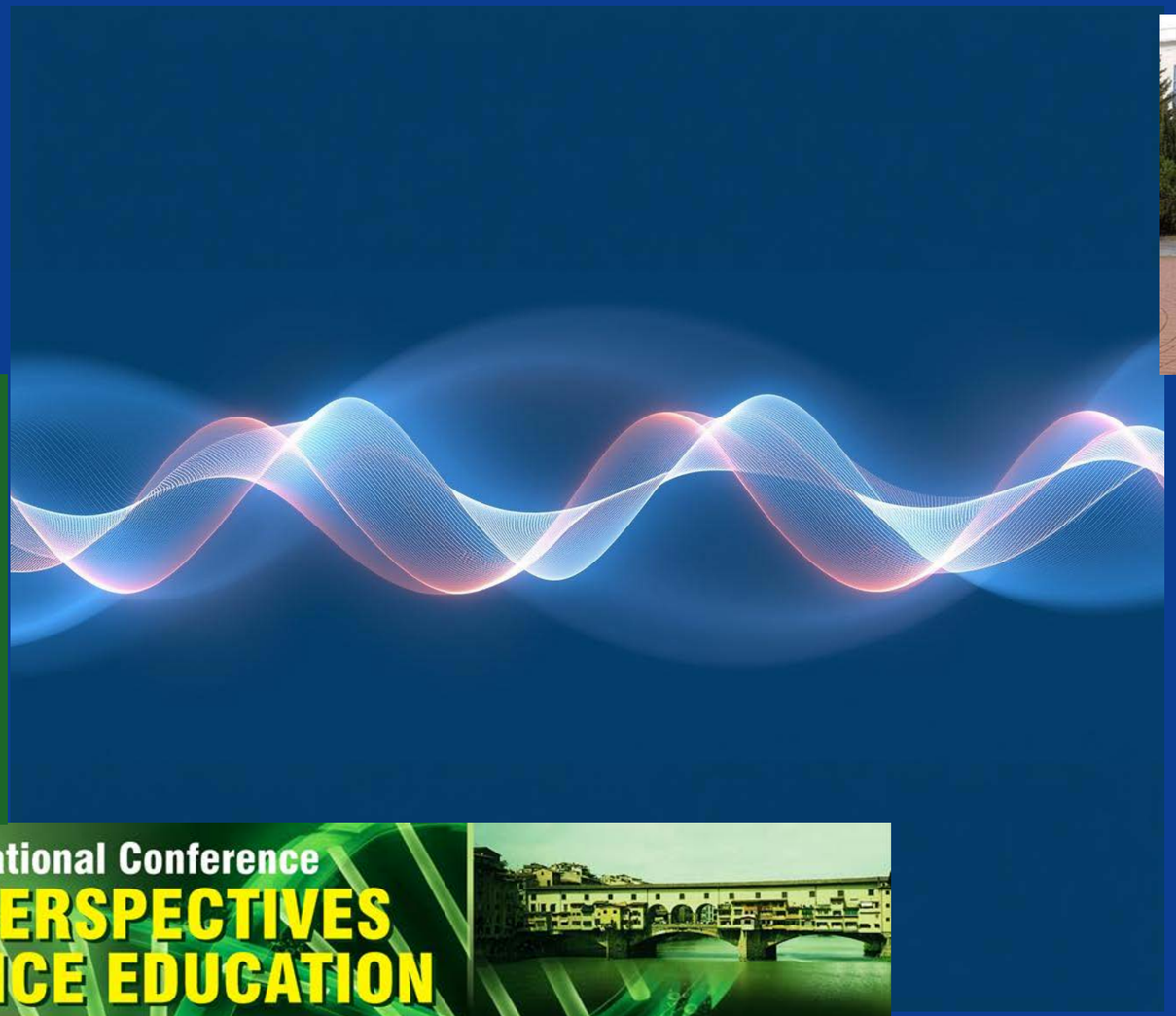
Rubric elaboration to evaluate a Physics Laboratory pract

Indirect measurement of the speed of light



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Objectives

In this presentation, I will introduce a physics laboratory practice based on the indirect measurement of the speed of light.

PRESENTATION OVERVIEW

- Introduction and educational context.
- Experimental methodology and the laboratory activity.
- Design of the assessment rubric within a competence-based framework.
- Main results and their educational impact.
- Conclusions and future perspectives.

Abstract Overview

Exploring Light's Speed and Competency Evaluation in Physics

This presentation proposes a comprehensive rubric to evaluate competencies in the indirect measurement of light's speed, integrating

- experimental physics
- competence-based education

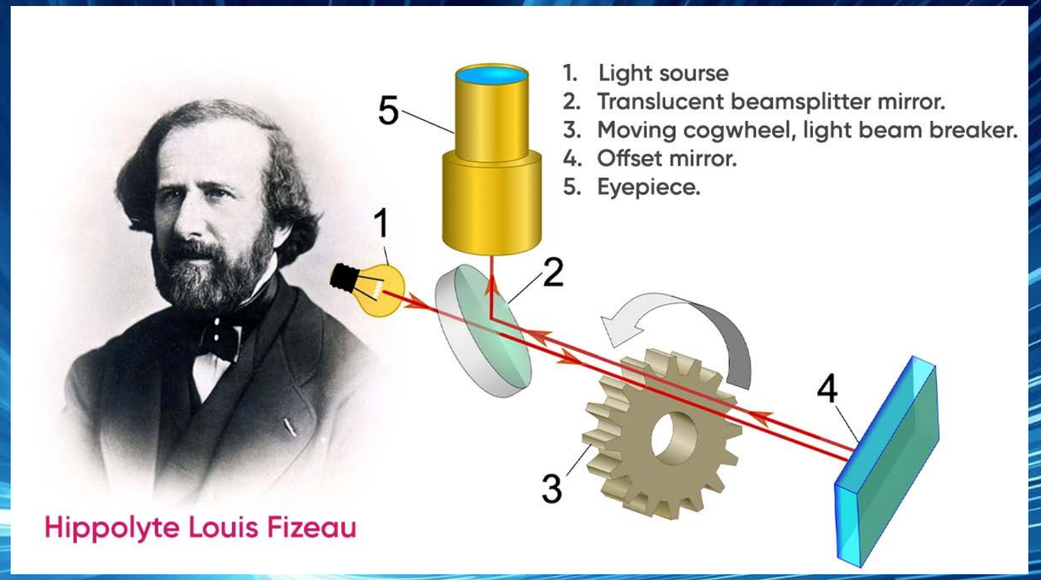
ensuring that students gain practical and theoretical insights throughout the learning process.

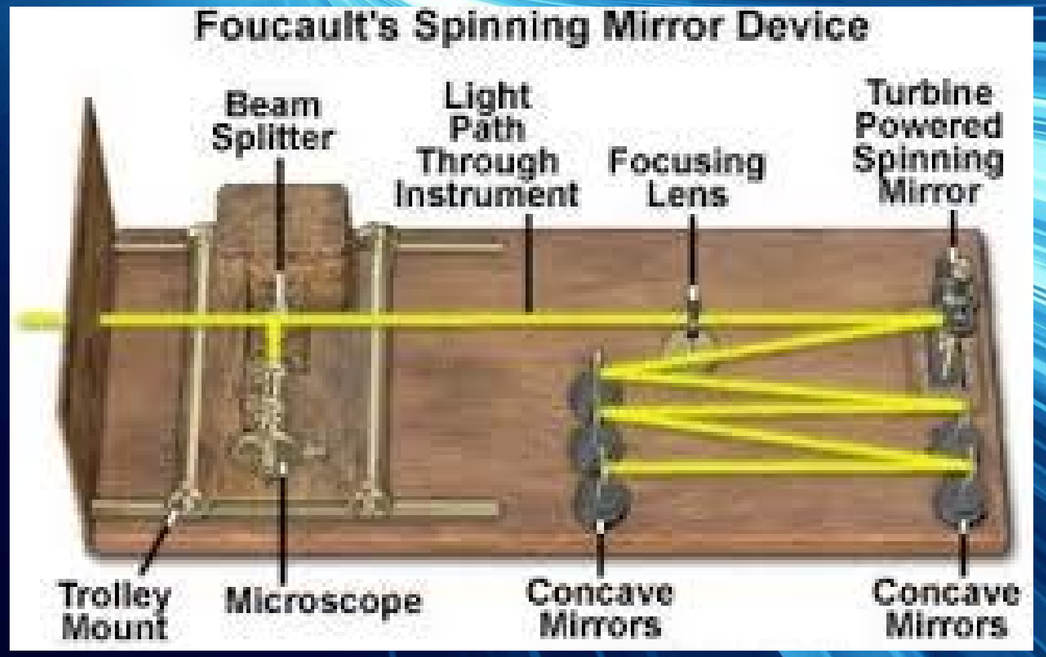
Why measure light speed?

- Fundamental constant in physics
- Key role in modern science
- Historical scientific challenge
- Bridge theory and experiment
- Strong educational value

Historical background

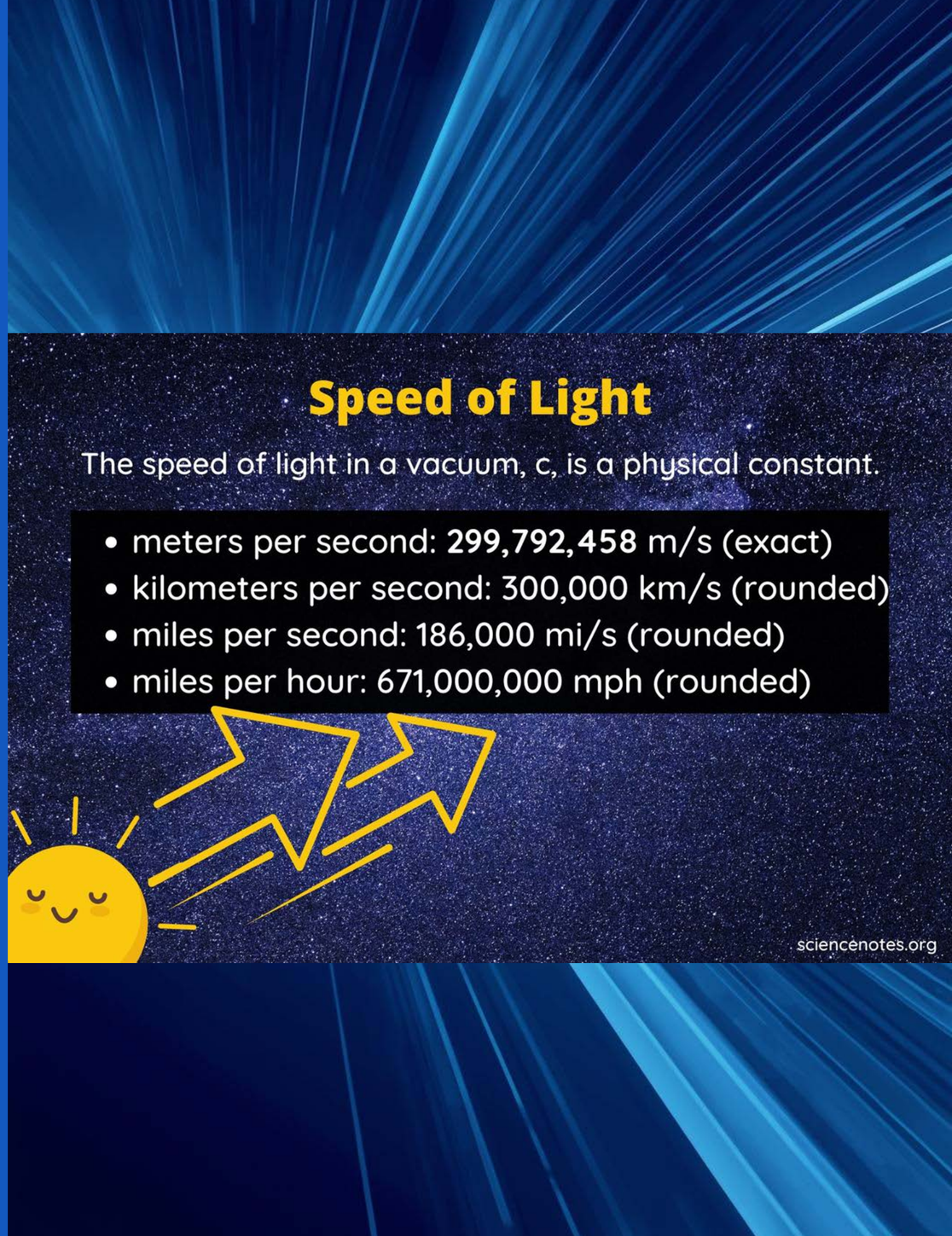
- From Galileo to Michelson
- Progressive refinement of measurements
- Conceptual scientific milestone
- Modern metrological definition
- Universal physical constant





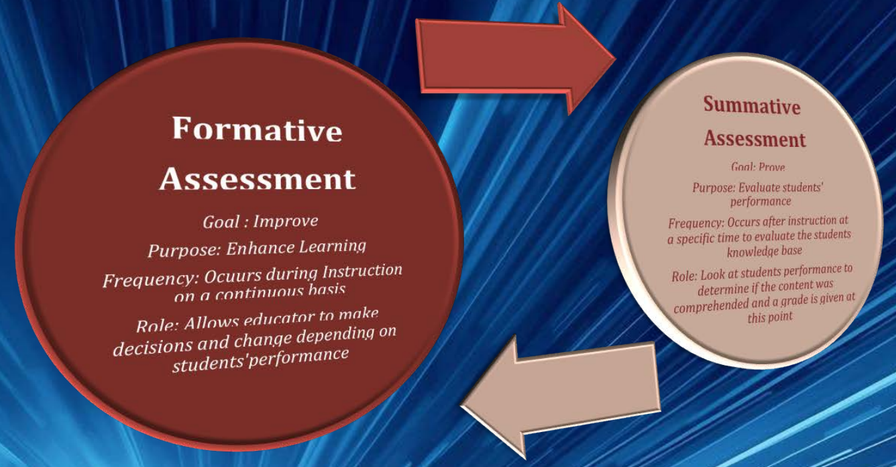
Educational motivation

- Connect theory and practice
- Develop experimental skills
- Encourage scientific reasoning
- Promote active learning
- Meaningful laboratory experience



Competencebased education

- Focus on real skills
- Knowledge + abilities + attitudes
- Problem-solving orientation
- Formative assessment model
- Student-centered learning

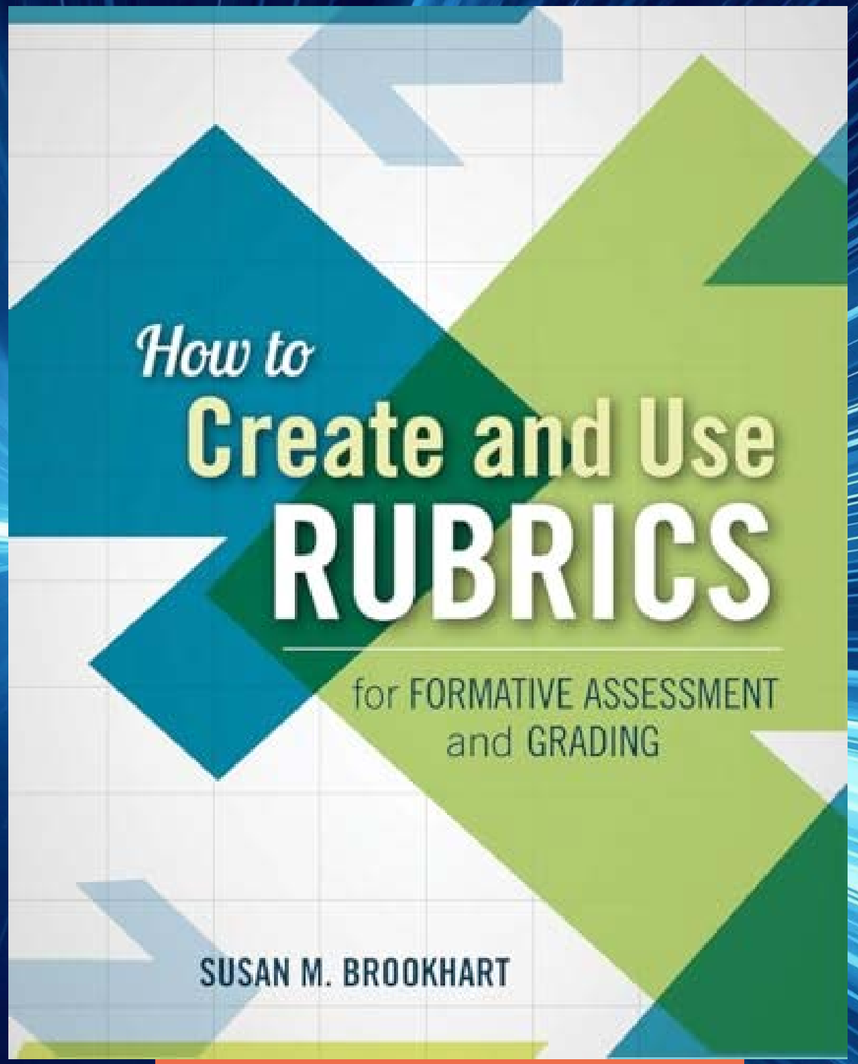


Role of assessment

- Evaluation guides learning
- Not only grading
- Supports student growth
- Provides feedback
- Encourages self-regulation

Why use rubrics?

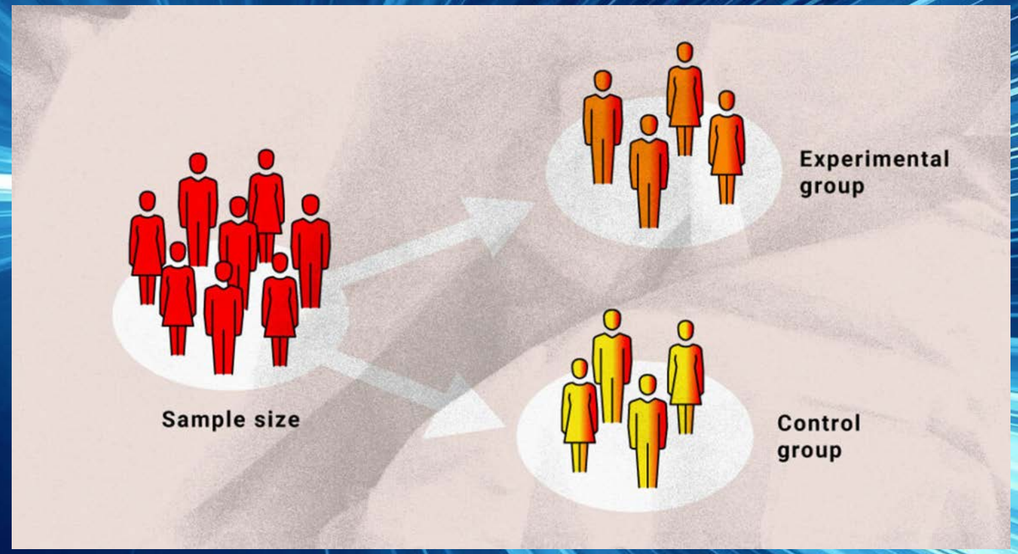
- Clear expectations
- Transparent evaluation
- Objective criteria
- Consistent grading
- Student autonomy



An interesting book

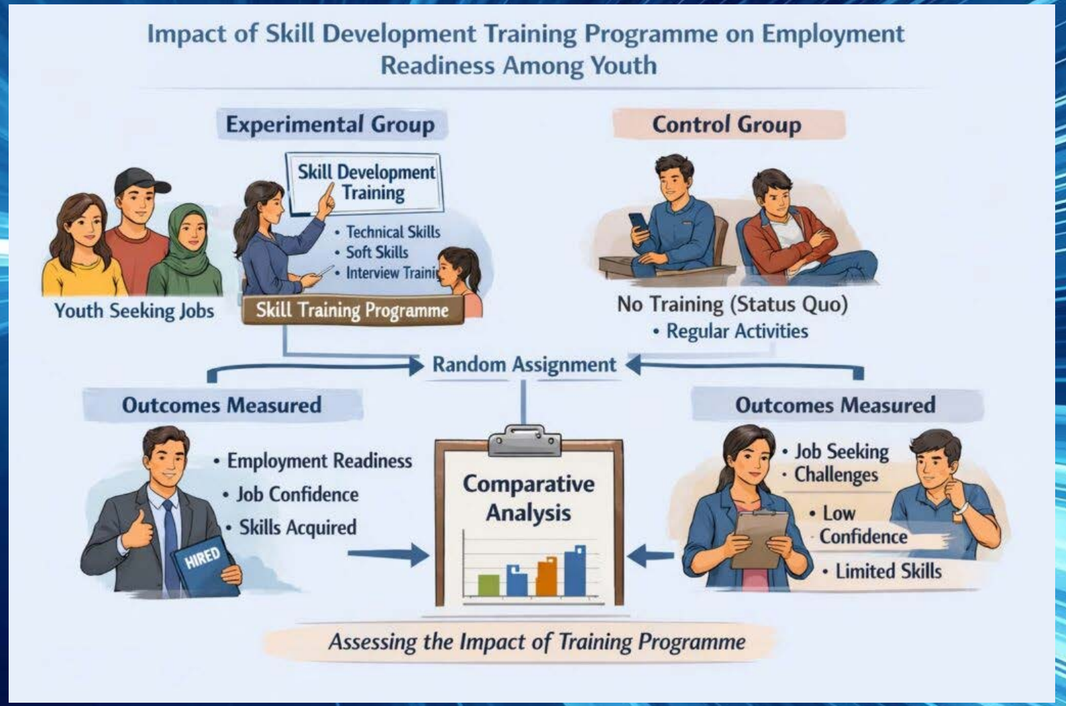
Study design

- Two student groups
- Control vs experimental
- Same laboratory activity
- Different evaluation approach
- Comparative analysis



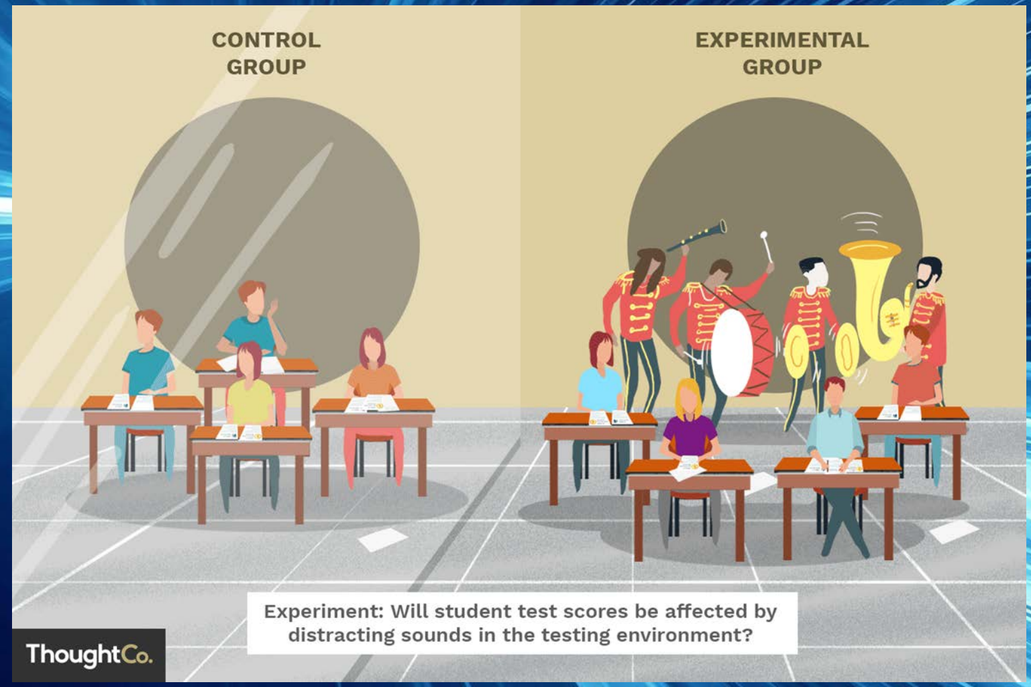
Control group

- Traditional evaluation
- No rubric access
- Conventional grading
- Instructor-centered assessment
- Standard laboratory report



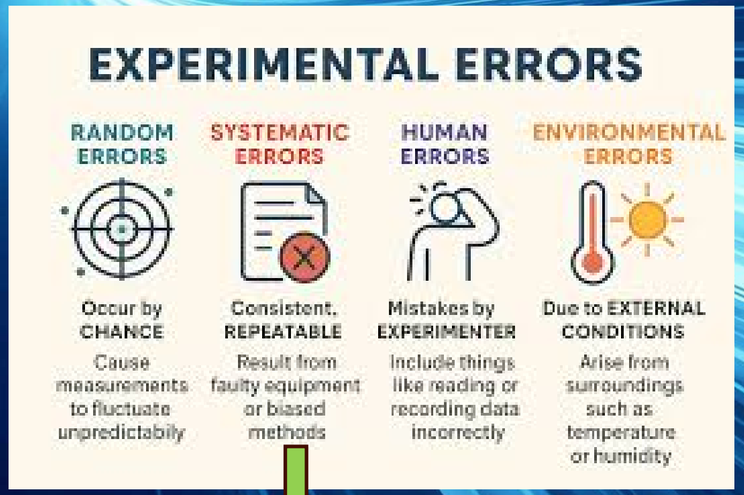
Experimental group

- Rubric available beforehand
- Clear performance indicators
- Defined achievement levels
- Structured expectations
- Competence-based evaluation



Laboratory goal

- Indirect measurement of light speed
- Calculate ε_0 and μ_0
- Apply physical relations
- Analyze experimental errors
- Estimate constant c

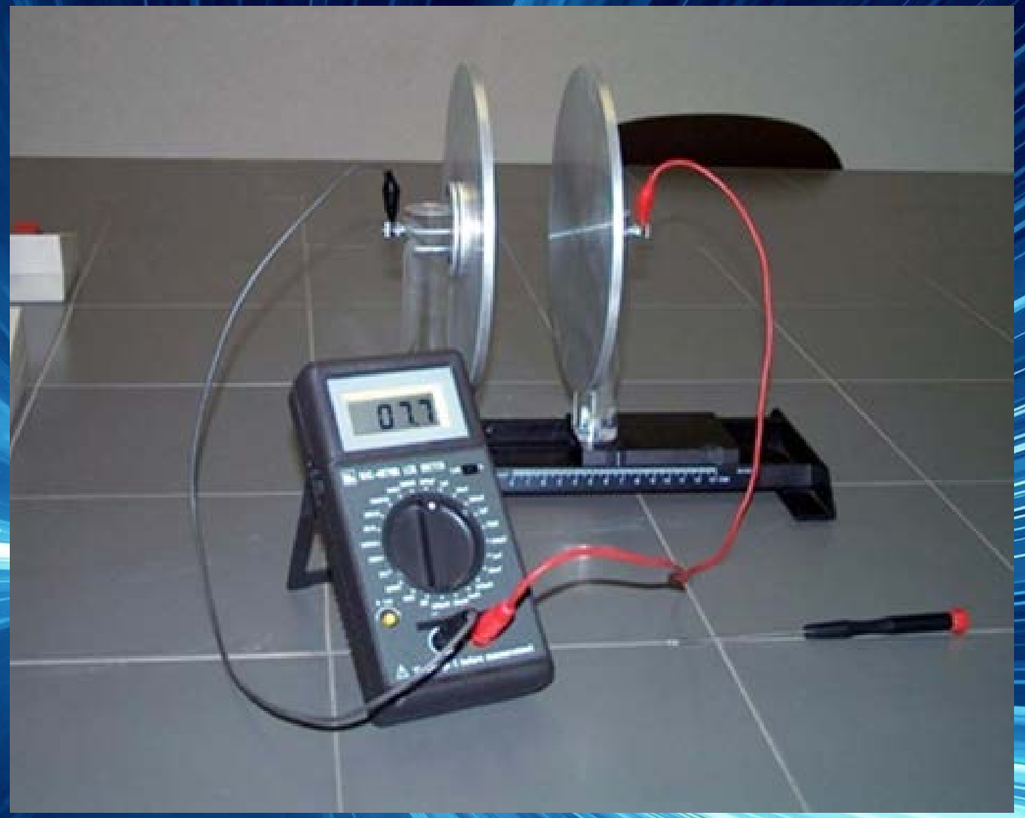


RMS error

Measuring ε_0

- Parallel-plate capacitor
- Variable plate distance
- Capacitance measurements
- Least squares adjustment
- Determine electric permittivity

$$C = \varepsilon_0 \frac{A}{d}$$



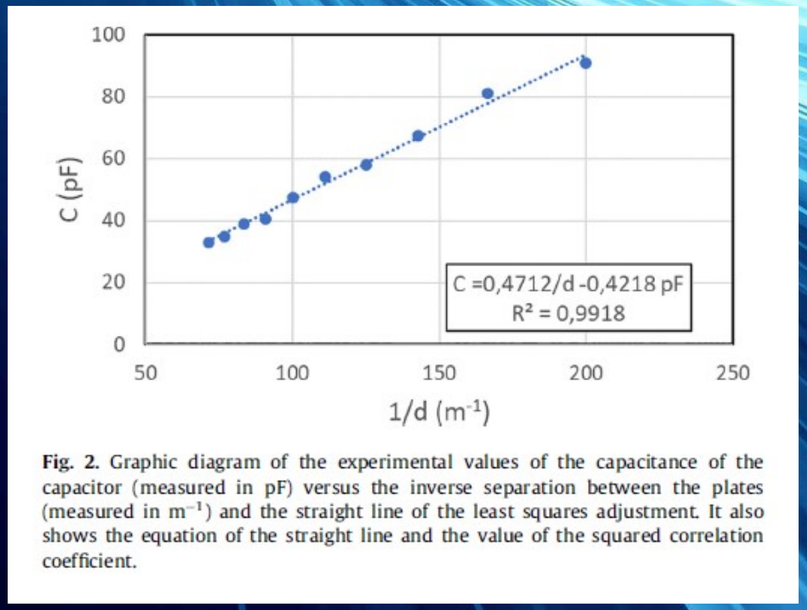
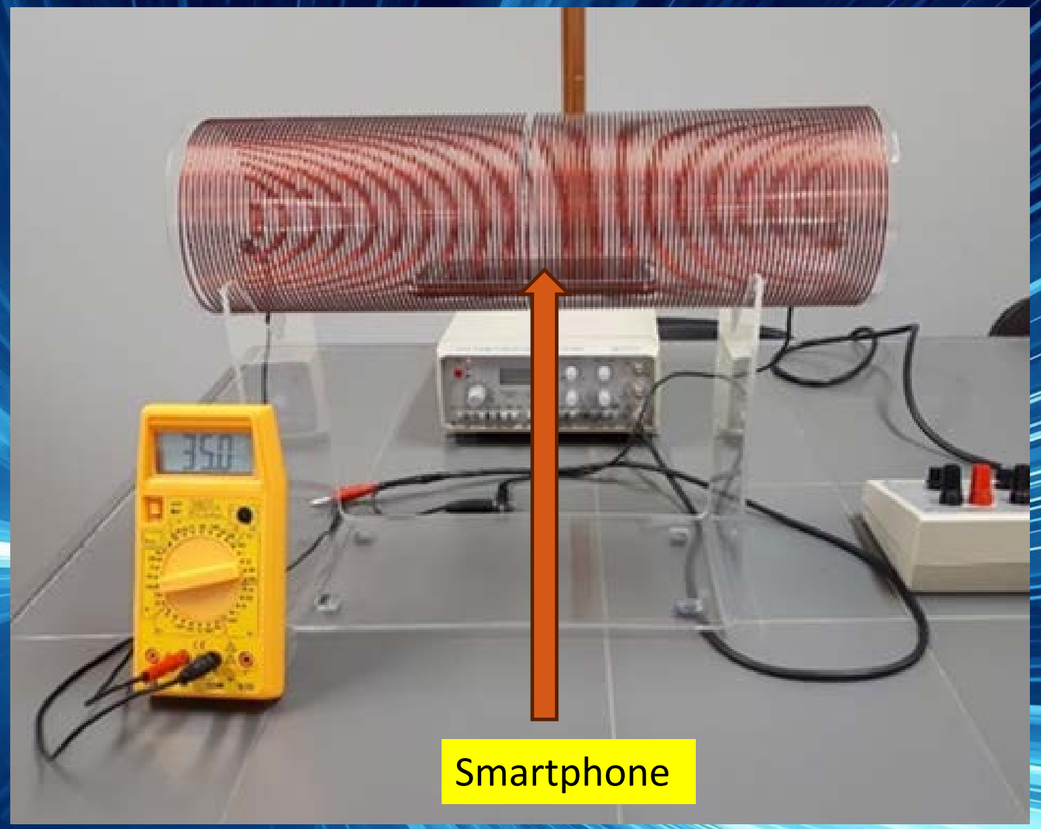


Fig. 2. Graphic diagram of the experimental values of the capacitance of the capacitor (measured in pF) versus the inverse separation between the plates (measured in m^{-1}) and the straight line of the least squares adjustment. It also shows the equation of the straight line and the value of the squared correlation coefficient.

Measuring μ_0

- Solenoid with electric current
- Smartphone magnetometer
- Magnetic field measurement
- Linear adjustment
- Magnetic permeability

$$B = \mu_0 n I$$



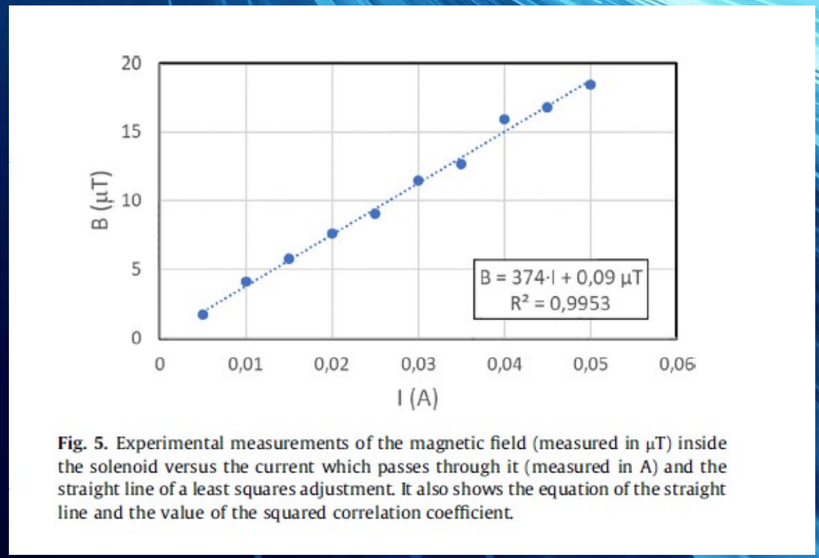


Fig. 5. Experimental measurements of the magnetic field (measured in μT) inside the solenoid versus the current which passes through it (measured in A) and the straight line of a least squares adjustment. It also shows the equation of the straight line and the value of the squared correlation coefficient.

Calculating c

- Use ε_0 and μ_0 values
- Apply theoretical relation
- Compute absolute error
- Compute relative error
- Compare accepted value

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

$\varepsilon_0 = 8.854 \cdot 10^{-12} \frac{\mathrm{F}}{\mathrm{m}}$, universal physical constant

$\mu_0 = 4\pi \cdot 10^{-7} \frac{\mathrm{Tm}}{\mathrm{A}}$, universal physical constant

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 299\,792\,458 \text{ m/s}$$

Typical values obtained by our students

$$\varepsilon_0 = (8.87 \pm 0.29) \cdot 10^{-12} \text{ F/m}$$

$$\mu_0 = (12.5 \pm 0.3) \cdot 10^{-7} \text{ Tm/A}$$

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = (3.00 \pm 0.06) \cdot 10^{8} \text{ m/s}$$

Data collection

- Performance grades
- Student surveys
- Instructor feedback
- Comparative statistics
- Quantitative analysis

Educational focus

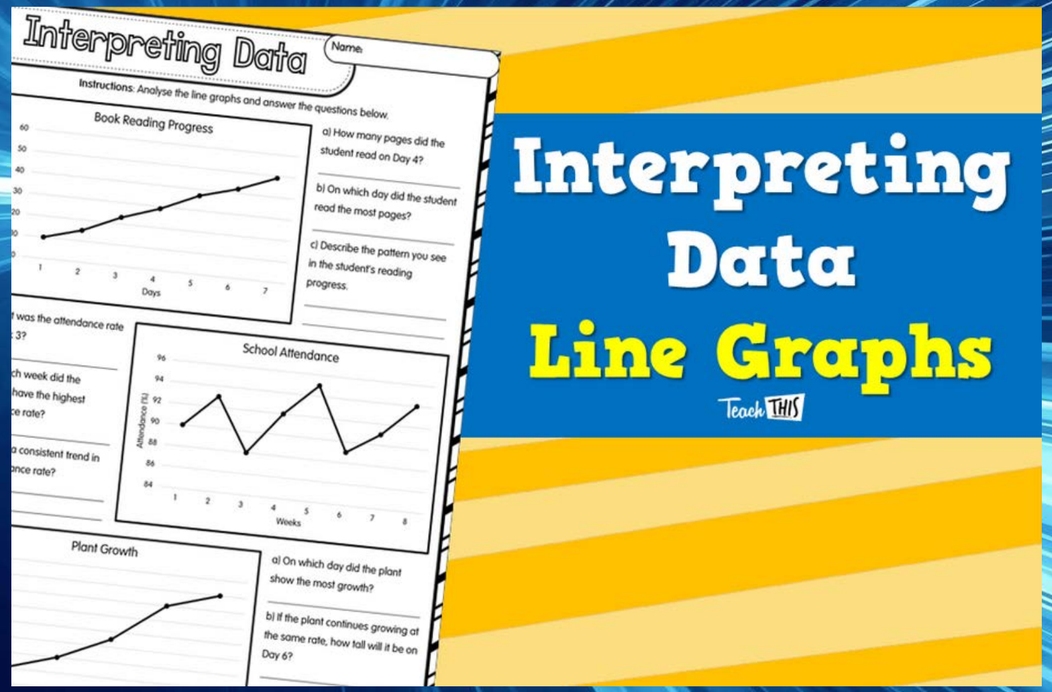
- Competence development
- Experimental reasoning
- Critical thinking
- Scientific communication
- Digital tools usage

Rubric structure

- Dimensions and subdimensions
- Clear evaluation criteria
- Five performance levels
- Quantitative scoring
- Transparent expectations

Rubric dimensions

- Data collection quality
- Mathematical analysis
- Graph interpretation
- Error expression
- Scientific reflection



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)	

Five performance levels

Rubric of Physics Laboratory Practice: Indirect measurement of the speed of light

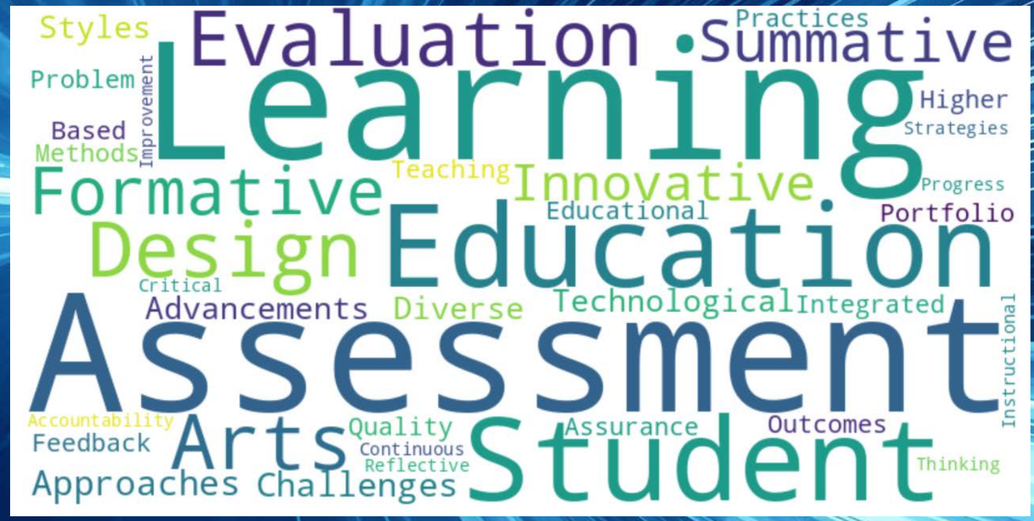
Analysis and values calculation	Least squares adjustment **C** vs **1/d**	It does not show any of these values: ***m, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, r*** of least squares adjustment line ***y = mx + b,*** nor does it make the two requested comments. (0 puntos)	Correctly shows only 1 of these values: ***m, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, r*** of least squares adjustment line ***y = mx + b***, in addition, correctly makes the two comments requested. (1 point)	
	Value of ε_0 well expressed with error	It does not obtain the value of ε_0, nor error. (0 points)	It incorrectly obtains the value of ε_0 with the correct exponent, without error calculation. (0.4 points)	It obtains the value of ε_0 with the correct exponent but miscalculates the error. (0.7 points)	It obtains the value of ε_0 with the correct exponent, and incorrectly expresses the error. (0.8 points)	Obtains the value of ε_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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, 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, $\varepsilon_a(m)$, b, $\varepsilon_a(b)$, r*** of least squares adjustment line ***y = mx + b***, in addition, correctly makes the two comments requested. (1 point)	
	Value of μ_0 well expressed with error	It does not obtain the value of μ_0, nor error. (0 points)	It incorrectly obtains the value of μ_0 with the correct exponent, without error calculation. (0.4 points)	It obtains the value of μ_0 with the correct exponent but miscalculates the error. (0.7 points)	It obtains the value of μ_0 with the correct exponent, and incorrectly expresses the error. (0.8 points)	Obtains the value of μ_0 with the correct exponent, and correctly express the error. (1 point)	

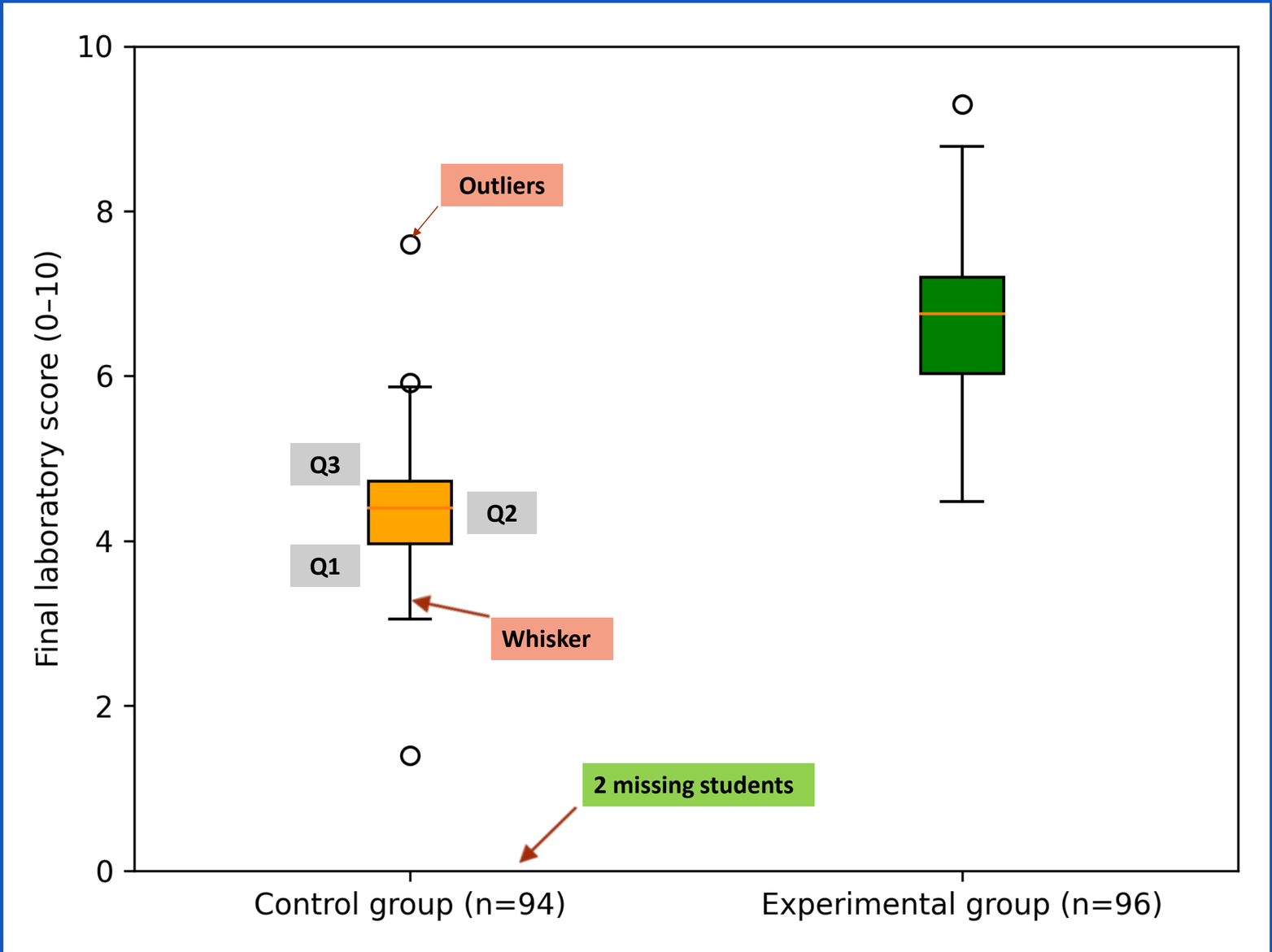
Rubric of Physics Laboratory Practice: Indirect measurement of the speed of light

	Graph 1 **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)	
	Graph 2 **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)	

Evaluation Process

Comparison of Experimental Methods and Student Perceptions





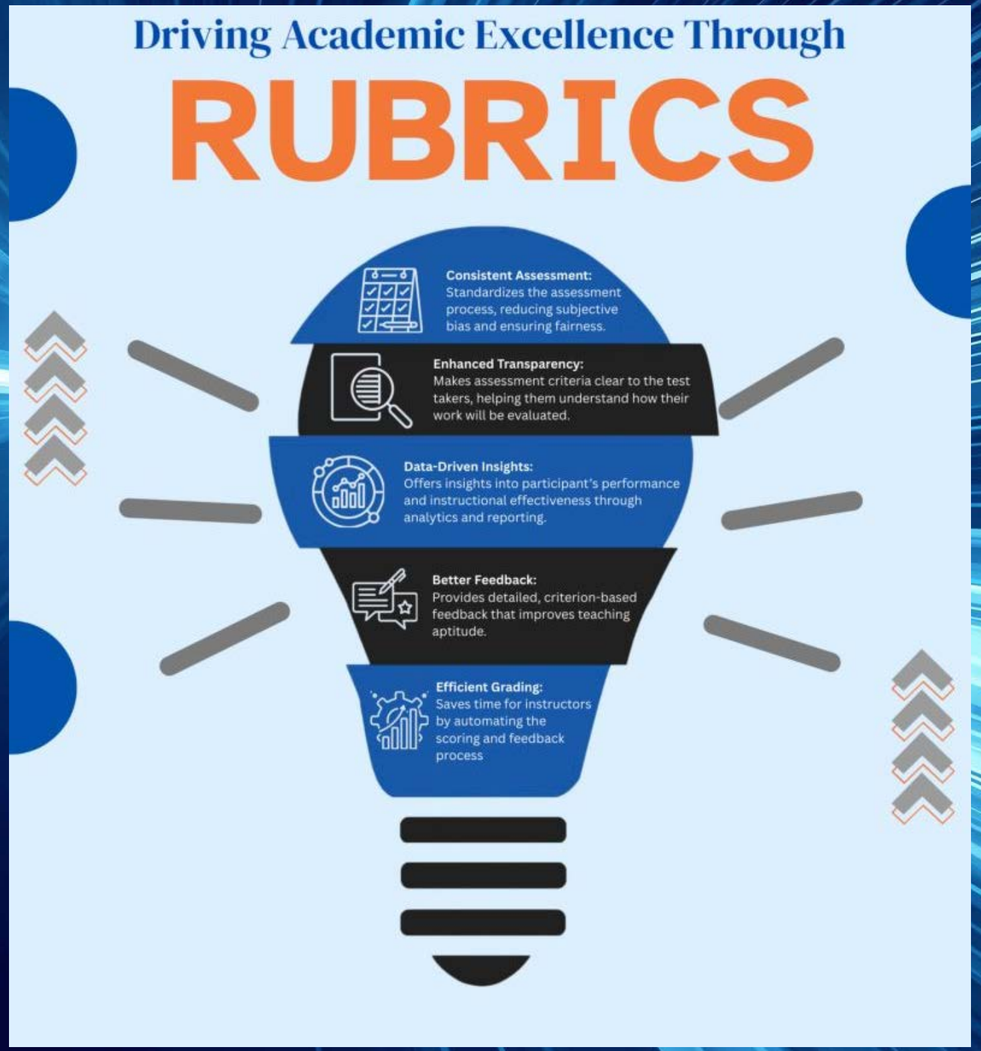
The means for the two groups are:

- Control group: 4.4
- Experimental group: 6.7

Boxplot comparison of final laboratory scores (0–10) for the control group (n = 94) and the experimental group (n = 96).

Rubric benefits

- Clarity for students
- Consistency for instructors
- Fair evaluation
- Self-assessment support
- Motivation increase

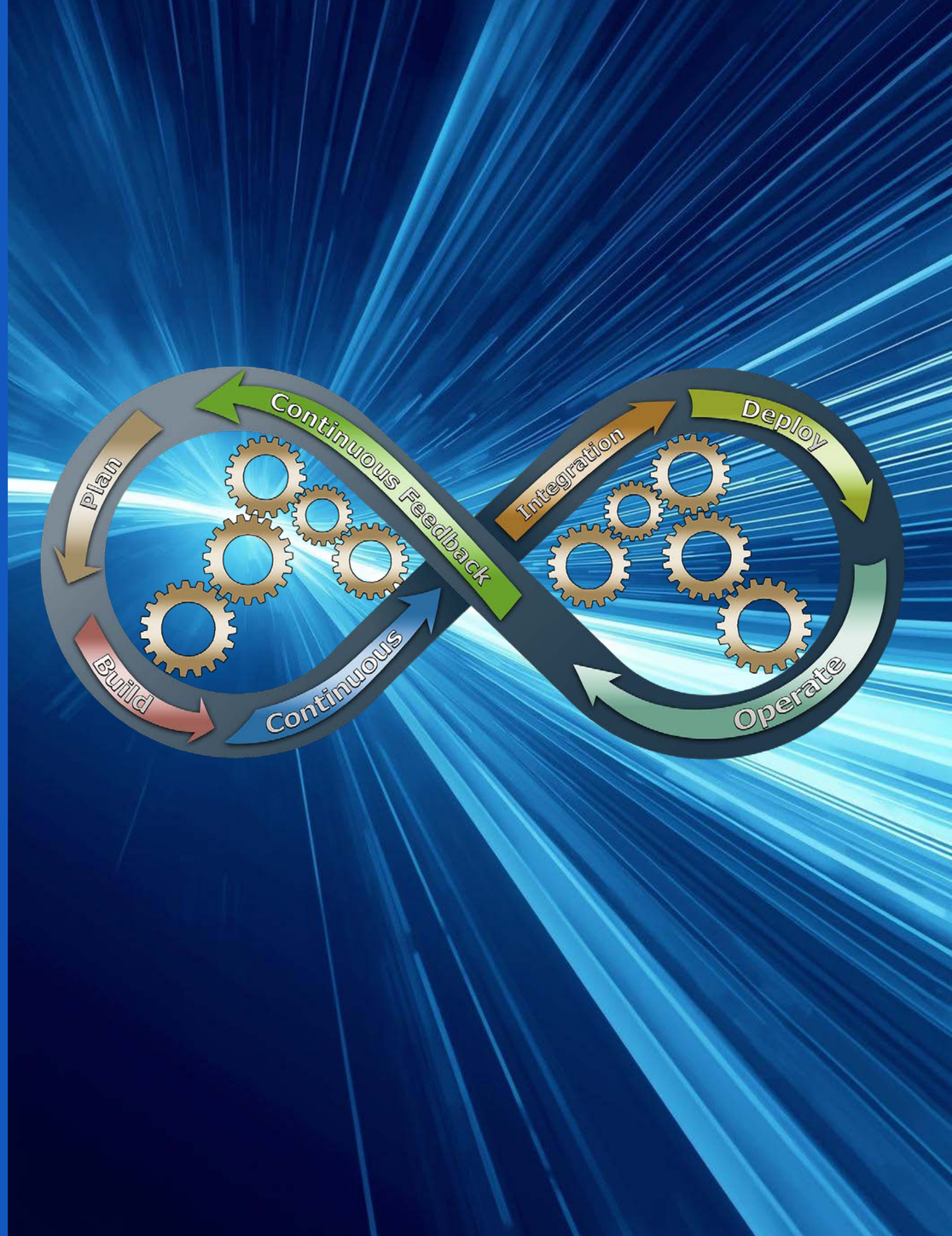


Learning impact

- Higher engagement
- Better organization
- Improved understanding
- Active participation
- Skill reinforcement

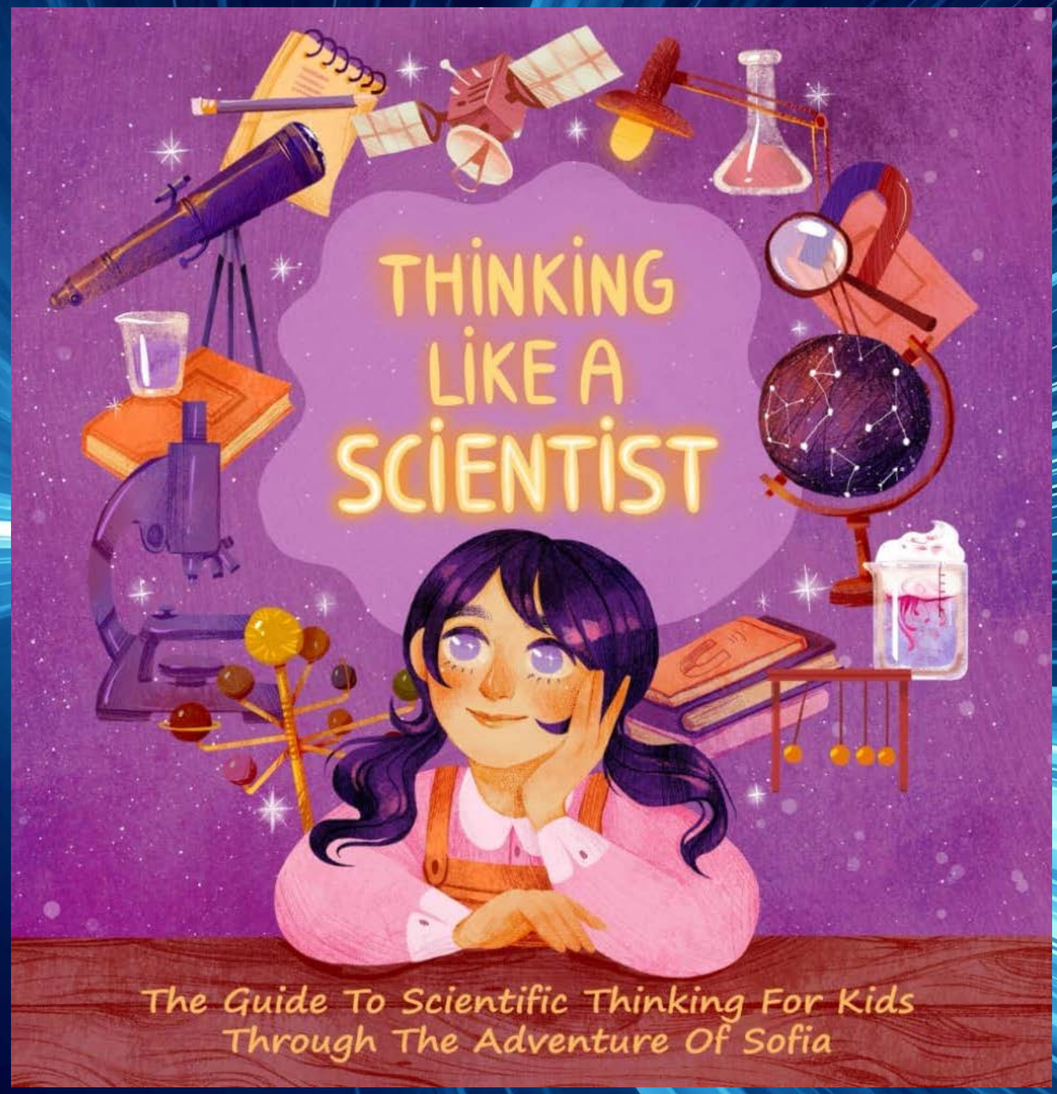
Results overview

- Positive student perception
- Clear evaluation process
- Stronger laboratory performance
- Better feedback integration
- Improved learning outcomes



Pedagogical value

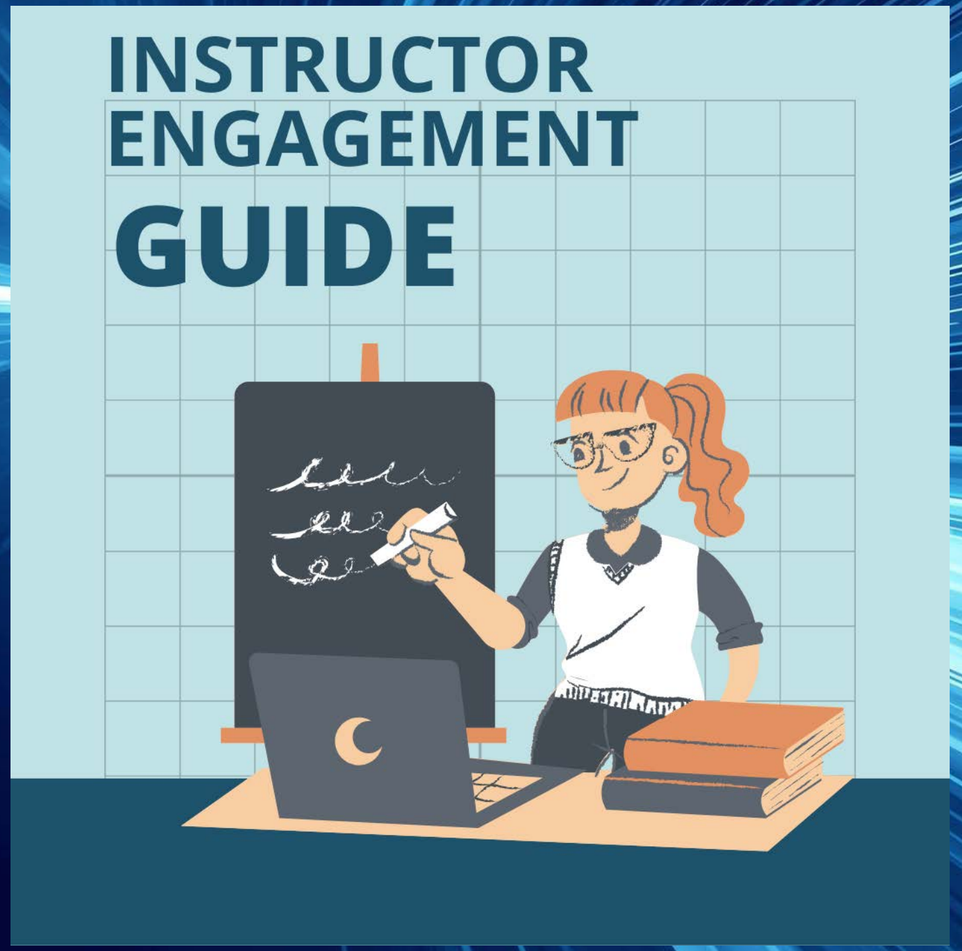
- Integrates theory and practice
- Encourages autonomy
- Promotes scientific thinking
- Supports competence development
- Enhances laboratory learning



stimulating
SCIENTIFIC THINKING

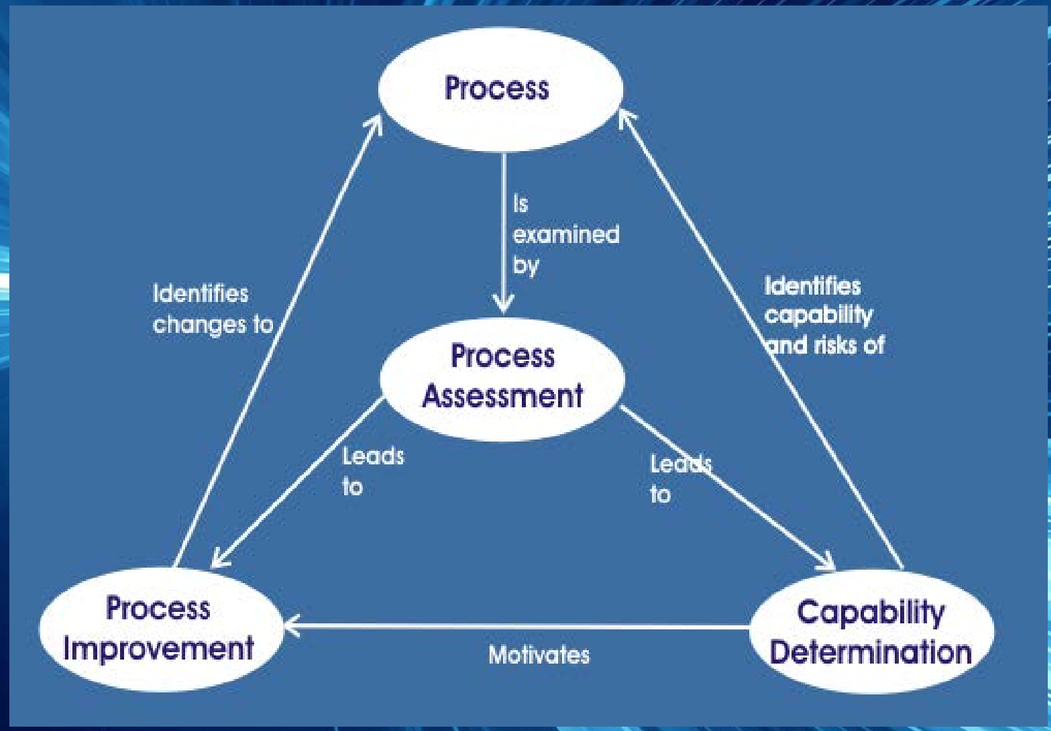
Limitations

- Rubrics require training
- Instructor involvement needed
- Time for implementation
- Continuous refinement required
- Context-dependent effectiveness



Future work

- Analyze long-term impact
- Expand to other laboratories
- Refine rubric design
- Collect larger datasets
- Improve assessment models



Final summary

- Experiment + evaluation integration
- Rubrics enhance transparency
- Students develop competencies
- Learning becomes formative
- Assessment supports growth

Summary

This work combines

- an experimental physics activity
- a competence-based assessment approach.

- The indirect measurement of the speed of light provides
  - A meaningful laboratory experience

- The analytical rubric ensures
  - Transparent
  - Objective
  - Formative evaluation

Summary

Together (indirect measurement of *c* and rubric), they promote

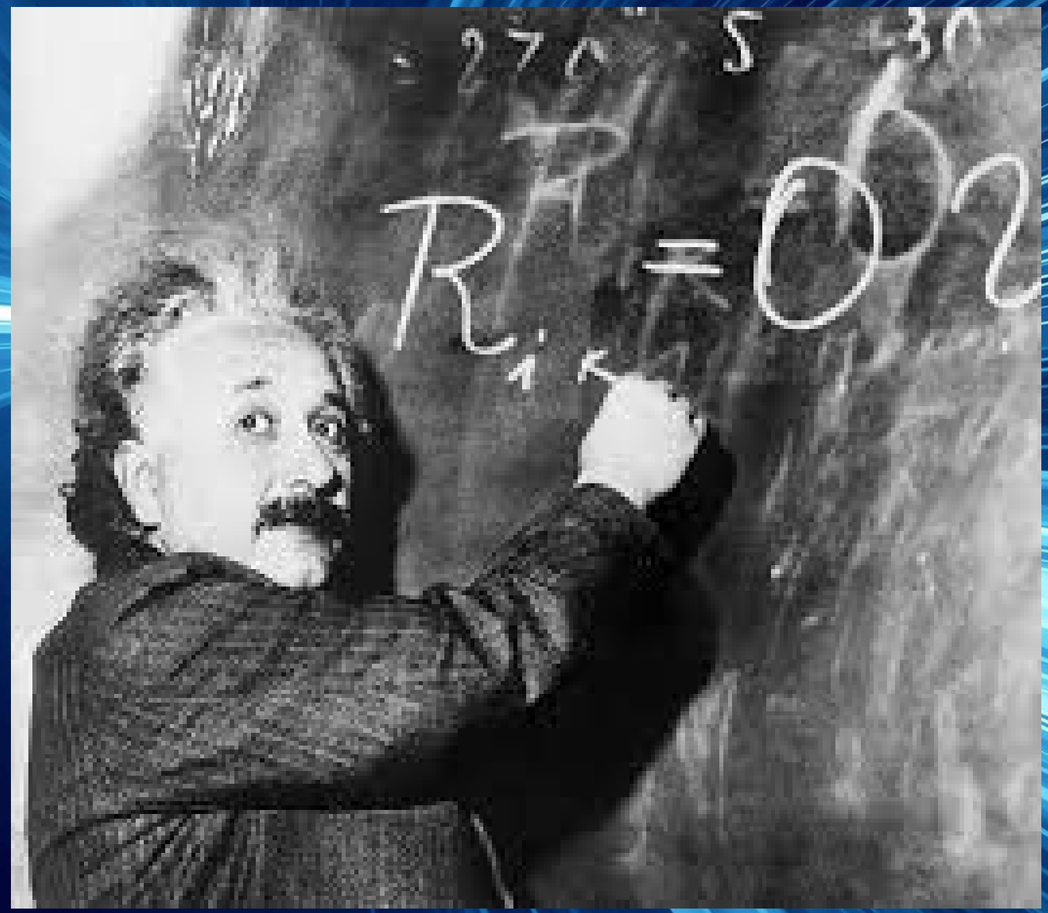
1. Deeper understanding
2. Student engagement
3. The development of essential scientific competencies

Beyond Measuring Light

One final reflection:

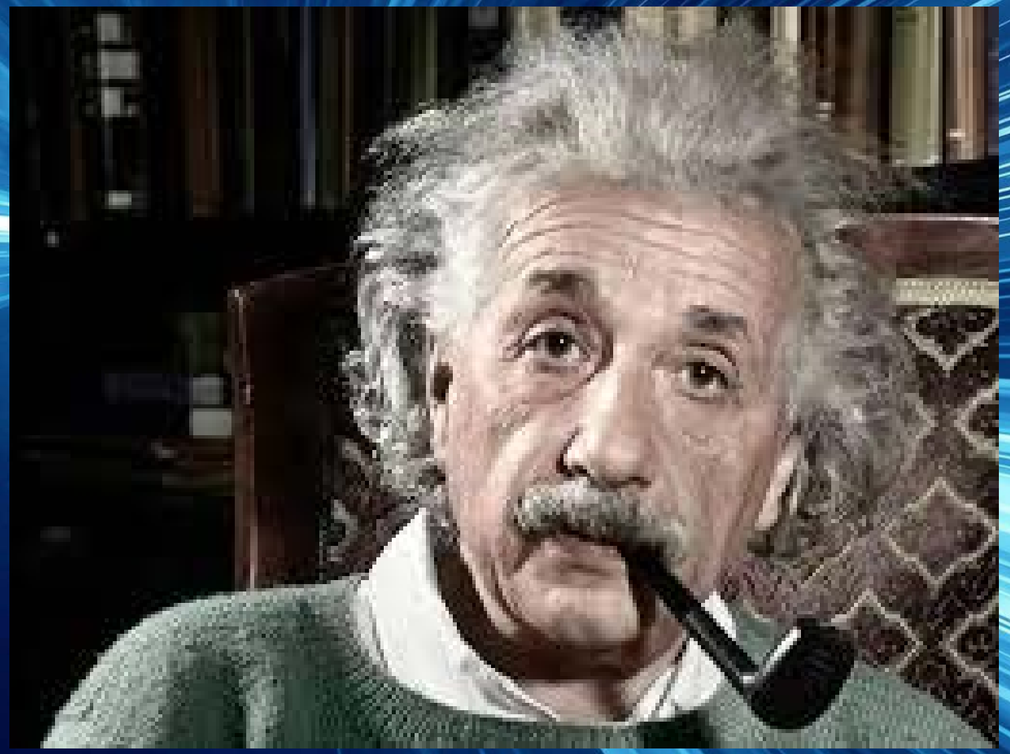
- In physics, we teach students that the speed of light is a universal constant (precise, fundamental, and rigorously defined: 299792458 m/s).

- But in education, what truly defines quality is not a constant.



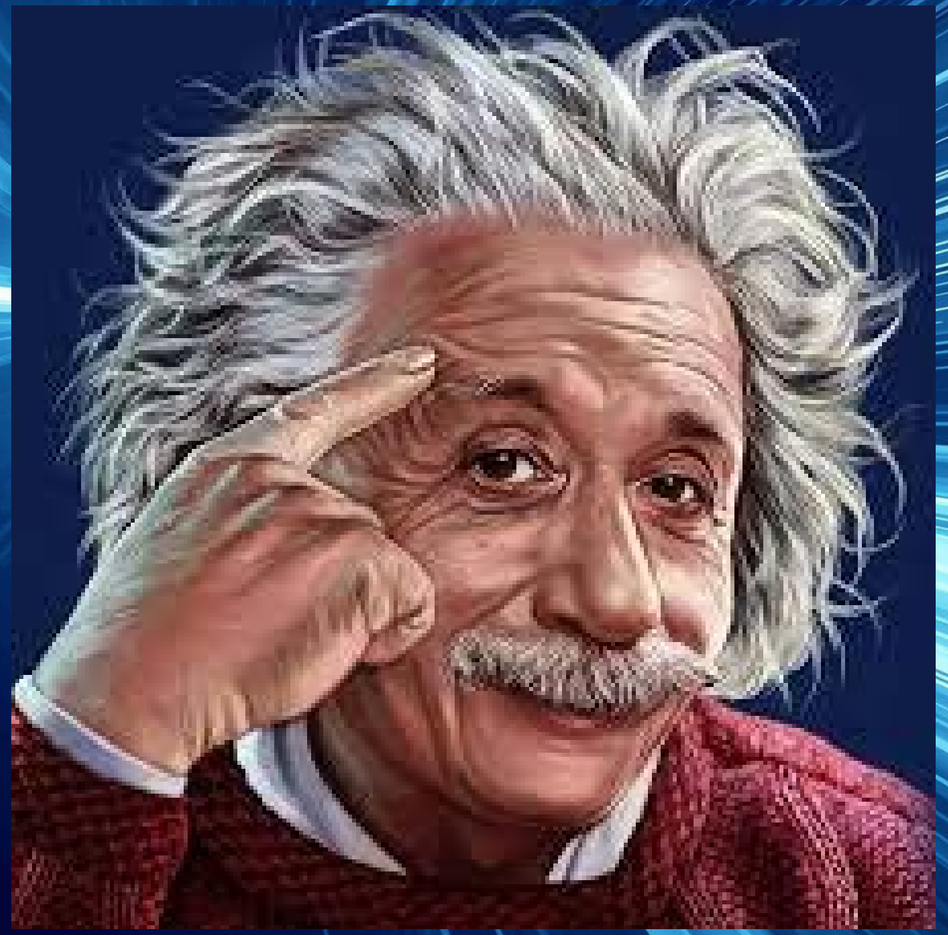
Beyond Measuring Light

- This work shows that when experimental rigor and structured assessment move in the same direction, learning becomes deeper, more transparent, and more meaningful.



Beyond Measuring Light

We are measuring how well our students learn to think scientifically.

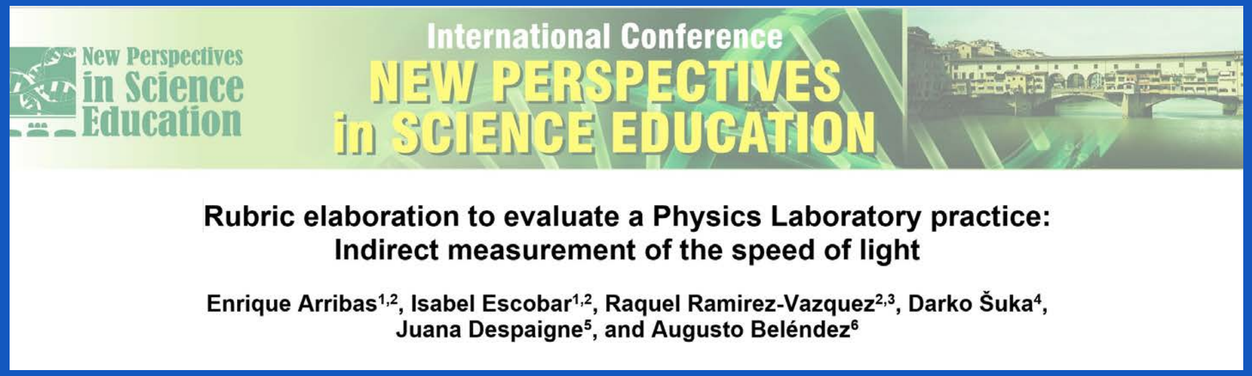


Thank you

- Thank you for your attention
- Questions are welcome
- Discussion is encouraged
- Feedback appreciated
- End of presentation

Sandro Botticelli, The Birth of Venus, 1485

The Uffizi Gallery, Florence



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

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Original article

An indirect measurement of the speed of light in a General Physics Laboratory

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