leading technology universities in Germany (TU9 group). The curricular analysis shows that the fundamentals of electrical engineering can be defined and understood in various ways. Each university has different curricula and subjects according to the specifications of their courses. Through this analysis, it is possible to see a division of meanings of the term fundamentals of electrical engineering from macro and micro points of view. In some universities, such as Technische Universität Dresden (TUD) [10] and the University of Stuttgart [11], it is considered the first module of the electrical engineering degree program. According to the study regulations, students can analyze electric circuits and networks, deal with basic electrical quantities (charge and current, voltage, energy, and power), explain resistive two-poles (definition, interconnections, linear two-poles, basic circuit, power transfer), name current and voltage sources (independent sources, controlled sources), apply methods of network analysis (superposition theorem, network description, node and mesh current analysis), and understand electrothermal analogies [10]. At Leibniz University Hannover [12], the fundamentals of electrical engineering are considered a series of first modules, including the fundamentals of electrical engineering: direct current (DC) and alternating current (AC) networks, electric and magnetic fields, and Special Network Theory. Other universities, such as the Technische Universität Berlin [13] and the University of Braunschweig [14], consider the fundamentals of electrical engineering both a compulsory area and an entry module.

There are also universities, such as RWTH Aachen University [15], the Technical University of Darmstadt [16], the Karlsruhe Institute of Technology [17], and the Technical University of Munich [18], where the fundamentals of electrical engineering are considered a significant foundational area. The curriculum at these universities includes a wide range of modules and subjects that equip students with a diverse spectrum of knowledge and abilities in electrical engineering.

In the context of this study, the subject Fundamentals of Electrical Engineering is considered the introductory module at Technische Universität Dresden (TU Dresden), and it is compulsory for students in their first semester. The main learning objectives include acquiring knowledge, understanding, and calculating electrical quantities; applying direct current analysis to linear and non-linear networks; and using basic network theorems in practical electrical problem-solving. Proficiency in higher mathematics (such as differential and integral calculus and solving systems of linear equations) is expected at the start of the course. However, due to variations in students' prior knowledge, mathematical concepts are also reviewed in the initial weeks. A significant challenge in electrical engineering is the high exam failure rate, which ranges from 30–50% for mechatronics, 40–60% for industrial engineering, and 50–70% for vocational engineering. These statistics highlight the difficulty many students face in meeting the module requirements. Identifying the specific challenges students encounter in this subject is essential to implementing targeted interventions to improve the teaching and learning processes. Therefore, this paper aims to explore the content of the fundamentals of electrical engineering and evaluate the learning environment for students at the start of their engineering programs. Specifically, the study seeks to understand how students acquire essential knowledge of electrical engineering principles and apply this knowledge to solve electrical problems. Consequently, it is crucial to assess both aspects thoroughly.

2.2 Problem solving competences in the fundamentals of electrical engineering

The term "competence" plays an essential role in the context of this paper. Competence can be described in various ways with different nuances, making it challenging to create a single concept [19]. Most concepts involve cognitive abilities and skills that individuals possess or can learn to bring about a transformation to solve specific problems [20] or that can be applied in new situations [21], "a learned ability to adequately perform a task, duty, or role" [22]. One way to analyze competence is by examining the connection between knowledge and ability [23] or the link between principles, theory, knowledge, and practice [24]. Furthermore, competence encompasses a broader subjective aspect than knowledge because it includes other components such as methodological, personal, and social aspects. Since competence includes a potential attribute, which is the ability that becomes visible when an individual demonstrates it in their performance [25], competence can only be measured in terms of performance [23].

In the German qualifications framework for lifelong learning (DQR) [26] and Bartram and Roe [22], competence is divided into various dimensions, including personal competence and professional competence, which specifically refers to the knowledge and skills required in a particular field [23]. This encompasses the subject-specific knowledge of electrical engineering and the ability needed to solve electrical engineering problems. Professional competence in the field of electrical engineering fundamentals encompasses not only specific technical knowledge but also the methods and attitudes [22] used to solve electrical engineering problems. It involves developing a deep understanding of fundamental theoretical concepts and applying this knowledge in practice. Competence establishes the connection between knowledge and ability and is to be seen as the ability to exert control over electrical engineering situations or tasks and to make changes to achieve a desired outcome [27]. Developing expertise and a repertoire of skills in the fundamentals of electrical engineering requires the acquisition of specialized electrical engineering knowledge. Klieme [23] specialized that, due to the central role of subject-related skills and knowledge, competences are highly domain-specific, and one consequence is that concrete operationalization of competences must first take place within the subject area (domain). This includes understanding electrical quantities, knowing calculation methods, applying network theorems, and more in our study.

By learning the basic concepts and methods and applying them to tasks, students develop their professional competence by improving their problem-solving skills and applying their knowledge to practical applications. Although professional competence goes beyond mere knowledge, in this specific study, there is a close relationship between professional competence (at the beginning of graduation) and knowledge applied to a problem, since the educational objective of this first module is precisely to make students competent in the fundamentals of electrical engineering. Therefore, in this specific module, it is also possible to measure competence, albeit indirectly, by analyzing the professional competence performance, "which is the extent to which competence is realized in one's actual work on a problem or set of problems" [27]. Hence, in this study, the assessment of students' performance in solving tasks in the fundamentals of electrical engineering is used to evaluate professional competence, since problem-solving is a central activity in the learning process and plays an essential role in engineering education [28]. Through the assessment of competences, different levels of competence can be identified, ranging from the basic to the advanced level of competence.

In addition to the challenge of defining competence, there is another challenge in this area, which is measuring competence. Rompelman [29] states that "everyone involved in engineering education, both students and teachers, knows that in order to get a degree, students have to pass examinations." Therefore, in engineering courses, the construction of level models as an independent sub-dimension of professional competence can be closely associated with the application of knowledge [30]. Furthermore, "there is a need for reliable instruments for measuring competence within the central specialties of the engineering sciences" [31]. This need for assessment, according to [29], is a very important element in education and arises from a clear definition of educational objectives.

Through assessment, the ability to solve problems by interpreting fundamental concepts, analyzing problems and methods, applying knowledge to electrical engineering scenarios, and defining problem-solving strategies is a direct reflection of the professional competence acquired.

2.3 Related research and state of the art

Two elements of investigation are often the subject of scientific research: the assessment of students' learning in the first years of an engineering course and the barriers they face that ultimately hinder their learning. Thus, it is possible to find research that evaluates the first year of an electrical engineering course in a more comprehensive way, assessing a group of subjects and aspects such as curriculum planning, implementation, and outcomes [32]. In a more specific manner, it is possible to find evaluations limited to the electronics course and its outcomes [33] based on Bloom's taxonomy, but with the intention of mapping the outcomes to enhance the electronics curriculum offered by the university. Joan Borg Marks [34], in her doctoral dissertation, investigated the understanding of electricity by undergraduate physics students based on the mental models of students' understanding of electricity. The contribution of this study was to identify the mental models of students' understanding in the process of learning electricity.

With regard to the content of basic electricity in the engineering course, which includes topics such as the analysis of DC circuits, Kirchhoff's law, mesh analysis, Ohm's law, electric charge, and energy, among others, it is interesting to note the contribution to the development of questions based on the analysis of the most common mistakes made by 110 students during a three-year observation period [35].

All these related studies, as well as the various studies on pedagogical insertions in engineering mentioned in the introduction, bring interesting aspects to both topics: the analysis of the didactic aspect of the content of the fundamentals of electrical engineering and the investigation of the difficulties of the students in the learning process, although their objectives are different from those of this study. While their objectives are aimed at developing curricula, identifying mental models, analyzing common errors, developing and applying methodologies, and using new technologies, our study focuses on the didactic analysis of the content itself by diagnosing and solving electrical problems. Thus, this study shares the same intention: to combine the didactic aspects of the fundamentals of electrical engineering with the investigation of the barriers faced by the students on the module. In order to proceed with this investigation, an interesting and correlating approach to realize this investigation is the study in the mechanical engineering field [31], which uses a competence model of empirical study on education and also the classification into four different levels of competence [30], in order to obtain a level description of each level's characteristics for discussion.

3 RESEARCH AIMS

The main objective of this study is to assess problem-solving competencies related to the fundamentals of electrical engineering and to implement a multi-level classification model. This classification into different levels of competencies allows for a deeper exploration of the main question: What characteristics make a (fundamental) electrical problem hard or complicated to solve? Through this analysis, the study aims to contribute to understanding the learning challenges students face in this domain. With these results, it is expected to identify opportunities for adaptation in teaching methodologies, with the ultimate goal of reducing the number of failed attempts and supporting students in their learning process. It will also provide a more detailed diagnosis of the current situation, which will help identify development points for future research and other studies.

4 METHODS

In order to address the study questions, the following chapter explains the study design, provides insights into the test items, and outlines the procedure for item analysis and selection. A German online service called DeepL [36] was utilized for machine translation of individual paragraphs of the article.

4.1 Research design

This study was conducted as a cross-sectional study at the end of the course using a paper-and-pencil test. The questions covered the fundamentals of electrical engineering, focusing on topics from section 2. The details of the questions are provided in Table 1. A total of 266 students participated in the data collection.

As the aim of this study is to diagnose the current situation, it was decided to utilize the existing system for the subject. Therefore, both the development of the assessment and its corrections were conducted by the professionals responsible for the subject at the university. The exam was divided into five electrical problems with subtasks, totaling 15 items (refer to Table 1). For all 15 items, it was possible to achieve intermediate scores (partial credits) to avoid simplifying the assessment to merely correct or incorrect answers.

Table 1. Overview of the electrical problems

Task	Item Description
1a	Replace the metal–oxide–semiconductor field-effect transistor (MOSFET) in the circuit with the given equivalent circuit and draw the resulting circuit
1b	Determine the MOSFET gate current and voltage using basic network analysis
1c	Calculate the voltage using the formula and the value for the differential voltage gain (MOSFET)
2a	Set up the system of equations for the nodal analysis of a circuit with three main nodes and three meshes consisting of only resistors and voltage and current sources
2b	Solve systems of two linear equations
3a	Determine the Thévenin equivalent circuit of a circuit consisting of four resistors, a voltage and a current source
3b	Determine the value of the equivalent resistance that provides the maximum output power of the Thévenin equivalent circuit
3c	Determine resistance for impedance matching of the Thévenin equivalent circuit
4a	Network analysis (superposition) on a circuit with four resistors, a voltage source and two current sources arranged in three meshes and three nodes to calculate two specific voltages
4b	Network analysis with dependent source and two resistors to calculate a specific voltage and a current value
4c	Determine the equivalent resistance of an arrangement of five resistors connected in series and parallel

(Continued)

Table 1. Overview of the electrical problems *(Continued)*

Task	Item Description
5a	Determine the functional equation and time constant of a generic circuit whose voltage load curve is shown graphically.
5b	Determine current using basic network analysis and plot the curve of the current over time
5c	Calculate emitted energy by integrating the product of the current and voltage curves
5d	Calculate transferred electric charge by the integration of the current

The data obtained from the assessment was processed using Microsoft Excel. The study used item response theory (IRT) analysis using ConQuest 5.0 [37]. The data analysis is grounded in IRT [38], commonly employed in large-scale surveys such as PISA or TIMSS. It offers more test design options, such as matrix sampling or computerized adaptive tests, and allows for a criterion-referenced interpretation of IRT-based test scores. This is made possible through the simultaneous localization of item difficulties and individual abilities on a shared scale [39].

A model that is frequently used when working with dichotomous items is the Rasch model [40]. However, since the answers to the test items in this study allow intermediate values, it was not possible to use the Rasch model. Instead, we utilized the partial credit model (PCM) by Masters [41].

Typical parameters for item analysis and interpretation can be found in the literature [30] and [42] as follows:

- The resolution rate of the item should be between 5% < p < 95%.
- T-value < |2|;
- EAP (Expected A Posteriori) > 0.7; and
- 0.5 < WMNSQ < 1.5 (weighted mean square).

The study then uses the data from the IRT analysis to run the level model, following the classification into four levels, as also adopted in [30], based on the person's ability (from level 1, least competent, to level 4, most competent). The anchoring of the levels is based on the TIMSS categories [43]. Following [30], only the categories "anchored" and "nearly anchored" are used. If an item has a solution rate of at least 65% in the selected interval, it is classified as "anchored" for the selected threshold. If the solution rate is over 50% but less than 65%, it is classified as "nearly anchored." In addition, the solution rate at the previous threshold should then be below 50%. By comparing the resolution rate of each level of competence with the categories "anchored" and "nearly anchored," it is possible to gain a better understanding and description of each level. The limits between the different levels of competence were determined by analyzing the threshold points of all the categories of all the items, according to [30]. Groups of people are then formed around the anchor points or intervals, and the solve rating of the items within the anchor groups is determined. Characteristic items from each anchor point are then determined and interpreted for the description of the levels [44]. This procedure is used in other large-scale studies such as PISA, NAEP, and TIMSS. This approach makes it possible to examine student performance in detail and establish connections between the performances.

4.2 Data adjustment and item-selection

Linacre [42] uses a range of WMNSQ values between 0.5 and 1.5, which may be considered less restrictive than some other possible ranges. However, this paper adopts a more conservative approach by selecting a range between 0.7 and 1.3 to ensure good reliability standards while maximizing the number of items included in the analysis and minimizing information loss. This range aligns with the findings of reference [45], which also supports the use of values between 0.7 and 1.3 for WMNSQ.

By analyzing the resolution rate, it was discovered that two items fell outside the reliability interval (between 5% and 95%). Specifically, item 1a had a resolution rate exceeding 95%, and item 1c had a rate below 5%. Consequently, these two items were excluded from the analysis, leaving only 13 items for further examination. These 13 items were divided into three scores (0, 1, and 2), forming the foundation for the level model and the description of the characteristics that determine difficulty. The three categories were assigned based on the accuracy level of the questions, which were reviewed by professionals responsible for the subject and the test correction following standard procedures. To maximize participant numbers and enhance the reliability of the PCM statistical model, participants scoring below 25% were categorized as category 0, those scoring between 25% and 75% as category 1, and those scoring at 75% or higher as category 2. Moreover, students who did not attempt any items or left several questions unanswered were excluded. Subsequently, the analyses in the upcoming chapters were conducted with 13 items and 196 participants.

5 RESULTS

In accordance with data protection regulations and to prevent the identification of individuals based on gender, score, or the specific small engineering studies program, this article cannot publish the basic data table of the study, which includes the list of participants and their exam scores. However, following the IRT analysis, the estimated values of the difficulty parameter, WMNSQ, and t-value for each item are presented in Table 2 ($n = 196$).

Table 2. Item parameters

Item	Estimate	Weighted Fit		
		MNSQ	CI	t
1	1.486	0.86	(0.75, 1.25)	–1.1
2	–1.029	1.03	(0.82, 1.18)	0.3
3	0.979	1.14	(0.77, 1.23)	1.1
4	–0.491	1.00	(0.84, 1.16)	0.0
5	1.038	1.02	(0.81, 1.19)	0.2
6	0.615	1.09	(0.81, 1.19)	0.9
7	0.494	1.01	(0.83, 1.17)	0.2
8	1.189	0.93	(0.77, 1.23)	–0.6
9	–0.221	1.15	(0.85, 1.15)	1.9
10	0.028	1.16	(0.84, 1.16)	1.9
11	1.098	0.88	(0.78, 1.22)	–1.1
12	1.376	0.83	(0.77, 1.23)	–1.5
13	1.463	0.81	(0.70, 1.30)	–1.3

The EAP/PV reliability for this study is 0.80.

Using the items from Table 2 and classifying them into the four levels of competence discussed in section 4.1, a Wright Map [37] was created with the help of the PCM and using ConQuest 5.0 software. This map allows for the visualization of the difficulty parameter of the items and the person's ability on the same scale, as shown in Figure 1. The right-hand side of the map illustrates the distribution of student levels based on measured abilities, ranging from the most proficient at the top (level 4) to the least proficient at the bottom (level 1) on the Logit scale (–2.0 to +2.5). The items on the left side of the map are arranged from the most difficult at the top to the least difficult at the bottom.

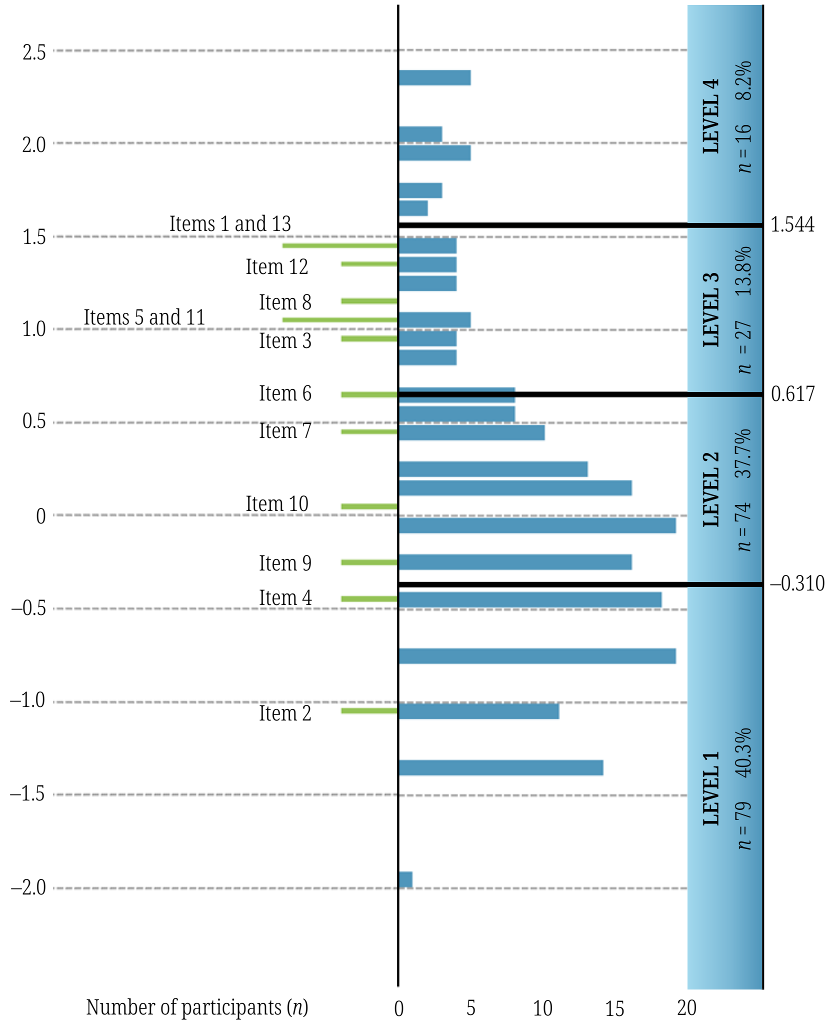

Fig. 1. Wright map/item-person map

6 DISCUSSION

To describe the different levels in the Wright map, there are generally two different approaches. First, the regression-analytical method [46] involves making ratings of difficulty determining characteristics in advance, enabling the development of a level model based on these task characteristics. Alternatively, a post-hoc description of the levels can be derived, tracing back to Beaton and Allen [44]. Since the first method can only be applied with a well-established preliminary groundwork (e.g., known difficulty determining characteristics), the second method is more suitable in this case. However, this approach has drawbacks as it does not consider the content of the construct being measured when categorizing the thresholds. Moreover, the arbitrary process of determining the number and width of the levels may need critical evaluation in certain cases [47]. By using the post-hoc analysis, the following levels can be identified:

Level 1 (*n* = 79 students, 40.3%): At this level, students have not yet reached any milestones that indicate problem-solving competence. Furthermore, the group of Level 1 students does not have at least a 50% solution rate. Therefore, no further information on the items can be used to describe the lowest level. Only students classified at higher levels demonstrate fulfillment of the requirements set out at level 1, as exposed in [48].

Level 2 (*n* = 74 students, 37.7%): Students at level 2 possess the skills to solve items 2 and 9 (almost anchored). These students have not fully mastered the subject, but they demonstrate some competencies in constructing and representing electrical circuits and their mathematical equations. Level 2 students can perform more basic circuit analysis using nodal analysis and calculate equivalent resistance. However, they struggle with complex analyses involving electrical elements such as electric dependent sources (item 8) and circuit analysis tools such as superposition (item 7) and Thévenin's equivalent circuit (item 4).

Typical tasks for this group of people include simple circuit analysis problems such as calculating equivalent resistance, analyzing simple nodal circuits, and evaluating simple mesh circuits with a maximum of two nodal or mesh elements. This is because item 2 contains three nodal elements and is not appropriately anchored for level 2 students.

Level 3 (*n* = 27 students, 13.8%): Students at this level have competencies to solve items 2, 4, 9, and 10 (anchored) and item 6 (nearly anchored). The third-level students are those who demonstrate an understanding of the principles of analyzing, constructing, and equating electrical circuits (items 2 and 4). They can use circuit analysis tools such as Thévenin's equivalent circuit and equivalent resistance (items 4 and 9). However, this group of students is not yet proficient in circuit analysis, as there are no anchored elements in items 7 and 8, which are strongly related to circuit analysis and are not yet anchored elements. Moreover, these students operate part of the dynamic and transient functioning over time of electrical components (item 10 anchored), but not proficiently, because items 11, 12, and 13 are not even "nearly anchored."

Students at this level can solve simple electrical problems involving Thévenin's equivalent circuit and simple transient analysis using mathematical methods such as graphical construction and integral calculation.

Level 4 (*n* = 16 students, 8.2%): Students at the highest level of the ability scale solve items 1, 2, 4, and 7–13 (anchored) and items 3 and 6 (nearly anchored). Therefore, it is possible to observe some specific characteristics of this group. This group stands out as the only one capable of conducting electrical and mathematical analyses of circuits (items 1, 2, 7, and 8), analyzing energy in electrical circuits through integral calculations, and dealing with transient elements (items 10, 11, 12, and 13). However, they encounter challenges when analyzing maximum power transfer in electrical impedance (item 5). Students at this level can tackle more intricate problems using circuit analysis techniques such as Thévenin's equivalent circuit, superposition, network analysis with dependent sources, and transient analysis involving time constants associated with charge and discharge elements.

After examining the progression of levels of electrical engineering problem-solving competence from level 1 to level 4, certain characteristics emerge that distinguish the different levels. At the first level, no significant characteristics are present. This is a limitation of the methodology [44, 48] because only students at higher levels have identified the abilities of the level below. Therefore, no description is possible for the first level. This is a fundamental problem because students at this level need the most support. When accessing level 2, competences regarding the analysis of electrical circuits and their respective equations appear through items 2 and 9 that are "almost anchored." In this second level, this ability still does not have a strong presence and anchorage, since items 7 and 8, which are strongly related to the analysis of electrical circuits and their equations, are not even "almost anchored." Then, in order to break the barrier of the second level (and the mean value of the ability parameter), there appears to be an anchoring of the ability related to the analysis of electric circuits and their equations, as evidenced by the consolidation of items 2, 9, and 10. Still at level 3, the use of tools for analyzing circuits, such as equivalence of components and Thevenin, also appears, as does the study of transient elements in an initial way (through the consolidation of item 10). However, without consolidating items 11, 12, and 13, which are items that also use the time dimension, it can be seen that they are not able to perform transient analysis proficiently. Finally, looking at the last level, it is possible to notice that the students of the fourth level are those who can perform circuit analysis in an exemplary way. They understand the use of circuit analysis tools, and they have knowledge of electricity related to the use of the dimension of time. This could be either using time as a mathematical variable (differential calculus, items 12 and 13) or with time as an element present in the concept of energy and power (items 12 and 13).

In the context of Kane's validity framework [49], there are several potential threats to validity that should be considered when interpreting the results of this single-shot survey. First, our survey may overlook important components of student learning or experiences in the process (which we will assess in the next step). Second, it was not possible to eliminate influencing variables such as fatigue, distraction, or motivation, so some survey responses could be unrelated to the construct being measured. Third, this study is specific to a module at a German university, so the results may not generalize to other educational settings. Perhaps this publication will also provide opportunities for exchanging ideas and replicating the results.

Combining this observation with John Sweller's theory of cognitive load [50], it can be seen that only level 4 students (8.2%) have sufficient cognitive schema to work with time-varying electrical tasks without overloading their working memory. The other 91.8% of the students, according to this theory, have difficulties processing more complex tasks with the time in their working memory. Another point about this theory is in relation to cognitive overload due to a lack of prerequisite knowledge. Although the theory states that the lack of cognitive schemas leads to cognitive overload, this study did not obtain any evidence of this theory since the aim of this study was to diagnose learning and not to investigate the educational process itself. However, this point could be the subject of future studies.

Another way of observing is to look at the average value of the parameter ability, which is the point that separates levels 2 and 3. At this transition point, the average value separates students (78.1%) who have not yet managed to learn to analyze electrical circuits and their equations from students (21.9%) who can carry out these analyses, even if not yet in a substantial way. A second analysis in relation to the number of students present in each of the levels is that at the end, 40.3% are present in level 1, which is the level in which the students present a deficiency in math and in the analysis of electrical circuits. Similarly, 37.8% show this understanding in an insufficient way. Thus, 78.1% of the students lack the competence to analyze and equate electrical circuits and have less than a 50% probability of solving exercises of average difficulty. On the other hand, above average (in terms of the difficulty parameter), there are 21.9% of students at level 3 who already demonstrate competence in solving electrical problems, but with some gaps, and only 8.2% of students at level 4, which represents the level of consolidation of competence in the subject of fundamentals of electrical engineering.

7 CONCLUSION

After collecting the data, processing it through quantitative analyses, and discussing it as described in the previous chapter, it is possible to arrive at a more abstract analysis of the representativeness of this study by observing the distinction between different aspects (or dimensions). These different aspects can be obtained by combining the description of the items (refer to Table 1) with their progression on the scale as the level of competence increases (see Figure 1). They are:

- Analysis and equations of electrical circuits.
- Analysis of equivalent components and circuit analysis methods.
- Time-dependent electrical systems and mathematics involve differential calculus.
- Time-dependent electrical systems and mathematics involve concepts such as voltage constants, time behavior over time, and current.
- Time-variant systems are crucial for analyzing energy and power in circuits.

It is also possible to observe that these aspects become more prominent as the ability increases, as illustrated in Figure 2.

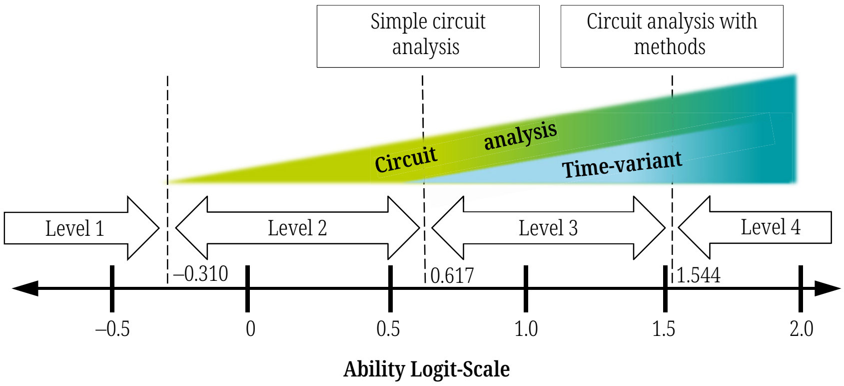

Fig. 2. Aspects of competence on the ability scale

By analyzing this figure, it is interesting to revisit the central question of this research and observe that the aspects presented in Figure 2 vary along the competence scale. Therefore, the elements shown in Figure 2 provide an indication of which characteristics require a higher level of competence to solve an electricity problem, making the problem more difficult or complex, and which characteristics require a lower level of competence (easier).

Regarding the various aspects outlined in Figure 2, a question arises: What could be the relationship between these aspects in the learning process? Are they interconnected in an evolutionary manner through predecessors and successors? In simpler terms, is it essential to grasp the analysis of electrical circuits and their equations before delving into the transient aspect? Or is the connection between them indirect, allowing individuals without a firm grasp of differential calculus to comprehend the energy and power aspects of electrical components in this electrical engineering module?

To help answer these questions, this study requires additional study assistance to investigate the relationship and correlation among the various aspects of learning electricity. In other words, this work suggests that the tasks of the measurement instrument (evaluation) should be designed considering these different aspects (or dimensions) of learning electricity. A limitation of this study was that the study instrument had a limited number of problems to thoroughly explore the division and arrangement among these dimensions. Although the sample size of students was adequate with 196 students, psychometric simulation studies discuss the impact of sample size on the fit statistics (e.g., t-statistics were highly sensitive to sample size, whereas mean square statistics remained relatively stable for polytomous data [51]).

Another crucial point to consider is the utilization of one of the primary tools or methods of circuit analysis (and physics in general), which is mathematics. In engineering, mathematics is a crucial and extensively used tool. In this analysis, it is noteworthy to observe the performance of different levels concerning items 12 and 13, which required the application of differential calculus for their resolution. By examining the success rate, it is evident that students in level 1 achieved 0% success, level 2 only achieved 1.4% success, level 3 showed an improvement (yet below 30% success), and only level 4 demonstrated proficient competence in items 12 and 13. Hence, there is a clear distinction among the various levels in terms of students' mathematical competence. Students in levels 1 and 2 exhibit significant deficiencies in this subject, while students in level 3 display some deficiencies, and only students in level 4 (8.2% of the total student population) possess the necessary mathematical skills to conduct electrical engineering calculations using differential calculus. This prompts further inquiry into the correlation between mathematics, calculus, and the acquisition of fundamental knowledge in electrical engineering. It is imperative to explore the extent to which mathematics serves as a prerequisite for developing the essential competence in electrical engineering. Moreover, considering that a considerable number of students who encounter challenges in the Fundamentals of Electrical Engineering module excel in the mathematics module, it is intriguing to delve deeper into the process of transitioning from mathematical proficiency to electrical engineering competence.

The findings of this paper indicate differences in the way students at various levels approach electrical problem-solving. Therefore, a potential area for future study could involve evaluating the cognitive load students experience at various levels while tackling problems in fundamental electrical engineering. This could lead to a more comprehensive understanding of the challenges students face when learning the basics of electrical engineering.

Since this paper presents results that demonstrate various dimensions or aspects of electrical problem-solving competence at different levels, it is possible to envision paths for future steps. One potential approach would involve conducting further investigations into the various dimensions of electrical phenomena, such as alternating current, frequency effects in electrical circuits, electric and magnetic field analysis, and their interrelationships with the ability to solve electrical problems. Subsequent studies could explore the correlation between these different aspects and the learning process for the fundamentals of electrical engineering. It would be intriguing to ascertain whether any of these dimensions (and if so, which ones) are associated with the learning process.

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