

Normalized Gain and Least Squares to Measure of the Effectiveness of a Physics Course

C. A. Collazos[1(✉)], Alejandra Rojas[1], Hermes Castellanos[1], Diego Beltrán[2], César A. Collazos[2], Darío Melo[3], Iván Ruiz[1], Iván Ostos[1], Carlos A. Sánchez[1], Emiro De-la-Hoz-Franco[4], Farid Meléndez-Pertuz[4], and César Mora[5]

[1] Universidad Manuela Beltrán, Vicerrectoría de Investigaciones, Bogotá D.C., Colombia
cacollazos@gmail.com
[2] Escuela Colombiana de Ingeniería, Facultad de Ingeniería, Bogotá D.C., Colombia
[3] Departamento de Tecnología e Informática, Universidad EAN, Bogotá D.C., Colombia
[4] Departamento de Ciencias de la Computación y Electrónica, Universidad de la Costa, Barranquilla, Colombia
[5] Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada del Instituto Politécnico Nacional, México DF, México

Abstract. We present a quantitative analysis using the concepts of Normalized Gain and Least Squares in a process of Physics Teaching. This paper presents the results of the strategy based in The Construction of Prototypes (TCP) and Project Based Learning (PrBL) which was applied in a course of Mechanics in Bogotá-Colombia. The strategy focuses on three topics of Rotational Dynamics Teaching (RDT) specifically at centripetal force, Inertia moment and theorem de parallel axes and angular momentum conservation. We present results and analysis of employed method.

Keywords: Normalized Gain · Least squares · Projects-based learning

1 Introduction

This paper takes some aspects of constructivism and more particularly uses the project-based learning and active learning. The project-based learning proposes interdisciplinary teaching activities in long or medium term and focuses on the student, instead of short and isolated educational processes. The instructional strategies based on projects are rooted in the constructivist approach that evolved from the work of psychologists and educators such as Lev Vygotsky, Jerome Bruner, Jean Piaget and John Dewey [1, 2]. Active learning for its part according to the approach that gives Sokoloff states that teaching physics can be undertaken using current technologies such as data acquisition systems and sensors. There are introductory laboratory modules defined

© Springer Nature Switzerland AG 2019
S. Misra et al. (Eds.): ICCSA 2019, LNCS 11619, pp. 66–77, 2019.
https://doi.org/10.1007/978-3-030-24289-3_6

using data acquisition tools with the computer to help students develop important physics concepts while they acquire skills in the laboratory, as in [3–6].

Data acquisition systems such as those presented in [3–6], allow the use of computers for mathematical and physical modeling, based on observations of real experiments. Besides, it also allows the cycle experimental of prediction, observation and validation that is fundamental in the research of the physics education. There are situations in which computation technologies are used to increase the efficiency of teaching physics and other sciences [7–11].

Despite the advantages of the use of data acquisition systems and computers, it is important to note that such costs are quite high, therefore we made a low-cost timer which is presented in [12]. This timer allows students to experiment properly with rotational dynamics projects as a complement to data acquisition systems and computers.

This research presents the results obtained in the design and construction of prototypes for centripetal force (P1), Moment of Inertia and Parallel Axis Theorem (P2) and Conservation of Angular Momentum based on our experience in 2018-1with student's projects belonging to Faculties of Engineering in the Manuela Beltrán University (MBU) and Colombian School of engineering (CSE) in Bogotá, Colombia. The paper is structured as follows: Sect. 2 we present the Methodology. Section 2.5 we present the results. Section 3 we present the conclusions of the strategy employed.

2 Methodology

2.1 Evaluation

Strategy (PrBL) and (TCP) to the (RDT) have two types of evaluation, one is the evaluation of projects ((Eva-1), (Eva-2), (Eva-3)) in subgroups of 3 students and the other is the conceptual multiple-choice test that is individual, (Si) and (Sf). Conceptual test for its part consists of 15 questions that were excerpted and translated the question bank of Mark Riley [13], is available in [14]. The questionnaire has 5 questions for each of the thematic of the projects (P1), (P2), (P3), (Annex 1). The conceptual evaluation is applied in the first week of classes (Si) and last week.

2.2 Population

The pedagogical strategy (PrBL) and (TCP) in the (RDT) was applied to eight groups (experimental group) where four groups (156 students) belonged to the (MBU) and four groups (144 students) belonged to the (CSE). Each group was made up of approximately 40 students. Subgroups were formed later with three students and exceptionally four students. In the case of (MBU) 52 subgroups were consolidated, in the case of (CSE) were formed 48 subgroups. Additionally, there were eight groups to which were applied traditional instructions (TI) (Control Group). The Fig. 1 illustrates the population.

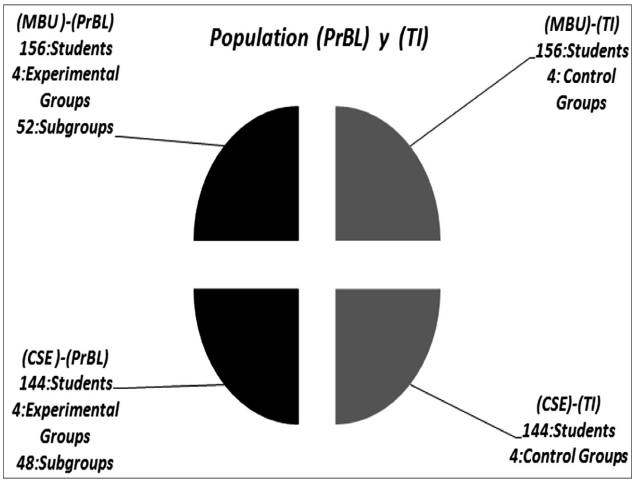

Fig. 1. Population

2.3 Theoretical Fundaments (Gain and Least Squares)

Using the concept of gain of Hovland (1947) used by Hake in [15], is defined the gain g by Eq. (1).

$$g = \frac{S_f - S_i}{100 - S_i} \tag{1}$$

Where $g = 0$ if $(S_i) = 100$; (S_f) (Post-Test) corresponds to the conceptual test applied after applying the strategy (PrBL) and (TCP) to the (RDT) and (TI). S_i (Pre-Test) corresponds to the entrance test without applying any strategy or traditional instruction. We proceeded to determine the average gain of each of the 4 experimental groups and 4 control groups before and after applying the strategy and traditional instruction in (CSE) and (MBU). Ordering the Eq. (1) we have the Eq. (2).

$$(Sf - Si) = (g) - \left(\frac{g}{100}\right)(Si) \tag{2}$$

Thus for a data set in [16], the best curve that fits is one for which the sum of the squares of the deviations is a minimum, then: $J^2 = \sum(y_i - \hat{y}_i)^2 = \text{minimun}$, y_i is the experimental value and corresponds to the measured values $(Sf - Si)$ and $\hat{y}_i$ is the theoretical value of $(Sf - Si)$.

For Eq. (2) is given the first-degree polynomial: $\hat{y} = a + bx$. In this case $a = (g)$, $b = \left(\frac{g}{100}\right)$ and $x = (Si)$. For N pairs of data, the regression parameters a and b are obtained from the following Eqs. (3) and (4) respectively:

$$a = \frac{\sum_{i=1}^{N} x_i^2 \sum_{i=1}^{N} y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} (x_i y_i)}{N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2} \tag{3}$$

$$b = \frac{N \sum_{i=1}^{N} (x_i y_i) - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2} \tag{4}$$

Considering that the line is calculated to approximate the experimental data obtained in the process of learning, it is convenient to measure the degree of linear association between two variables ($Sf - Si$) and (Si).

There is a quantitative measure of the data that follows the straight line obtained by the least squares fit. It is given by the values called correlation coefficient r which is calculated using Eq. (5).

$$r = \frac{N \sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{\sqrt{\left[N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2\right]\left[N \sum_{i=1}^{N} y_i^2 - \left(\sum_{i=1}^{N} y_i\right)^2\right]}} \tag{5}$$

For the analysis of the data are considered a good correlation, $|r| > 0.9$. In the case of the regressions is possible to determine the standard error a (σ_a) and b (σ_b). In the linear regression method, we assume that the real values a and b (a* and b*, respectively) should be in a certain range so that the regression line is acceptable. The ranges for a* and b*, are:

Range of a*: (a – σa < a < a + σa)
Range of b*: (b – σb < b < b + σb)

The values of σa and σb, known as standard errors of a and b respectively, are calculated using Eqs. (6) and (7).

$$\sigma_a = \sigma_y \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}} \tag{6}$$

$$\sigma_b = \sigma_y \sqrt{\frac{N}{N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}} \tag{7}$$

Where:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{N} (\delta y_i)^2}{N-2}} \text{y } \delta y_i = y_i - (a + b x_i)$$

Therefore, the range of experimental error of the regression obtained is between the graphs of the following Eq. (8).

$$\begin{aligned} Y_{max} &= (a+\sigma_a)+(b+\sigma_b)x \\ Y_{min} &= (a-\sigma_a)+(b-\sigma_b)x \end{aligned} \tag{8}$$

In the case of gain, the Eq. (8) are represented by Eq. (9):

$$\begin{aligned} &(Sf-Si)g\left(\frac{g+\sigma_g}{100}\right)_{max} \\ &(Sf-Si)g\left(\frac{g-\sigma_g}{100}\right)_{min} \end{aligned} \tag{9}$$

Equation (9) are valid only when we work with experimental samples (experimental or control groups) belonging to the same population (University). In the case of working with a different population is recommended to use standard deviation instead of standard error. This produces more dispersion models and thus greater reliability.

2.4 Experimental Data (Conceptual Test)

To calculate the average gain score we use a histogram obtained for an experimental group of 40 students (MBU) before and after the strategy was applied. Figure 2 show the average obtained before the test (S_i, Pre-test) that is 21.98 points and the average obtained after the test (S_f, Post-test) that is 45.96 points over 100 points. After implementing the strategy using the Eq. 1 we determined the average gain $\bar{g} = 30.74$ of one experimental group (MBU) using (PrBL). The average gain of each of the 4 control groups and 4 experimental groups (CSE) and (MBU) are presented in Tables 1 and 2 respectively.

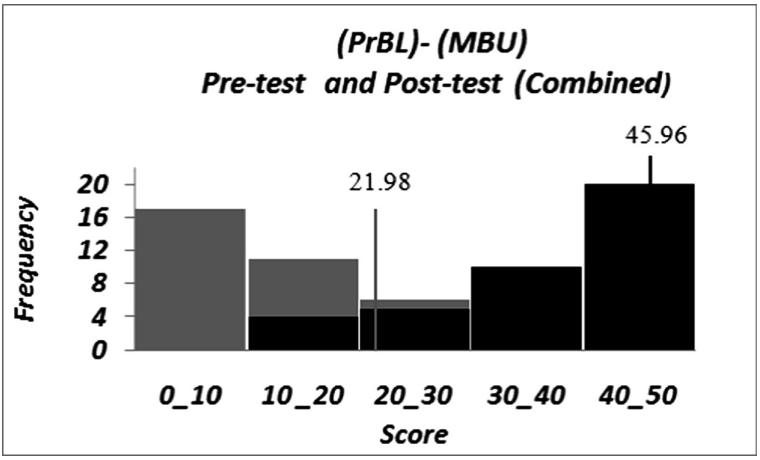

Fig. 2. Histogram (MBU), (PrBL), Pre-test and Post-test combined

Table 1. Average gains for (MBU)

(S_i)	(S_f)	$(S_f - S_i)$	$\bar{g}$
22.07	42.08	20.01	25.68
19.94	43.98	24.04	30.03
21.98	45.96	23.98	30.74
20.06	48.04	27.98	35.00
25.94	35.96	10.02	13.53
23.90	31.90	8.00	10.51
22.04	34.03	11.99	15.38
17.96	27.98	10.02	12.21

Table 2. Average gains for (CSE)

(S_i)	(S_f)	$(S_f - S_i)$	$\bar{g}$
23.98	56.99	33.01	43.42
22.12	56.07	33.95	43.59
19.91	57.95	38.04	47.50
21.16	61.08	39.92	50.63
26.08	40.05	13.97	18.90
21.96	32.94	10.98	14.07
20.13	34.11	13.98	17.50
15.96	31.97	16.01	19.05

The blank area in Tables 1 and 2 corresponds to the experimental groups and the gray area corresponds to the control groups. Based on the gain equation is a linear model and due to the dispersion of the data we apply the method of least squares as in Sect. 2.3.

Figures 3, 4, 5 and 6 show the maximum and minimum models of experimental and control groups in (MBU) and (CSE), based on Eq. (10). This methodology allows to look at the dispersion σ_g of the gain g with the (PrBL) and (TI) using least squares.

Figures 7 and 8 show simultaneously the experimental groups and control (MBU) and (CSE) with the models calculated by the method of least squares and the correlation coefficient r.

2.5 Quantitative Analysis Results

Based on theoretical Fundaments of Sect. 2.3, the mathematical models were obtained for each educational process. Figure 9 shows all groups (control and experimental) in (MBU) and (CSE), indicating the gain and the classification provided by Hake in [10].

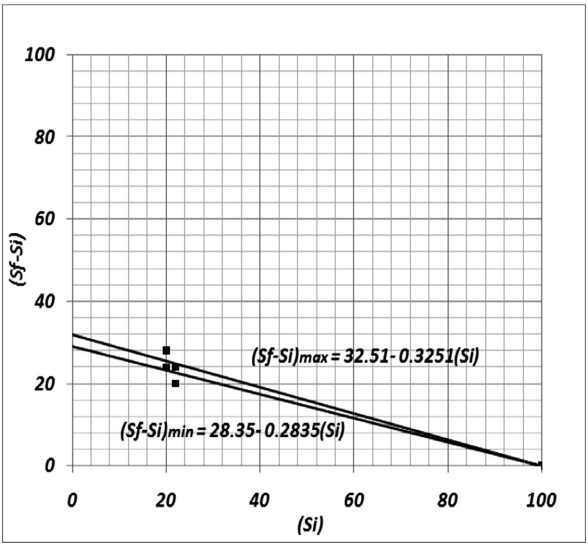

Fig. 3. Experimental groups (MBU), (PrBL), maximum model (top), minimal model (bottom), g = 30.43; $\sigma_g = 2.08$

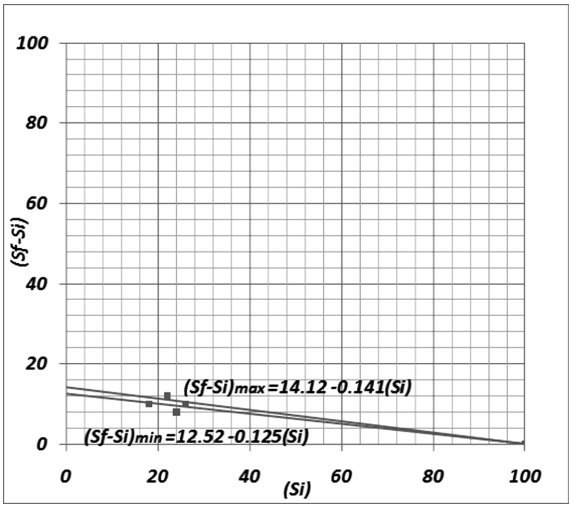

Fig. 4. Control groups (MBU), (TI), maximum model (top), minimal model (bottom), g = 13.04; $\sigma_g = 1.14$

Figure 9 also shows that the gain for the (MBU) with (PrBL) is (30.43 ± 2.08) and is located in medium gain, but with (TI) is (13.04 ± 1.14) and is located in low gain. For (CSE) with (PrBL) is (46.52 ± 1.88) and is located in medium gain, but with (TI) is (17.48 ± 1.23) and is located in low gain. The results show the efficiency of (PrBL) in contrast to the (TI) at both universities.

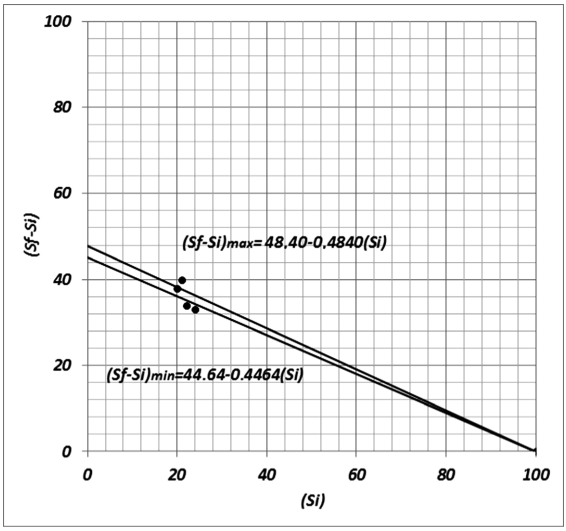

Fig. 5. Experimental groups (CSE), (PrBL), maximum model (top), minimal model (bottom), g = 46.52; $\sigma_g = 1.88$

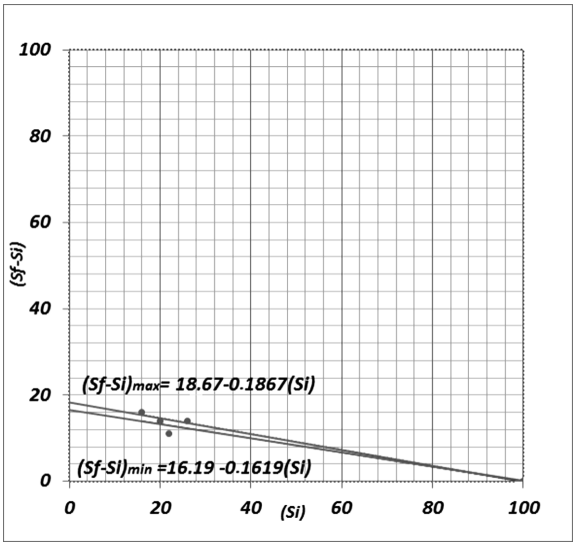

Fig. 6. Experimental groups (CSE), (TI), maximum model (top), minimal model (bottom), g = 17.48; $\sigma_g = 1.23$

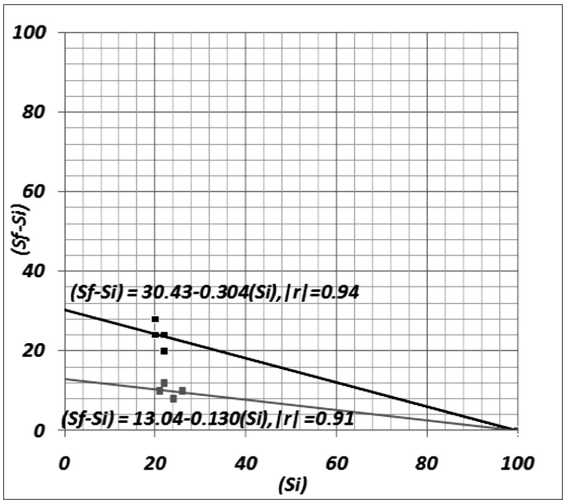

Fig. 7. Experimental and control groups (MBU), (PrBL): g = 30.43, top; (TI): g = 13.04, bottom.

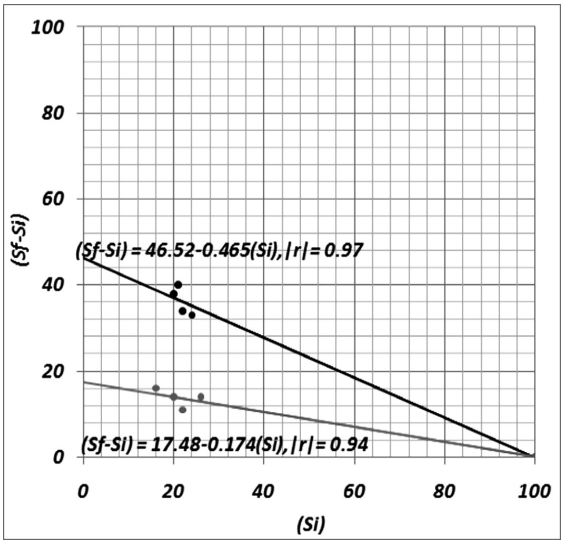

Fig. 8. Experimental and control groups (CSE), (PrBL): g = 46.52, top; (TI): g = 17.48, bottom

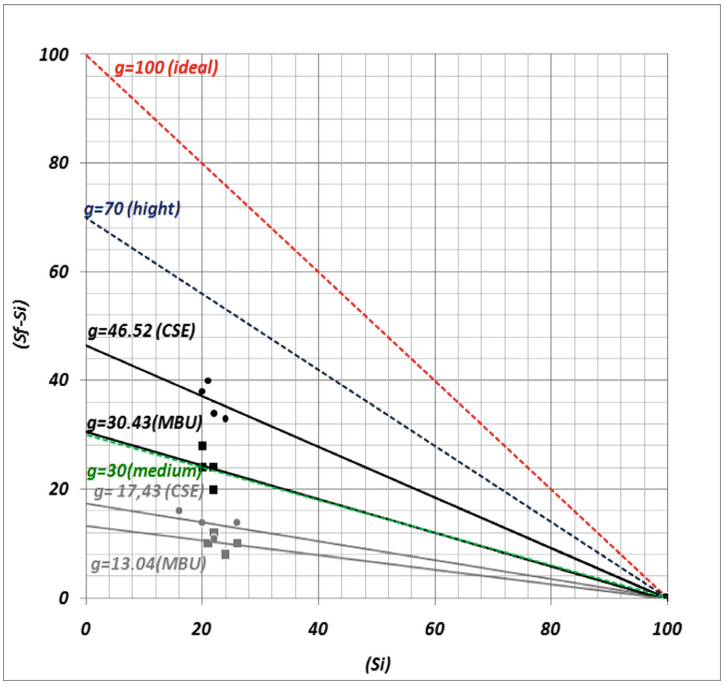

Fig. 9. Experimental (black) and control (gray) groups (CSE, MBU), red (ideal: $g = 100$), blue (hight: $g \geq 70$), green (medium: $70 > g \geq 30$), low ($g < 30$) (Color figure online)

3 Conclusions

The method used in this work is part of the current curriculum of both universities (MBU) and (SCE). Moreover, this research can be applied in various areas of physics, such as optics, electromagnetism, Physics of Sound, Biophysics, Thermodynamics, Fluid Mechanics and Modern Physics, among others. The prototypes for Mechanics (Rotational Dynamics) are show in [17–21], for Electromagnetism (Electrostatic) in [22, 23] and Fluid Mechanics in [24].

Based on the results (Sect. 2.4), the strategy allows for gains in the medium range. Results obtained a gain to (MBU) of (30.43 ± 2.08) and to (SCE) of (46.52 ± 1.88). The methodology used in this paper presents a gain compared to traditional instruction (TI), which had a lower gain range than for the (MBU) that was of (13.04 ± 2.08) and to (SCE) that was of (17.43 ± 1.24).

General speaking, the results analysis scheme allows quantitative measurement and qualitatively evaluate the strategy used. It was possible to establish that the students:

- Built prototypes that allowed them to properly conceptualize the topics of rotational cinema.
- Identified and corrected some mistaken concepts related to the fundamental principles of rotational dynamics.

- Engaged actively and collaboratively in the execution of projects.
- Developed a question on the topic raised, for which they carried out the review of different sources (pages on the web, books, journals of scientific dissemination, sought expert advice, among others). Then selected the information that allowed them to solve the formulated project.
- Could establish an experimentation process (prediction, observation and validation). Although the theory of error and graphic analysis was difficult and generated confusion at the beginning, then the students were able to perform correct analyses and interpretations of the experimental data.
- Constructed and modeled the prototype physically. For this they used methods of inductive and deductive reasoning that allowed to identify the physical variables involved as well as defining dependent variables, independent and constant. Similarly, they obtained measures of the mentioned variables in order to perform the analysis. In this regard the theoretical and practical solution of the project strengthened investigative skills, such as: observing, analyzing, deducing, conjecturing, designing, producing, among others.

References

1. Hernández, C.: Aprendizaje de la Física en estudiantes de diseño Industrial dentro de una innovación pedagógica consistente en el constructivismo, Tesis de Maestria en Educación, Uniandes (2004)
2. Vygotsky, L.: Pensamiento y lenguaje. Alfa y Omega, México (1985)
3. Thornton, R.K., Sokoloff, D.R.: Learning motion concepts using real-time microcomputer-based laboratory tools. Am. J. Phys. **58**, 858–867 (1990)
4. Mokros, J.R., Tinker, R.F.: The impact of MicroComputer Based Labs on children's ability to interpret graphs. J. Res. Sci. Teach. **24**, 369–383 (1987)
5. McDermott, L.C., Rosenquist, M.L., van Zee, E.H.: Student difficulties in connecting graphs and physics: examples from kinematics. Am. J. Phys. **55**, 503–513 (1987)
6. Redish, E.F., Saul, J.M., Steinberg, R.N.: On the effectiveness of active-engagement microcomputer-based laboratories. Am. J. Phys. **65**, 45–54 (1997)
7. Stankova, E.N., Barmasov, A.V., Dyachenko, N.V., Bukina, M.N., Barmasova, A.M., Yakovleva, T.Yu.: The use of computer technology as a way to increase efficiency of teaching physics and other natural sciences. In: Gervasi, O., et al. (eds.) ICCSA 2016. LNCS, vol. 9789, pp. 581–594. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-42089-9_41
8. Lisachenko, D.A., Barmasov, A.V., Bukina, M.N., Stankova, E.N., Vysotskaya, S.O., Zarochentseva, E.P.: Best practices combining traditional and digital technologies in education. In: Gervasi, O., et al. (eds.) ICCSA 2017. LNCS, vol. 10408, pp. 483–494. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-62404-4_36
9. Dyachenko, N.V., Barmasov, A.V., Stankova, E.N., Struts, A.V., Barmasova, A.M., Yakovleva, T.Yu.: Prototype of informational infrastructure of a program instrumentation complex for carrying out a laboratory practicum on physics in a university. In: Gervasi, O., et al. (eds.) ICCSA 2017. LNCS, vol. 10408, pp. 412–427. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-62404-4_30

10. Comas, Z., Echeverri, I., Zamora, R., Vélez, J., Sarmiento, R., Orellana, M.: Tendencias recientes de la Educación Virtual y su fuerte conexión con los Entornos Inmersivos. Revista Espacios **38**, 4–10 (2017)
11. Stankova, E.N., Dyachenko, N.V., Tibilova, G.S.: Virtual laboratories: prospects for the development of techniques and methods of work. In: Gervasi, O., et al. (eds.) ICCSA 2018. LNCS, vol. 10963, pp. 3–11. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-95171-3_1
12. Collazos, C.A.: Construcción de un prototipo para experimentos de Mécanica. Lat. Am. J. Phys. Educ. **4**(Suppl. 1), 840–843 (2010)
13. http://www.fisicacollazos.260mb.com. Accessed 15 Jan 2019
14. Riley, M.: Test Bank. W. H. Freeman and Company, New York (2003)
15. Hake, R.R.: Interactive-engagement vs traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. Am. J. Phys. **66**, 64–74 (1997)
16. Spiegel, M.: Estadística. McGraw-Hill, Madrid (1991)
17. Collazos, C.A.: Prototipo para la Enseñanza de la dinámica rotacional (conservación del momento angular). Lat. Am. J. Phys. Educ. **3**, 446–448 (2009)
18. Collazos, C.A.: Enseñanza de la conservación del momento angular por medio de la construcción de prototipos y el aprendizaje basado en proyectos. Lat. Am. J. Phys. Educ. **3**, 428–432 (2009)
19. Collazos, C.A.: Prototipo para la Enseñanza de la dinámica rotacional (Momento de Inercia y teorema de ejes paralelos). Lat. Am. J. Phys. Educ. **3**, 619–624 (2009)
20. Collazos, C.A., Mora, C.E.: Prototipo para medir Fuerza Centrípeta en función de masa, radio y periodo. Lat. Am. J. Phys. Educ. **5**, 520–525 (2011)
21. Collazos, C.A., Mora, C.E.: Experimentos de mecánica con temporizador de bajo costo. Revista Brasileira de Ensino de Física **34**, 4311 (2012)
22. Collazos, C.A., Otero, H.R., Isaza, J., Mora, C.: Enseñanza de la Electrostática por Medio de la Construcción de Prototipos de Bajo Costo y el Aprendizaje Basado en Proyectos. Formación universitaria **9**, 115–122 (2016)
23. Collazos, C.A., Otero, H.R., Isaza, J.J., Mora, C.: Diseño y Construcción de una Máquina de Wimshurst para La Enseñanza de la Electrostática. Formación universitaria **9**, 107–116 (2016)
24. Castellanos, H.E., Collazos, C.A., Farfan, J.C., Meléndez-Pertuz, F.: Diseño y Construcción de un Canal Hidráulico de Pendiente Variable. Información tecnológica **28**, 103–114 (2017)