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Activities designed to establish relationships between concepts as a didactic strategy in the metrology teaching process

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Abstract

The teaching of metrology in undergraduate courses includes concepts such as traceability, calibration and uncertainty. This paper proposes a certain activity that students will have to realize in the Metrology Laboratory. The purpose of this activity is that students understand the contribution that the traceability chain has in the estimation of the uncertainty of a measurement. The activity should be realized in three stages. The first one consists of the construction of a mass measuring device. In the second stage, the pupil realizes the calibration of the device with two different patron mass kits. In the third stage, the student weighs different problem masses and informs the value of the measurand with an uncertainty statement, calculated with the information of his previous calibrations. Once the student has obtained different uncertainties of the same measurand, estimated with the same instrument, the instruments' traceability relevance will be set.

Key Words: *Metrology teaching, Calibration, Traceability, Uncertainty*.

1 Introduction.

In the ISO VIM (DGUIDE 99999.2) 2006 "International Vocabulary of Basic and general terms in metrology (VIM) – Third edition", Traceability is defined as a "property of a measurement result whereby the result can be related to a stated reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty"[1]

Because of its simplicity, this concept is easily understood by undergraduate students; however, its importance is often forgotten or misunderstood. This document's goal is to present an activity proposal for the Metrology course so that undergraduate students fully comprehend the meaning and importance of traceability.

The activity consists of three stages, which are detailed below.

2 Stage 1: Device construction.

2.1 Fundamental principles of the device.

The setting up of the electromagnetic balance was based on the application of the following principle: The magnetic force ($\vec{F}_B$) exerted on the electrical charge that travels through the surface of a conductor is equal to the product of the intensity of circulating current (i), the length of the conductor (L), and the magnetic field (B) around it [2] [6], as showed in the equation (1).

$$\vec{F}_B = i\vec{L} \times \vec{B} \tag{1}$$

This magnetic force can be applied to counter the weight of an object with a specific mass (m). Analyzing the generated torques, the following relation between the electric current traveling through the conductor and the mass of the weighted object can be established as follows:

$$i = m\left(\frac{g}{LB}\right) \tag{2}$$

2.2 Device description.

The design of the electromagnetic balance was based on the structure of a balance of equal beams. The balancing force is generated by the electromagnetic field around a conductive coil which transports an electrical current. This force counters the weight of the object placed on the opposite end of the arm. The circulating electrical current was provided using a DC power supply connected to the coil. On the opposite end of the balance, a container was placed as well as an equilibrium indicator. Zero was established as the equilibrium without any object in the container. The device is shown in Figure 1.

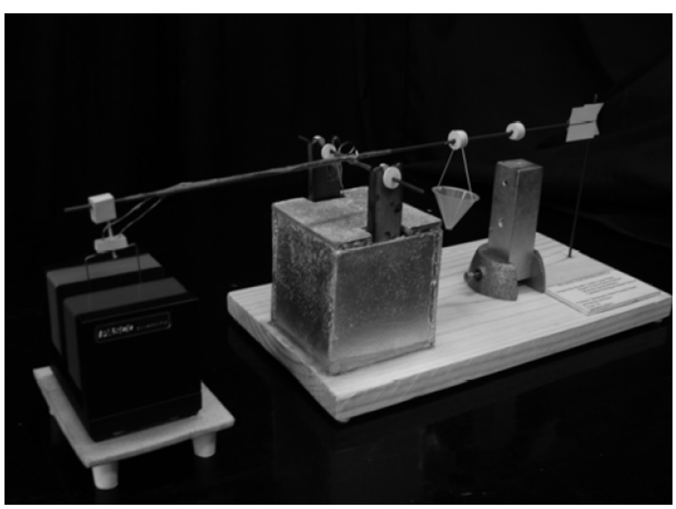


Figure 1 Electromagnetic Balance

2.3 General operation of the device.

Once the zero of the balance is adjusted, an object is placed in the container. Later, the intensity of electrical current in the coil is adjusted until the magnetic force on it counters force generated by the weight of the object and the dial returning to the equilibrium position [7].

3. Stage 2: Calibration of the device.

In stage 2, students must calibrate the devise. This will be done with two different standard mass sets; one of them traced to the NIST, the other to the Chemistry Faculty of the UNAM.

The calibration of the electromagnetic balance took place using different standard masses and several currents associated to each mass standard were obtained [4][5]. The value of the electrical current associated to each mass standard, was repeatedly determined until achieving regular outcomes. The average values of electrical current for each known mass are shown in Table 1.

		Table 1	
Standard mass traceable to NIST (g)	Average electric current (A)	Standard mass traceable to UNAM (g)	Average electric current (A)
$0,5 \pm 3,5X10^{-5}$	$0,54 \pm 5X10^{-3}$	$0,5 \pm 6X10^{-5}$	$0,52 \pm 5X10^{-3}$
$1 \pm 3,5X10^{-5}$	$1,18 \pm 5X10^{-3}$	$1 \pm 6X10^{-5}$	$1,15 \pm 5X10^{-3}$
$1,5 \pm 3,6X10^{-5}$	$1,78 \pm 5X10^{-3}$	$1,5 \pm 6X10^{-5}$	$1,81 \pm 5X10^{-3}$
$2 \pm 3,6X10^{-5}$	$2,31 \pm 5X10^{-3}$	$2 \pm 7X10^{-5}$	$2,33 \pm 5X10^{-3}$
$2,5 \pm 4,2X10^{-5}$	$2,94 \pm 5X10^{-3}$	$2,5 \pm 7X10^{-5}$	$3,10 \pm 5X10^{-3}$
$3 \pm 4,2X10^{-5}$	$3,50 \pm 5X10^{-3}$	$3 \pm 7,5X10^{-5}$	$3,50 \pm 5X10^{-3}$
$3,5 \pm 6,1X10^{-5}$	$4,20 \pm 5X10^{-3}$	$3,5 \pm 8,3X10^{-5}$	$4,60 \pm 5X10^{-3}$
$4 \pm 6,1X10^{-5}$	$4,77 \pm 5X10^{-3}$	$4 \pm 8,3X10^{-5}$	$4,93 \pm 5X10^{-3}$

3.1 Treatment of experimental data.

The relationship between each mass standard, and its corresponding electric current used to put the balance beam into equilibrium was obtained with a graph using the data obtained during the experiment. Through a linear regression, two mathematical models were obtained.

$$I = (a_{NIST})m + b_{NIST} \quad (3)$$

$$I = (a_{UNAM})m + b_{UNAM} \quad (4)$$

where:

a_{NIST}, is the slope parameter in the linear regression of the calibration curve with standard masses traceable to NIST.

b_{NIST}, is the Y-intercept parameter in the linear regression of the calibration curve with standard masses traceable to NIST.

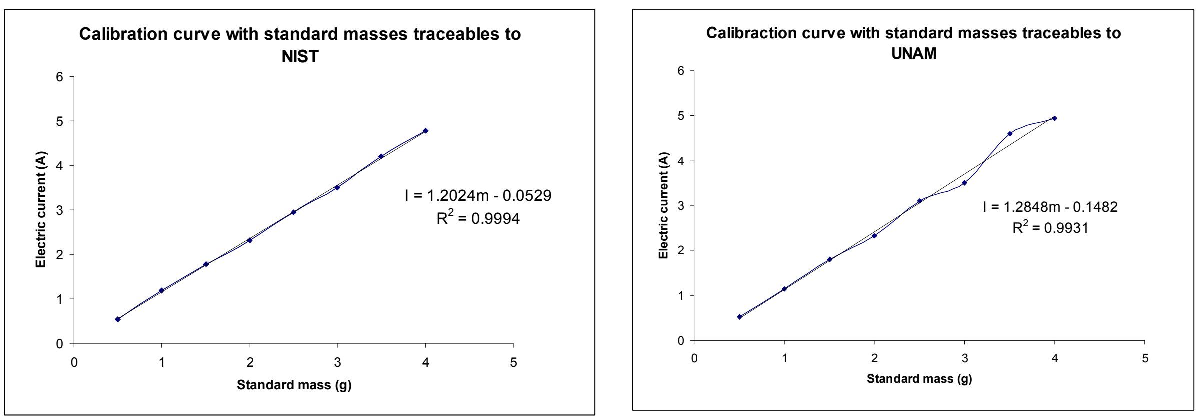
a_{UNAM}, is the slope parameter in the linear regression of the calibration curve with standard masses traceable to UNAM.

b_{UNAM}, is the slope parameter in the linear regression of the calibration curve with standard masses traceable to UNAM.

m is the unknown mass.

i is the Electric current indicated by de electromagnetic balance.

These models define the electric current as a function of the mass standard. The obtained graph was used as a calibration curve (Figure 2)



Calibration curves
Figure 2

The values and uncertainties [3] of the parameters obtained in the linear regressions are showed in Table 2.

Table 2		
	Calibration curve traceable to NIST	Calibration curve traceable to UNAM
Slope	$(1,20 \pm 3,95X10^{-2})$ Ag^{-1}	$(1,29 \pm 1,14X10^{-1})$ Ag^{-1}
Y-intercept	$(-5,29X10^{-2} \pm 9,98X10^{-2})$ A	$(-1,48\ X10^{-2} \pm 2,89X10^{-1})$ A
Correlation factor	0,9997	0,997

Based on the information provided in Table 2, and with equations (3) and (4), students will be able to determine the unknown mass of a body, as well as the related uncertainty. This will be one as shown on the following model:

$$Um = \sqrt{\left(\frac{\partial m}{\partial I}\right)^2 U_I^2 + \left(\frac{\partial m}{\partial a_{NIST}}\right)^2 U_{a_{NIST}}^2 + \left(\frac{\partial m}{\partial b_{NIST}}\right)^2 U_{b_{NIST}}^2} \qquad (5)$$

$$Um = \sqrt{\left(\frac{\partial m}{\partial I}\right)^2 U_I^2 + \left(\frac{\partial m}{\partial a_{UNAM}}\right)^2 U_{a_{UNAM}}^2 + \left(\frac{\partial m}{\partial b_{UNAM}}\right)^2 U_{b_{UNAM}}^2} \quad (6)$$

4. Stage 3: Measurement of an unknown mass.

Once the students have the mass measuring device and the model with which to determine the value of the mass problem and its related uncertainty, they can proceed to compare the measurement results by studying two different traceability chains.

Once stages 1 and 2 have been finished, students can measure the same mass, with only one instrument, and under the same metrological conditions and still, depending on the traceability chain used, obtain different values, such as are shown on Table 3

Table 3

	NIST Traced Result	UNAM Traced Result
I*	3,42 A	3,42 A
Predicted mass	2,89 g	2,78 g
Uncertainty of predicted mass	$1{,}26\text{X}10^{-1}$ g	$3{,}34\text{X}10^{-1}$ g

* Mean electric current used for the measurement of an unknown mass, using an electromagnetic balance.

As can be seen on Table 3, the uncertainty value of the measurement obtained with the balance that is traced to NIST is about half the value of the one obtained when traced to the UNAM. This conveys the importance of traceability in the estimation of uncertainty values and measurement results.

5. Conclusions.

At the end of this activity, students understood the interaction between a magnetic field and electric current, they became familiar with a simple calibration process, and they were able to determine the uncertainty values of measurement results

The development of this activity achieved the didactic goal of integrating different concepts related to electromagnetism, dynamics and metrology. It also allowed students to understand the importance of the traceability chain in the estimation of the measurand and its uncertainty.

6. References.

[1] ISO VIM (DGUIDE 99999.2), International Vocabulary of Basic and general terms in metrology (VIM) – Third edition, 2006.

[2] W. Hayt, Teoría Electromagnética, McGraw-Hill Internacional Editions, Singapore, 1978.
[3] Instituto Mexicano de Normalización y Certificación, *NMX-CH-140-IMNC-2002, Guía para la expresión de incertidumbre en las mediciones*, IMNC, México, 2002.
[4] Elizabeth Prichard, *Measurement of Mass*, Royal Society of Chemistry, 2003. 2.
[5] CENAM, *CNM-MMM-PE-001 Calibración de masa y masa convencional por el método de doble sustitución ABBA*, CENAM, México 2002.
[6] Resnick R., Halliday D., Krane K., *Física*, Vol. 2, CECSA, México, 1994.
[7] Santamaría M. Praxedis I., Rosado E. Laura, Miranda G. Roberto, Rosete V. Karina, *Physics Instruction for undergraduate Collage Courses through the design of an experimental device*, WSEAS Transactions on Advances in Engineering Education, Issue 10, Vol 3, October 20062.

7. Acknowledgements.

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