



## Rubric elaboration to evaluate a Physics Laboratory practice: Indirect measurement of the speed of light

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### Abstract

*Many properties of light have represented a major challenge to humanity for centuries. Aristoteles and Descartes believed that its speed was infinite until in the second half of the 17th century, when the first measurements began to be made. The speed of light in vacuum ( $c$ ) is a universal constant with an exact value in the International System of Units of 299792458 m/s. In the air, its value is 299705543 m/s, and this speed does not depend on the reference system in which it is measured.*

*Competence-based education is oriented towards an evaluation model linked to student training, encouraging the development of abilities to identify and solve problems and make informed decisions. Rubrics for evaluating competencies have emerged as a tool that enables the collection of evidence of competency acquisition and the application of knowledge outside the classroom.*

*In this work, we present a proposal for a turbulent to evaluate competencies for a Physics laboratory practice in which the speed of light is measured indirectly. First, the electrical permittivity of air  $\epsilon_0$ , is obtained, using a capacitance meter to measure the capacitance of a parallel-plate capacitor while varying the separation between its plates. Through least squares fit, the slope of the resulting line is calculated, which is related to  $\epsilon_0$ .*

*Next, the magnetic permittivity of air  $\mu_0$  is obtained by using a solenoid through which different currents are circulated, and the magnetic field at its center is measured using a smartphone's magnetic sensor. Again, through least squares fit, the slope of the resulting line is calculated, which is related to  $\mu_0$ .*

*Once  $\epsilon_0$  and  $\mu_0$  have been obtained, the speed of light is calculated by using the expression*

*$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$ , with its corresponding absolute and relative errors.*

**Keywords:** Competence-based approach, rubric, teaching-learning, speed of light.

### 1. Introduction

The speed of light,  $c$ , has long been a subject of debate and progressive refinement, from Galileo and Römer's early attempts to the experiments of Fizeau, Foucault, and the conceptual milestone of Michelson–Morley ([1]-[6]). Today, the speed of light in vacuum,  $c$ , is recognized as a universal constant that plays a leading role in modern physics—from Maxwell's electrodynamics to cosmology and advanced communication technologies. Its exact value,  $c = 299792458$  m/s, has been fixed in the International System of Units since 1983, defining the meter as the distance traveled by light in vacuum during a time interval of  $1/299792458$  s. This decision underscores the metrological and conceptual significance of  $c$ , which is no longer measured in routine practice but assumed as a fundamental reference.

From an educational perspective, the indirect measurement of  $c$  offers an exceptional opportunity to integrate theoretical knowledge with experimental skills in introductory physics courses. In a university



laboratory,  $c$  can be estimated indirectly by determining  $\varepsilon_0$  and  $\mu_0$  and applying the relation:  $c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$ .

This approach, using accessible instrumentation (a capacitance meter, a solenoid, a DC power supply, and a smartphone magnetometer), achieves low relative errors (<2–3%) and provides strong pedagogical value for a General Physics course ([7], [8]).

In parallel with scientific advances, higher education has undergone a profound transformation through the adoption of the competence-based learning model, promoted by the European Higher Education Area (EHEA) and international trends since the late 20th century [9]. This approach conceives university education as an integrated process that combines knowledge, skills, attitudes, and values, aiming to prepare students to solve real-world problems, make informed decisions, and adapt to dynamic contexts. Assessment is no longer merely summative; it becomes a formative tool that guides learning, provides feedback, and fosters student self-regulation [10].

Within this framework, rubrics have emerged as essential tools for objective and transparent assessment of competence. Rubric establishes clear criteria, performance levels, and expected evidence, enabling students to understand what is required and instructors to apply consistent standards ([11], [12]). Rubrics may be holistic, offering an overall evaluation, or analytical, breaking down the activity into specific dimensions (such as comprehension, analysis, and reflection), which facilitates detailed feedback and identification of areas for improvement. Their use also promotes student autonomy, self-assessment, and peer evaluation—key elements of active and collaborative learning. Several studies ([13]–[15]) have shown that implementing rubrics in laboratory practices enhances both academic performance and students' perception of fairness and clarity in the evaluation process.

This work lies at the intersection of these two approaches: experimental physics and competence-based assessment. We present an analytical rubric designed for a laboratory practice that indirectly measures the speed of light [7]. The practice not only yields results consistent with accepted values but also fosters transversal competencies such as critical thinking, ICT proficiency, and scientific communication, contributing to meaningful and contextualized learning.

## **2. Methodology**

This study adopts an experimental design involving two distinct student groups: a control group and an experimental group. The primary objective is to assess the impact of rubric-based evaluation on student performance and perception during a physics laboratory practice focused on measuring the speed of light indirectly. For statistical analysis, we will employ IBM SPSS Statistics (v22) and R Studio (v3.5.1) to process quantitative data and perform comparative evaluations between groups.

### **2.1 Context**

The laboratory activity and its corresponding analytical rubric have been developed for students enrolled in Physics courses within the Degree in Computer Engineering at the School of Computer Science Engineering (Albacete) and the Degree in Telecommunication Technologies Engineering at the Polytechnic School of Cuenca, both part of the University of Castilla-La Mancha (UCLM), Spain. Competence-based assessment using rubrics has been progressively integrated into these courses. Previous research [16] demonstrated that rubrics significantly enhance student engagement and clarity in evaluation, benefiting both learners and instructors. Building on these findings, this study aims to validate the effectiveness of a rubric in a new context: a laboratory practice that estimates the speed of light indirectly.

### **2.2 Experimental Design**

The implementation will follow these steps:

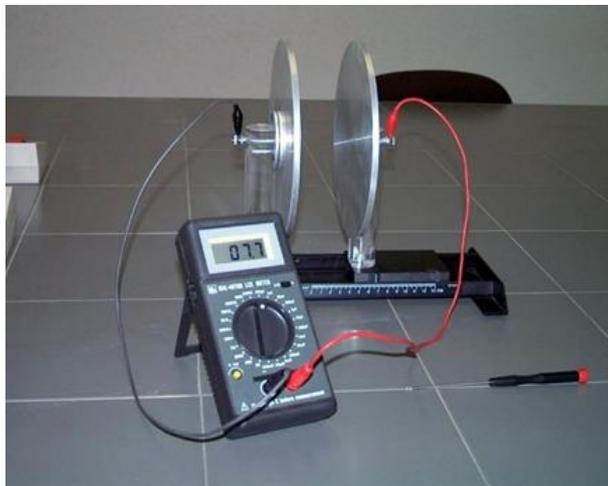
- Control Group: Completes the laboratory practice without access to the rubric, evaluated using conventional grading criteria.
- Experimental Group: Performs the same practice with full access to the rubric, which outlines performance indicators, dimensions, and achievement levels.

The laboratory practice involves:

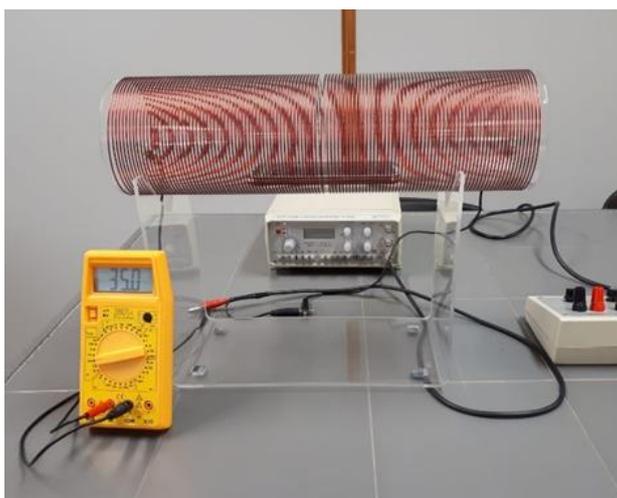
1. Measuring the electric permittivity of air ( $\varepsilon_0$ ) using a parallel-plate capacitor and a capacitance meter (Figure 1).



2. Determining the magnetic permeability ( $\mu_0$ ) with a solenoid and a smartphone as magnetometer (Figure 2).
3. Calculating the speed of light ( $c$ ) using the relation  $c = 1/\sqrt{\epsilon_0\mu_0}$ , including absolute and relative error analysis. A typical value obtained is  $c = (3.00 \pm 0.06) \cdot 10^8$  m/s.



**Fig. 1.** Measuring  $\epsilon_0$  using a parallel-plate capacitor and a capacitance meter.



**Fig. 2.** Determining  $\mu_0$  with a solenoid and a smartphone as magnetometer  
Experimental set-up to determine  $\mu_0$ , we can see a smartphone inside the solenoid (acting as magnetometer), a variable DC voltage generator and a digital ammeter.

### **2.3 Evaluation and Data Collection**

At the end of the implementation phase, we will:

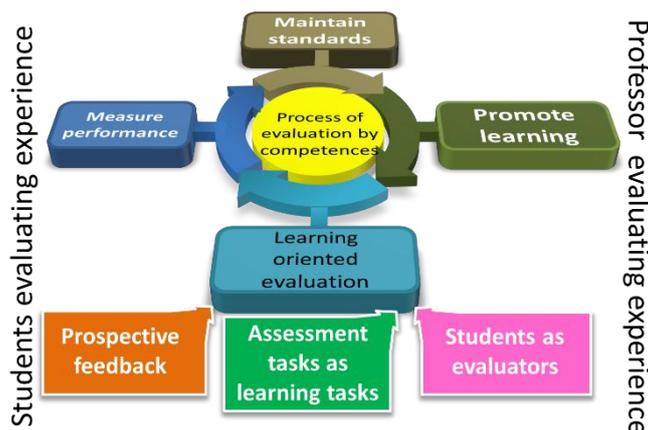
- Collect student performance data (grades) from both groups.
- Administer perception surveys to students and instructors regarding the usefulness and clarity of the rubric.
- Conduct a comparative analysis to determine whether rubric-based evaluation improves learning outcomes and student satisfaction.

This methodology ensures a rigorous approach to assessing the pedagogical value of a rubric in competency-based education while reinforcing experimental and analytical skills through a meaningful physics application.



### 3. Results

With the development of this work, framed within a teaching–learning approach focused on competencies, assessment becomes a cornerstone of the educational process. Through evaluation, both instructors and students can objectively demonstrate the acquisition of skills and competencies, supported by tangible evidence. In this sense, assessment is not merely a grading mechanism; it is a formative process that guides and shapes student learning. It fosters active participation from both professor and student, who act as key agents in achieving meaningful outcomes. This collaborative dynamic enables the development of essential competencies that are valuable not only for academic



success but also for future professional practice [17] (see Figure 3).

**Fig. 3.** Process of evaluation by competences, oriented to the learning [15].

Table 1 presents an analytical rubric designed to evaluate competencies in a physics laboratory practice: Indirect measurement of the speed of light, as described above.

The rubric specifies clear evaluation criteria and performance levels that students must meet, and instructors will use to assign grades. Each level is associated with a defined score, ensuring transparency and consistency in assessment. The interpretation of levels is as follows: **Null** = Not suitable, complete modification of the activity (value 0) or not presented, **Fail** = Not suitable with important modifications (value 3), **Good** = Apt with some observations and modifications (value 6), **Very good** = Suitable with some small observations but no modifications (value 8), and **Outstanding** = Not modified (value 10)

**Table 1.** Rubric of Physics Laboratory Practice: Indirect measurement of the speed of light.

CRITERIA TO BE EVALUATED		QUALITATIVE/QUANTITATIVE EVALUATION LEVELS					Observations
Dimension	Subdimension	Very Deficient: 0 points	Insufficient: 3 points	Well: 6 points	Notable: 8 points	Outstanding: 10 points	
Comprehension and observation to be able to take the data	Value of $d$ , $C$ and $1/d$ with errors	In the tables, it does not show any of the 30 values of variables $d$ , $C$ and $1/d$ . (0 points)	The tables show incorrectly the 30 values of variables $d$ , $C$ and $1/d$ (10 values of each variable). (0.2 points)	In the tables, only 15 values of variables $d$ , $C$ and $1/d$ are shown correctly (5 values of each variable). (0.6 points)	In the tables it shows correctly only 21 values of variables $d$ , $C$ and $1/d$ (7 values of each variable). (0.8 points)	In the tables it shows correctly the 30 values of variables $d$ , $C$ and $1/d$ (10 values of each variable). (1 point)	
	Value of $I$ , and $B$ with errors	In the tables, it does not show any of the 20 values of variables $I$ and $B$ . (0 points)	The tables show incorrectly the 20 values of variables $I$ and $B$ (10 values of each variable). (0.2 points)	In the tables, only 10 values of variables $I$ and $B$ are shown correctly (5 values of each variable). (0.6 points)	In the tables it shows correctly only 14 values of variables $I$ and $B$ (7 values of each variable). (0.8 points)	In the tables it shows correctly the 20 values of variables $I$ and $B$ (10 values of each variable). (1 point)	
Analysis and values calculation	Least squares adjustment $C$ vs $1/d$	It does not show any of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ , nor does it make the two requested comments. (0 puntos)	Correctly shows only 1 of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ and very briefly makes the two comments requested. (0.3 points)	It shows correctly only 2 of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ and makes the two requested comments very briefly. (0.6 points)	Shows correctly only 3 of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ , and very briefly makes the two comments requested. (0.8 points)	It shows correctly the 5 values: of $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ , in addition, correctly makes the two comments requested. (1 point)	



	Value of $\epsilon_0$ well expressed with error	It does not obtain the value of $\epsilon_0$ , nor error. (0 points)	It incorrectly obtains the value of $\epsilon_0$ with the correct exponent, without error calculation. (0.4 points)	It obtains the value of $\epsilon_0$ with the correct exponent but miscalculates the error. (0.7 points)	It obtains the value of $\epsilon_0$ with the correct exponent, and incorrectly expresses the error. (0.8 points)	Obtains the value of $\epsilon_0$ with the correct exponent, and correctly express the error. (1 point)	
	Least squares adjustment B vs I	It does not show any of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ , nor does it make the two requested comments. (0 puntos)	Correctly shows only 1 of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ and very briefly makes the two comments requested. (0.3 points)	It shows correctly only 2 of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ and makes the two requested comments very briefly. (0.6 points)	Shows correctly only 3 of these values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ , and very briefly makes the two comments requested. (0.8 points)	It shows correctly the 5 values: $m$ , $\epsilon_a(m)$ , $b$ , $\epsilon_a(b)$ , $r$ of least squares adjustment line $y = mx + b$ , in addition, correctly makes the two comments requested. (1 point)	
	Value of $\mu_0$ well expressed with error	It does not obtain the value of $\mu_0$ , nor error. (0 points)	It incorrectly obtains the value of $\mu_0$ with the correct exponent, without error calculation. (0.4 points)	It obtains the value of $\mu_0$ with the correct exponent but miscalculates the error. (0.7 points)	It obtains the value of $\mu_0$ with the correct exponent, and incorrectly expresses the error. (0.8 points)	Obtains the value of $\mu_0$ with the correct exponent, and correctly express the error. (1 point)	
	<b>Graph 1</b> C vs 1/d (with axes)	It does not show the experimental points in the graph from the equation $y = mx + b$ , nor requested points. (0 points)	Shows incorrectly experimental points in the graph from the equation $y = mx + b$ , does not show the magnitudes represented in the two axes and respective units; nor least squares adjustment line. (0.3 points)	It shows correctly the experimental points in the graph from the equation $y = mx + b$ but does not show the magnitudes represented in the two axes and units; nor least squares adjustment line. (0.6 points)	It shows correctly experimental points in the graph from the equation $y = mx + b$ but does not clearly indicate the magnitudes represented in the two axes and units; nor least squares adjustment line. (0.8 points)	It shows correctly experimental points in the graph from the equation $y = mx + b$ , indicating the magnitudes represented in the two axes and their units; and shows least squares adjustment line. (1 point)	
	<b>Graph 2</b> B vs I (with axes)	It does not show the experimental points in the graph from the equation $y = mx + b$ , nor requested points. (0 points)	Shows incorrectly experimental points in the graph from the equation $y = mx + b$ , does not show the magnitudes represented in the two axes and respective units; nor least squares adjustment line. (0.3 points)	It shows correctly the experimental points in the graph from the equation $y = mx + b$ but does not show the magnitudes represented in the two axes and units; nor least squares adjustment line. (0.6 points)	It shows correctly experimental points in the graph from the equation $y = mx + b$ but does not clearly indicate the magnitudes represented in the two axes and units; nor least squares adjustment line. (0.8 points)	It shows correctly experimental points in the graph from the equation $y = mx + b$ , indicating the magnitudes represented in the two axes and their units; and shows least squares adjustment line. (1 point)	
	Value of $c$ well expressed with error	It does not obtain the value of $c$ , nor error. (0 points)	It incorrectly obtains the value of $c$ , without error calculation. (0.4 points)	It obtains the value of $c$ but miscalculates the error. (0.7 points)	It obtains the value of $c$ and incorrectly expresses the error. (0.8 points)	Obtains the value of $c$ and correctly expresses the error. (1 point)	
Reflection to obtain conclusions	Answering the 4 questions	Does not respond well to any question. (0 points)	Answer only 1 question well. (0.2 points)	Answer 2 questions well. (0.5 points)	Answer 3 questions well. (0.7 points)	Answer all questions well (1 point)	

This structured approach provides students with clear expectations and promotes self-regulation, while enabling instructors to apply objective and consistent standards.

#### 4. Conclusions

The implementation of an analytical rubric ensures that evaluation is objective, transparent, and formative. This structured assessment tool provides clear performance indicators and levels, enabling students to understand expectations and improve progressively. For instructors, rubrics offer consistency and clarity in grading, while fostering a shared responsibility for learning outcomes. The comparative analysis between control and experimental groups will allow us to measure the real impact of rubric-based evaluation on academic performance and student perception.

In a broader context, adapting evaluation methods to competency-based models is essential to maintain educational quality and respond to the evolving demands of the labor market. Students must be prepared to solve complex problems and adapt to dynamic professional environments. Competence-oriented assessment, supported by tools such as rubrics, contributes to this goal by integrating knowledge, skills, attitudes, and values into the learning process. However, it is important to emphasize that rubrics are not a universal solution; their effectiveness depends on the active involvement of both teachers and students in a formative and collaborative approach.

Finally, this work highlights the need for continuous innovation in teaching and assessment practices, particularly in science education, where abstract concepts often require practical reinforcement. Future studies will focus on analyzing the data collected from this implementation to validate the usefulness of rubrics and identify opportunities for improvement. By combining rigorous experimental activities



with competency-based evaluation, we aim to create meaningful learning experiences that prepare students for both academic success and professional challenges.

### Funding

This study received financial support from the Junta de Comunidades de Castilla-La Mancha of Spain with the Project SBPLY/23/180225/00089, and from University of Castilla-La Mancha grant number 2022- GRIN-34356.

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