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The magic blower as a didactic element in learning the Bernoulli's law of hydrodynamic pressure in engineering students

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Abstract

This article presents an interacting discrepant experiment (DeX), its physical modeling as well as its pedagogical benefits of the assembly to learn the Bernoulli's Law of Hydrodynamic Pressure. The impact of the results is presented on a population of students and the interactive engagement is measured starting from a process of dissonance to a process of consonance. The prototype has been implemented as a project in order that the student´s population makes time by their own during four weeks. The evolution of the learning process is specified with the Hake's average normalized gain and the Bao's concentration factor. The Hake´s gain value, above 0.5 means that the experience has turned out to be quite fruitful from a pedagogical standpoint.

Keywords: Didactic material, discrepant experiments, physics education, teaching methods.

Resumen

Se presenta un prototipo novedoso que al accionarlo vislumbra un experimento discrepante con bondades pedagógicas muy favorables para apropiar la ley de presión hidrodinámica de Bernoulli. Se presenta resultados del impacto sobre una población de estudiantes y se mide su desempeño surgido del proceso de ir desde un estado de disonancia a un estado de consonancia. El aparato se ha usado como proyecto para que la población en estudio lo trabaje en su tiempo independiente durante 4 semanas. La evolución del aprendizaje se precisa con la ganancia normalizada de Hake y el factor de concentración de Bao. Se ha obtenido una ganancia de Hake mayor a 0.5 que en consecuencia representa una experiencia muy enriquecedora pedagógicamente.

Palabras clave: Material didáctico, experimentos discrepantes, enseñanza de la Física.

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I. INTRODUCTION

The Bernoulli's Law of Hydrodynamic Pressure (BLHP) is one of the most remarkable equations posed by humankind. Guillen himself confirms this premise on his scientific essay about the Five Equations that Changed Word [1]. This equation sets a theoretical mechanism including pressure and fluid speed variables applicable to a great deal of phenomena such as the origin of human voice [2], liquid flow through the atomizer [3] and the way carburetors work in cars [4], the efficiency of fireplaces [5], a spin shot in football [6], and suchlike. Despite the importance of this law one surveillance done by McDermott and Redish there are few studies available regarding the tuition of the aforementioned law in Physics curriculum that might demonstrate a real learning process [7]. With regards to the interpretation of this equation, Bauman and Schwaneberg [8] report certain misconceptions frequently implemented in the deduction and clarification of this equation in University textbooks [9], in the same way, Weltner and Ingelman-Sundberg report a set of misunderstandings frequently adopted by teachers as applications to introduce BLHP that turn out to be counterproductive by being obscure when explaining the pressure gradient from the change of the line-speed of the streamline [10]. Thus, it is indispensable an applicable condition to introduce the equation but simultaneously it is required a maneuverability to appropriate the concept. Accordingly, two new prototypes of experiments are reported, they are named blowers which are highly qualified from a pedagogical standpoint to appropriate the underlying concept of BLHP for fluids inspired by Walker and by a work previously reported [11, 12]. The main quality of these prototypes is that, when they are activated they discern a discrepant phenomenology that, as it is known from previous works it attracts a great deal of students to appropriate physics affairs and to develop their investigation skills [13, 14, 15, 16 and 17].

Being said that, the purpose of this article is to present two prototypes of discrepant experiments (DeX) as well as certain physics modeling turning to Bernoulli equation. It is also reported the impact on a bunch of students qualifying the discrepant pedagogical merit based on an idea about the Bao's concentration [18]. Thus, it is reported the average normalized gain of Hake on a student's population where the two assemblies were implemented to introduce Bernoulli's equation [19]. The next stages of the article, the two aforementioned prototypes are illustrated; section 2 poses a physics modeling of the phenomenon to be implemented on students of introductory levels; section 3 specifies discrepancy and its pedagogical assessment; section 4 presents the outcome on student´s population qualifying the Hake's average normalized gain; finally conclusions are presented.

II. SUGGESTED ASSEMBLY

The presented prototypes as follows can be constructed in acrylic, glass or flexible hosepipe, they are named magic blowers. The eye-catching turns out to be encouraging to draw student´s attention. As Einstein said to mean the behavior of the compass, "*The intellectual development is to a certain extent to surmount stunning sensations: The never-ending escape of the astonishing, magical, miraculous facts*" [20].

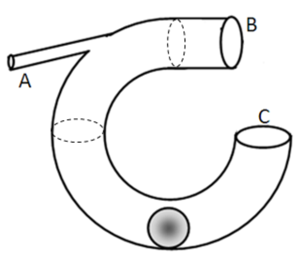

FIGURE 1. The Blower magic 1.

The assembly must be built in transparent materials for naked eye observation of the sphere in the lower part of the assembly when the air flows through tube A. As it is observed in Fig. 1 the blower has three open mouths containing a wood-made and light sphere in the bottom of the assembly or prototype that can be easily moved. The prototype of Fig. 2 is similar to the first one. To activate the device air must flow through tube A and watch the movement of the sphere. The difference in this prototype is the way the open mouths are placed in the device.

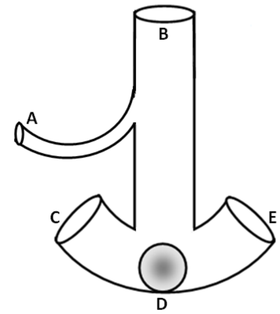

FIGURE 2. The Blower magic 2.

Both prototypes are DeX since when they are activated (to blow through tube A) the sphere in the bottom of the prototypes moves towards tube B. This is counter-intuitive related to case 1, since most of students foretell that the sphere will move towards tube C and in case 2, most of them foretell that the sphere will not move at all. Both prototypes have plenty of inquiring options for students. It is suggested not to display both prototypes simultaneously, but keep away on of them to assess the student´s learning.

III. MODELING THE PHENOMENON

To model the phenomenon as a first approach, we suppose that what makes the sphere to move is because of the air flow when blowing through tube A. Particularly, the speed of the air through tube B is higher than the place where the sphere is. Thus, air pressure where speed is higher slowdowns and unleashes an airflow dragging the sphere towards tube B. The aforementioned airflow is a stable airflow with negligible viscosity described by the Bernoulli's equation as,

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2. \qquad (1)$$

As we are concerned to survey the path to sphere m, we consider a part of the prototype and two positions to implement the Bernoulli's equation, (see Fig. 3).

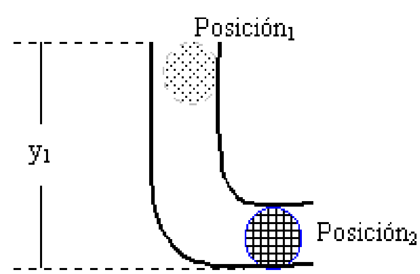

FIGURE 3. Blower Section.

The speed of the airflow initially is equivalent to zero, in position two. By the same token, the height is null, so the equation is,

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2. \quad (2)$$

From Eq. (2) it is concluded that to maintain the equivalence when blowing, the pressure p_1 must slowdown drastically with respect to P_2 since the speed v_1 increases, the height y_1 remains constant and P_2 is the atmospheric pressure. This difference of pressures causes the airflow that ultimately drags the sphere found in the bottom of the tube. On top of that, to find the value of the speed, v_1, of the equation, it is said that

$$v_1 = \sqrt{2\left(\frac{P_2 - P_1 - \rho g y_1}{\rho}\right)}. \quad (3)$$

This is approximately the airflow speed in the mouth of tube B of the blower. With ρ as air density, g as gravity, P_2 as atmospheric pressure and y_1 is the height of the blower approximately. This is the airflow that drags the sphere, holding the same speed than the sphere considering the sphere as a part integrated to the airflow caused by the effect of blowing through the prototype.

In this case the pressure P_1 it is unknown, but it could be found out by determining the dragging of the air as well as the Newton's second law. If it is pondered that the dragging of air pushes and acts over the effective area directly exposed to the airflow, whose value is,

$$A = \frac{\pi d^2}{4}, \quad (4)$$

d as the diameter of the sphere, it could be obtained an equation for pressure P_1 minimizing friction losses.

By the Newton's second law,

$$F - mg = ma. \quad (5)$$

With m is the mass of the sphere. If using the relationship between force and pressure,

$$F = PA. \quad (6)$$

Eq. (5) combined with (6) allows you to find the pressure P_1,

$$P_1 = \frac{4m(a+g)}{\pi d^2}. \quad (7)$$

Substituting (7) in the speed Eq. (3) yields a new equation,

$$v_1 = \sqrt{\frac{2}{\rho_{aire}}\left(p_{atm} - \frac{4m_{esf}(a+g)}{\pi d^2} - \rho_{aire} g y_{sop}\right)}. \quad (8)$$

For blowing strong and short in duration, it can be assumed that the acceleration is null and derive a simple expression for the speed of the sphere. An exercise for students can derive an equation for the speed of the ball out of the plane kinematic analysis of semi-parabolic trajectory of the ball. One can mathematize some interesting observations, but this modeling we pretty close to the description of the discrepant movement of the sphere through the BLHP.

IV. PEDAGOGICAL VALUE AND MEASURING THE DISCREPANCY

A. Concept and use of the discrepancy

The motor activate of interacting engagement students to learn and develop their skills in this methodology is the cognitive dissonance generated by the phenomenon. Cognitive dissonance is a state and highly destabilizing, Festinger says that a person has cognitive dissonance when she perceives two contrary information of a same stimulus or she maintain simultaneously two conflicting thoughts [21]. That is to say, when there is incompatibility of two simultaneous cognitions. Festinger argues that this inconsistency to occur appreciably, the person is automatically motivated to strive to generate new ideas and beliefs to reduce stress to get all their ideas and attitudes fit among themselves, achieving a certain internal coherence or "consistent".

The way he produces dissonance reduction may involve different ways. Of course, as the phenomenon of the assembly cannot be changed, then the only way to reduce this imbalance is changing ideas. The physics teacher, should not rush to respond, will be better interact with their students, play, enjoy the phenomenon, ask questions and express the student begins a fascinating work to uncover how and why the phenomenon. As the task is to reduce the dissonance, it is appropriate to assign tasks to succeed. It is important to suggest a work methodology as observe, record details, ask questions, generate conjectures, using a conceptual model and chains of reasoning to describe the phenomenon, agreeing to submit progress now, and search for information.

B. Concentration factor and measuring the discrepancy

Bao and Redish constructed a simple measure that gives the information on the distributed of the responses for a multiple-choice single-response (MCSR) [18]. They define a factor C, called concentration factor as a function of the responses of students that takes a value in the range [0, 1] and is given by,

$$C = \frac{\sqrt{m}}{\sqrt{m}-1} x \left(\frac{\sqrt{\sum_{i=1}^{n} n_i^2}}{N} - \frac{1}{\sqrt{m}}\right). \quad (9)$$

Where m represents the number of elections for a particular question, N is the number of students; n_i is the total number of students who selected choice *i*. The average percentages of correct answers for each question show the trend in the number of mental models in a population. For example, C=0 is a random selection of responses a selection, C=1 is that all students select the same response. If C>0.5 implies a high concentration since more than 60% of the students have selected the same response. If C is between 0.2 and 0.5 indicates that the population has two models of selection and a lower value of 0.2 requires a distribution of three models or random trend. Bao and Redish encodes the score and concentration factor as shown in Table I.

TABLE I. Coding proposed of concentration by Bao.

Score (S)	Level	Concentration (C)	Level
0.0-0.4	Lower (L)	0.0-0.2	L
0.4-0.7	Middle (M)	0.2-0.5	M
0.7-1.0	Higher (H)	0.5-1.0	H

Based on the above idea we can establish a way to measure a discrepancy that a discrepant experiment has in a population when an assembly is operated. Then you could set a pattern to distinguish the "level of discrepancy". Combining score and concentration factor can be established three patterns that represent the level of discrepancy as shown in Table II.

TABLE II. Coding to assign "Level of Discrepancy".

Discrepancy		The patterns
Higher	LH	One incorrect model
Null	HH	One correct model
Middle	LM	Two possible incorrect models
Middle	MM	Two popular models
Without reading	LL	Near random situation

According to Eq. (1) we can construct a graph in the plane with Score (S) on the abscissa and the concentration factor (C) in the vertical for obtained information of areas of high or low concentration level and therefore know the discrepancy that a DeX creates in a student´s population, when an assembly is operated for the first time.

V. THE BLOWER AS A PROJECT

A. Methodology: From dissonance to consonance

The assembly of Fig. 1 was used alternatively to the traditional classroom with a total of 81 students of three groups (27, 28 y 26, respectively). The first two groups were from the University of La Salle and the third group of the Central University of Bogotá. All three groups took the course in mechanical physics and its contents there are fluid concepts: Hydrostatics and Hydrodynamics [23].

Before presenting the assembly to students for them to work as a project for 5 weeks in independently time, applied a test of 12 questions to identify misconceptions of BLHP. Only three questions were chosen (*see Fig. 5*) to assess the evolution of learning with the blower magic of Fig. 1. They were given a workshop with some ideas that guided its construction and subsequent analysis [23]. The teacher emphasized with a parable to start the workshop that says: "I'll tell you a conversation between the teacher and the pupil when last one objected to his master: *¡Great sage! You always tell us parables but never give us the meaning, and the teacher replied, ¡Small grasshoppers! ¿Would you like to give you an apple and chew?"*

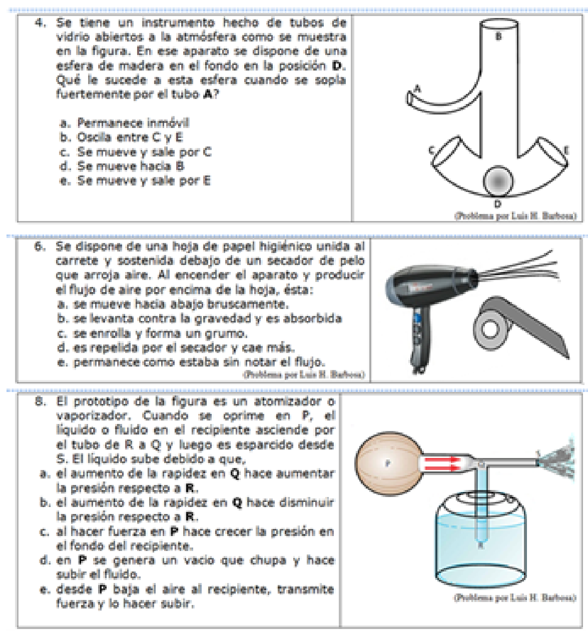

FIGURE 5. Questions chosen to apply to people mentioned pre-test and post-test.

For 4 weeks they inquired in their free time, built mechanisms of explanation and made calculations to approach the understanding of the phenomenon.

- In the fifth week programmed a socialization activity for two hours and finally the teacher gave a summary of the BLHP to explain the phenomenon.
- From the fifth to the fourteen week were not back to the subject in the groups.
- In the Fifteen week again applied the same test.

The student responses are shown in Table IV and the questions analyzed are shown in Fig. 5. We assume that these questions (4, 6 and 8) are the best to evaluate a conceptual change in the population of students.

TABLE IV. Selection of students for questions in Fig. 5.

Responses	No Resp.	A	B	C	D	E
Pre test	Fourt	62	5	4	8	2
	Six	55	8	3	2	13
	Eight	1	6	12	47	15
Pos test	Fourt	0	10	6	63	2
	Six	6	61	1	12	1
	Eight	2	58	5	11	5

The concentration as a function of score results in the graph in Fig. 6. The circles correspond to the pre-project and triangles correspond to the post-project.

It is noted that the study population increases their understanding of the phenomenon going from a region of high discrepancy with an incorrect model of reasoning to a zone of high consonance with a correct model of reasoning. The student population has a high discrepancy in question 4 with the pre-test, but this state becomes consonance in the pos-test. This shows a great evolution of learning and understanding of the phenomenon of the student population.

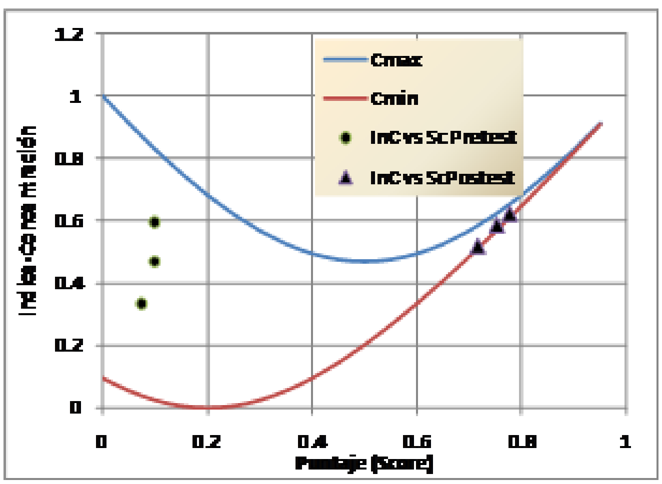

FIGURE 6. Student's concentration responses before (circle-pre) and after (triangle-post-project).

B. Measuring the Hake´s gain

The Hake´s normalized gain is a parameter that accounts for the evolution of student learning and avoids the problem of comparing students who start a course better prepared than others [19]. Used to determine whether a methodology is efficient with respect to the student's initial knowledge. Normalized gain *g* is defined as the change in score divided by the maximum possible increase,

$$< g >= \frac{\%pos - \%pre}{100 - \%pre}. \tag{10}$$

TABLE V. Responses in the pre/post-test for groups of questions in Fig. 5.

Responses	Grupo	A	B	C	D	E
PRE test Question 1	1	23	0	0	4	0
	2	20	3	3	2	0
	3	19	2	1	2	2
PRE test Question 2	1	17	4	1	1	4
	2	20	2	2	0	4
	3	18	2	0	1	5
PRE test Question 3	1	0	2	4	19	2
	2	0	3	5	13	7
	3	1	1	3	15	6
POS test Question 1	1	2	13	4	6	2
	2	0	2	2	24	0
	3	0	5	2	17	2
POS test Question 2	1	3	18	1	4	1
	2	0	20	0	8	0
	3	3	23	0	0	0
POS test Question 3	1	0	3	2	22	0
	2	0	21	1	4	2
	3	0	24	0	1	1

The distribution of the student's responses for these questions is given in the Table V. These responses are given for pre-and post-test.

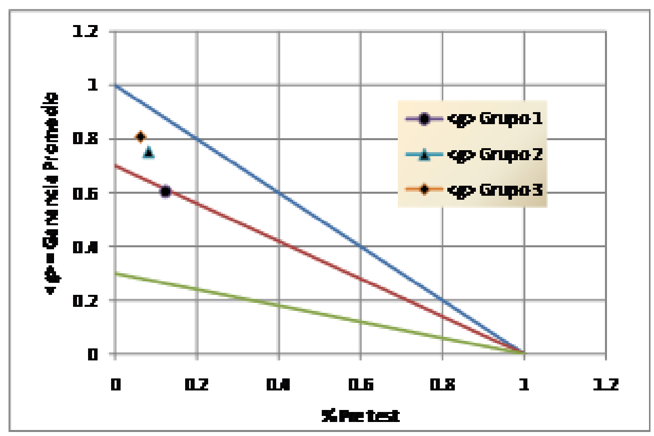

FIGURE 7. Hake´s normalized gain versus pre-test average.

According to information from Table V the first group´s gain is 0.60 with standard deviation of 0.35, for the second group is 0.77 with standard deviation of 0.26, while the third group is 0.80 with standard deviation of 0.20. The gain was measured by group, since in each of these are different and unique circumstances. Based from Eq. (10) and taking into account the information of Table V we can obtain graph in Fig. 7.

VI. CONCLUSIONS

We have illustrated the educational value of magic blower to appropriate the Bernoulli´s law of hydrodynamic pressure in engineering students first semester. The educational value is the interacting engagement that occurs in students when they go from the state of mind "dissonance" to mental state "consonance" and then they learn. This learning has been calculated with the Bao´s concentration factor and the Hake´s normalized gain using data from the distribution of three responses from a calibrated test applied to a student´s population of engineering. When students research the blower in your free time and then report their analysis and modeling, we found that there was a great learning evolution of the population under study. A gain greater than 0.5 in three experimental groups is an indicator of a high efficiency of this DeX to learn and appropriate concept in a given population using their free time.

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