José Luis Escamilla Reyes
(organizador)

EDUCAÇÃO E ENSINO DE CIÊNCIAS EXATAS E NATURAIS

VOL II

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2024

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PRÓLOGO

En este volumen, se presentan los resultados de varios y diversos proyectos de investigación en innovación educativa relacionados con la enseñanza de las ciencias y la ingeniería, tanto en niveles universitarios como básicos. Es así como, a través de distintas experiencias, se aborda la enseñanza de la Física, la Química Analítica y la enseñanza de temas matemáticos tales como la Aritmética y el Álgebra. También, se explora la incorporación de nuevas alternativas como la Inteligencia Artificial y sus aplicaciones en la enseñanza de las ciencias, particularmente de la Química.

Adicionalmente, en este libro se discuten los procesos de evaluación, no sólo de las actividades realizadas por los alumnos en los diferentes niveles educativos, sino de la pertinencia y adecuación del currículum en las disciplinas científicas, dentro de las que se puede mencionar a la Química Analítica y las Ciencias Exactas en general.

Por supuesto, hago la invitación a nuestros lectores para que disfruten la lectura de estos artículos de innovación educativa y, si son docentes en activo, que implementen alguna o varias de las estrategias y metodologías expuestas en este volumen con el fin de enriquecer su práctica docente y, de esta manera, contribuir en la mejora de los procesos educativos desde los niveles básicos hasta los universitarios.

Finalmente, los autores de este libro agradeceremos la retroalimentación y los comentarios propositivos que nos hagan llegar, puesto que lo más importante es asegurar que nuestros alumnos tengan una educación de calidad y que logren un aprendizaje significativo que les permita superar con éxito los problemas tanto en su formación académica como en su vida cotidiana.

Dr. José Luis Escamilla Reyes

SUMÁRIO

CAPÍTULO 1

LINEAR MOTION AND STATIC FRICTION COEFFICIENT USING HOTWHEELS TOYS

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ABSTRACT: This manuscript presents an automated and interactive STEM tool for estimating the average speed of a hotwheels car under the scheme of a non-uniform linear motion phenomenon, as well as to obtain the coefficient of static friction. The changing and sensing of the physical parameters of the experiment and the programming of the entire process, was carried out with a micro:bit, an expansion board and ultrasonic distance sensors; while the physical mounts for the cards and sensors were built using recycled MDF material and 3D printing. The educational resource is suitable to be applied in middle school, high school and first semesters of undergraduate levels in the field on Physics and Engineering.
KEYWORDS: Linear motion. Coefficient of static friction. STEM resource. Experiment.

MOVIMIENTO LINEAL Y COEFICIENTE DE FRICCIÓN ESTÁTICA USANDO JUGUETES HOTWHEELS

RESUMEN: Este manuscrito presenta una herramienta STEM automatizada e interactiva para estimar la velocidad promedio de un automóvil hotwheels bajo el esquema de un fenómeno de movimiento lineal no uniforme, así como para obtener el coeficiente de fricción estática. La modificación y sensado de los parámetros físicos del experimento, así como la programación de todo el proceso, se realizó con un micro:bit, una tarjeta de expansión y sensores de distancia ultrasónicos; mientras que los soportes físicos para las tarjetas y sensores se construyeron utilizando material MDF reciclado e impresión 3D. El recurso educativo es adecuado para ser aplicado en los niveles de secundaria, preparatoria y primeros semestres de licenciatura en el área de Física e Ingeniería.
PALABRAS CLAVE: Movimiento lineal. Coeficiente de fricción estática. Recurso STEM. Experimento.

1 INTRODUCTION

There are several interpretations around the pedagogical meaning of student’s interest, for instance: interest is the students’ psychological state which develops over time as the students interact with the environment

(Hindi and Renninger, 2006), a dynamic state that arises through an ongoing transaction among goals, context, and actions (Thoman et al., 2012). Interest is the predisposition of students to spend time on topics, concepts, ideas, or activities. It has been also found by researchers that the interest of students in any topic or course of study have positive influence on their learning process and contributes to the choice of subjects/courses and careers they make (Hulleman and Harackiewics, 2009).

In accordance with the aforementioned, STEM (Science, Technology, Engineering and Mathematics) based education is one of the options to develop skills and keep/promote interest of students. For instance, it enhances exploration and curiosity on students from all ages, by: showing real-world applications, incorporating hands-on learning, developing critical thinking, encouraging creativity and experimentation, fomenting independent exploration and also collaboration, acquiring an overview of future careers by giving people skills that make them more employable and ready to fulfill the labour requirements, among others.

So, STEM educational resources applied in Physics or Engineering laboratories substitute classical teaching-learning processes focusing on project-based learning and including technology to emphasize the application of science. Some differences (Widya et al., 2019) between traditional and STEM education can be seen in the following figure.

Figure 1. Most relevant differences between traditional and STEM education.

Traditional education	vs	STEM education
-Memorize information		-Understand information
-Passive learning		-Active learning
-Closed projects/experiments		-Open-ended projects/experiments
-Theoretical/Relevant to test		-Hands-on/Relevant to real world
-Teacher centered (one-way transfer of knowledge)		-Student focused (one-way transfer of knowledge)
-Pre-defined knowledge application		-Creative knowledge application
-Simple technology		Technology-enhanced
⋮		⋮

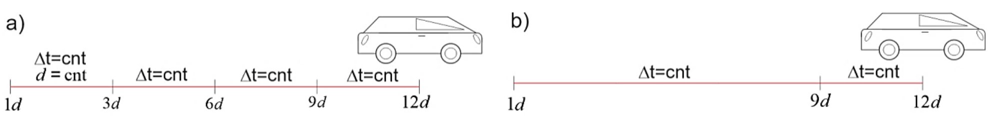
This proposal is based on the fact that the phenomenon of an object moving in linear motion (following a straight path) and its average speed are very common topics taught in Physics and Engineering middle school, high school, graduate and undergraduate courses. Also, sometimes they are covered by educators by following the traditional education methodology. In our day-to-day lives, linear motion and speed can be found in: the speedometer of a vehicle, a moving vehicle, the average speed while jogging, the speed of an sport ball and so on. Due to this, it is important to reinforce the comprehension and interest of this phenomenon through a laboratory experiment by using an interactive and low cost STEM educational resource as the one proposed in this manuscript (taking into account that in some cases, the cost of didactic and educational equipment (PASCO CI-6724A, INDOSAW SW471) is very high).

In addition, a brief qualitative demonstration of how friction affects the motion of a mobile is carried out by using sand paper of different textures over the track.

2 THEORETICAL FRAMEWORK

Rectilinear motion, also known as linear motion occurs when an object changes its position from one point to another by following a straight line in one dimension. There are two types in this motion: uniform linear motion (constant velocity, hence zero acceleration) and non-uniform linear motion (with variable velocity, hence non-zero acceleration). Figure 2a) shows a vehicle moving a constant distance d in constant time intervals $\Delta t = \text{cnt}$ (uniform linear motion, ulm). Figure 2b) shows a vehicle moving non-uniform distances in constant time intervals (non-uniform linear motion, nulm), so then presenting a variable velocity.

Figure 2. a) uniform linear motion and b) non-uniform linear motion.



The average speed (Zakariyah, 2014) is the total distance traveled for the object divided by the total elapsed time taken to travel that distance (the total period of time).

$$v_{avg} = \frac{d_2 - d_1}{t_2 - t_1} = \frac{\Delta d}{\Delta t}. \tag{2}$$

When an object increases its velocity in a period of time, this object experiments acceleration. On the other hand, if the velocity decreases in intervals of time, it experiments deceleration:

$$a = \frac{v_o - v_f}{t} \quad ; \quad a = \frac{v_o^2 - v_f^2}{2d}. \tag{3}$$

Where:

a =acceleration (desceleration if decreasing speed, $-a$)

v_o =initial velocity

v_f =final velocity

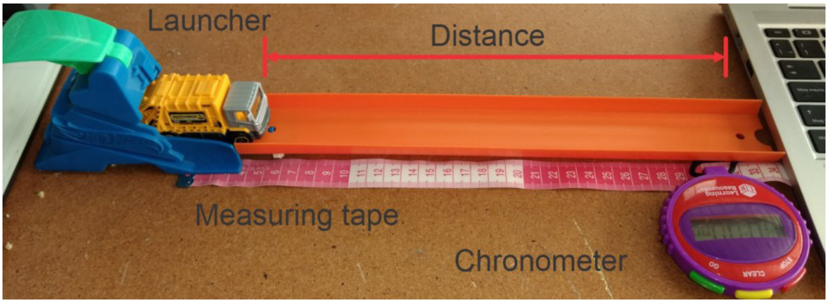
A force that goes against or resist the motion of one object over another is called friction force, F_f . So, friction acts in a direction opposite to its motion and slows it down. For a high coefficiente of friction there will be more friction. Hence, the resistance to the movement between two surfaces in contact is high. So then, the coefficiente of static friction (Xie et al., 2000) is the ratio between F_f and the normal force F_N

$$F_f = \mu_s F_N . \qquad (4)$$

3 METHODOLOGY

The present proposal calculates the instantaneous speed of a hotwheels car moving with linear motion over a straight track. Commonly, in classrooms or Physics laboratories it is accomplished by launching a toy car or a mobile object by hand or by using an external launcher. In which, the time and distance are measured with a chronometer and a measuring tape; respectively, as seen in Figure 3.

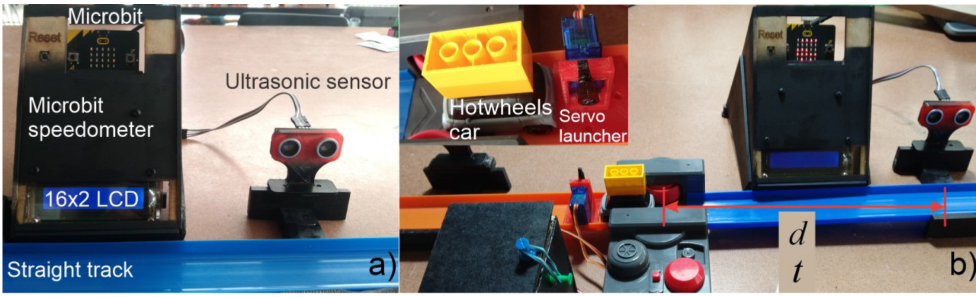
Figure 3. Common setup used to measure the speed of a mobile.



However, eventhough this a very simple methodology, it presents different error souces. For instance: it is hard to apply the same impluse for each experiment and, the initial and final time depend on the reaction of the user when using the chronometer. Therefore, different values regarding to the instantaneous speed would be obtained. In order to overcome the aforementioned drawbacks, the initial velocity of the car is given by a modified motorized car launcher controlled with a micro:bit board and an h-bridge motor driver (L298N).

The time in which the car passes thorugh an specific distance is determined by an ultrasonic sensor (HC-SR04). So, by using Eq. (2), the instant speed can be obtained and shown in a 16x2 LCD. The time is internally taken from another micro:bit, which is also used to compute the formulas and to store the data from each experiment in a file that could be exported in Excel, for instance. Figure 4 shows the sensor and the speed measurement unit (micro:bit speedometer).

Figure 4. a) Motor speed controller and a modified car launcher, b) Speed measurement unit conformed by a micro:bit, a micro:bit expansion board, a 16x2 LCD and an ultrasonic sensor.

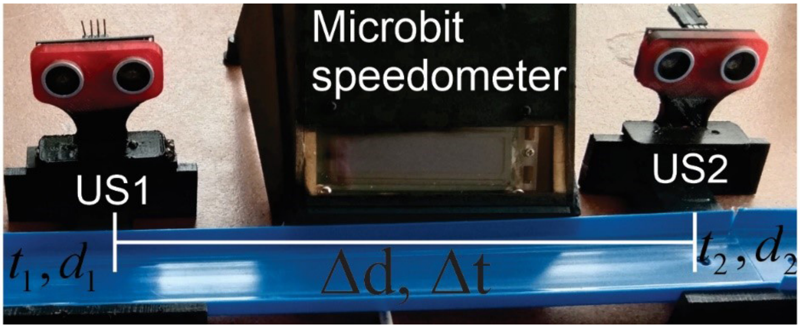


As mentioned in Eq.(2), the input variables needed to calculate the instant speed of a hotwheels car are: distance d and time t. The distance is given by the user before the experiment begins by continuosly pressing the "A" button in the microbit:board, and pressing "B" to start the experiment. Once the car is impulsed by the modified car launcher (with an initial impulse given by a servo motor, so the error generated by users manipulation can be eliminated), an internal time counter starts and will stop when the car passes in front of the ultrasonic sensor; calculating with this the instantaneous speed in that particular instant of time. Experimentally, the given input distance and the calculated instantaneous speed can be observed in the LCD.

Because the object loses speed with respect to time, it presents a decelerated movement, which obeys Eq. (3). A negative sign of the acceleration means a decelerated movement.

The average speed (v_{avg}) can be calculated with the experimental setup depicted in the previous Figure 5. The internal time in the board will start counting when the car passes through the first ultrasonic sensor US1 and will stop when it passes through US2; obtainig with this the variable t_1 and t_2, respectively. Before starting this experiment, the input distance from US1 to US2, Δd has to be previously given by the user.

Figure 5. The speed between two different points can be carried out under the following scheme.



3.1 COEFFICIENT OF FRICTION

Friction is a little more complex topic generally discussed in highschools and universities. However, this proposal deals with the coeficient of static friction with a simple modification of the experiment that is carried out by placing sand papers (or any other material) of different textures over the track; changing with this the value of μ_s as show in Figure 6.

Figure 6. a) Different sand paper for different values of coeficient of friction.

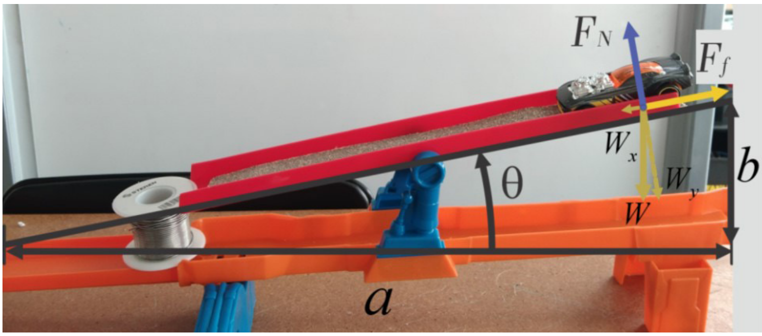
Even though the calculation of the coefficient of static friction (μ_s) is not the main objective of this educational resource, it can be easily estimated by measuring the angle (friction angle, $\theta = \theta_f$) at which an object begins to move over an incline plane

$$\mu_s \approx \tan \theta_f \approx \frac{b}{a} \,. \tag{5}$$

The object will reach the critical angle (friction angle) when it starts moving. This is because while increasing the inclination of the plane θ, the perpendicular component of the weight will decrease ($W_y = mg\cos\theta$, being m the mass of the object and g the acceleration due to gravity).

By making a small modification to the previously described experiment, θ_f can be estimated by inclining a straight track and measure the angle at the precise moment that the car starts moving (it worth mentioning that the wheels should be fixed or glued before the experiment). The student can also qualitatively prove the effect of changing the coefficient of μ_s and also calculate it by placing sand paper of different textures over the track. Figure 7 shows the forces acting on a hotwheels car and the experimental setup used to calculate θ_f and μ_s.

Figure 7. Experimental setup used to calculate the friction angle and the coefficiente of friction.

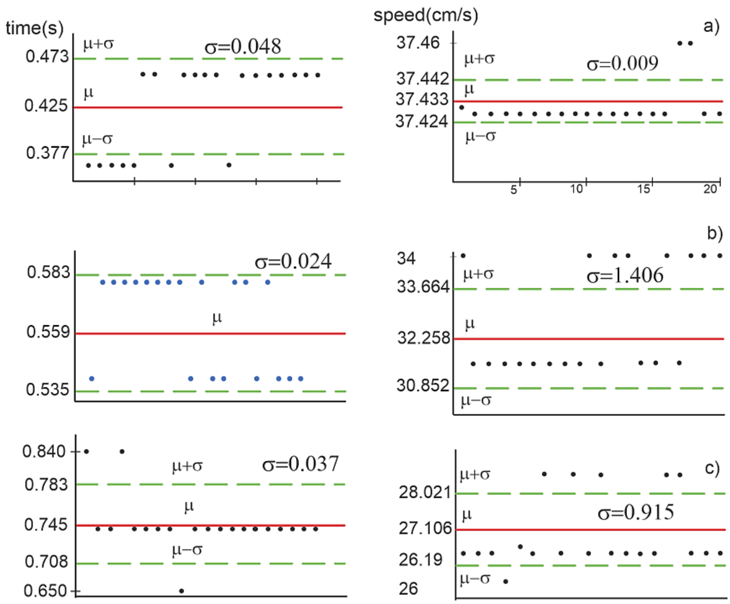


4 EXPERIMENTAL RESULTS

4.1 AVERAGE SPEED

The average (μ) and the average±standard deviation ($\mu \pm \sigma$) due to a maximum, medium and low speed, regarding to 20 experiments under equal experimental conditions, for a distance of 18 cm can be seen in Figure 8.

Figure 8. a) Time and instantaneous speed regarding to a a) maximum, b) medium and c) low speed.



As standard deviation is used to measure the spread of values in a sample, it will be used to calculate the coefficient of variation regarding to the population (Jalilibal et al., 2021) in order to measure how spread out values are relative to the mean.

$$CV = \frac{\sigma}{\mu} \,. \tag{6}$$

Table 1 depicts the calculated coefficient of variation regarding to the low, medium and high speed and time, respectively.

Table 1. Coeficient of variation regarding to the low, medium and high speed.

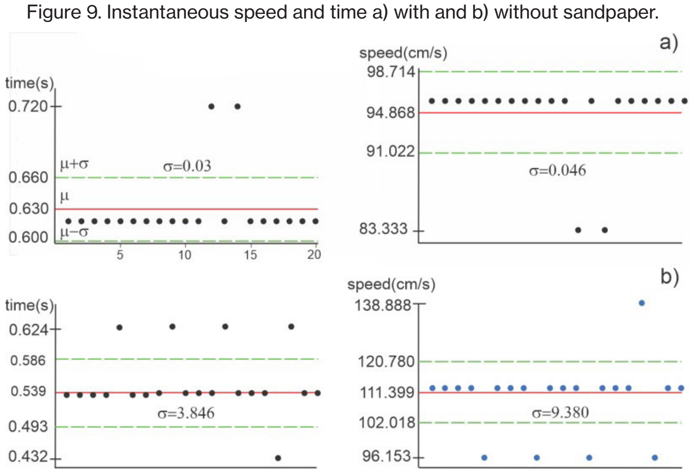
Speed (cm/s)			Time (s)		
Low speed	Medium speed	High speed	Low speed	Medium speed	High speed
μ=27.106	μ=32.258	μ=37.443	μ=0.745	μ=0.559	μ=0.425
σ=0.915	σ=1.406	σ=0.009	σ=0.037	σ=0.024	σ=0.048
CV=0.033	CV=0.043	CV=.0002	CV=0.049	CV=0.043	CV=0.113

A coefficient of variation of 5% (multiplying the CV by 100 to get the percentage) or less, denotes a good performance. So, the high speed presented a better performance. However, the medium and low have also relievable results.

4.2 AVERAGE SPEED WITH FRICTION

Figure 9 shows experimental results regarding to the speed and time of a hotwheels car traveling through a track with and without sand paper, respectively (d=54 cm). It can be observed that the speed diminishes by increasing friction between the surfaces.

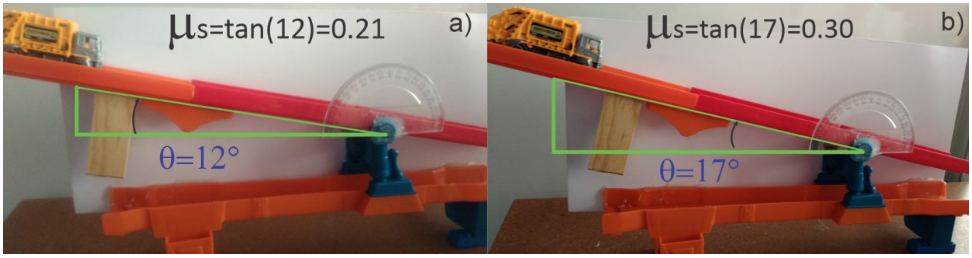
Figure 9. Instantaneous speed and time a) with and b) without sandpaper.



4.3 COEFFICIENT OF STATIC FRICTION

The following figure shows an example of how the coefficient of static friction between tires of a hotwheels car (remembering that the tires must be fixed) and a track could be calculated without a significant modification of the original setup.

Figure 9. Calculation of μ_s a) without and with masking tape over the track.



It can be observed that by covering the track with masking tape, θ_f increases and, in consequence μ_s. Materials with different rugosity can be added over the track in order to demostrate this effect. In a hands-on class implementation, it would be firstly recommended to calculate the coefficient of friction before launching the car in order to observe its effect over the speed.

5 CONCLUSIONS

It has been presented an interactive and low-cost open source STEM tool (which means that the code can be easily modified in order to accomplish different user needs) with the aim of easing the teaching-learning process regarding to the topic of linear motion and friction; focusing on the concept of instantaneous speed and coefficient of static friction, for middle, high school and even first semester of university.

The main advantages of this educational resource, relies on the fact that it is accomplishes the STEM methodology. Which, unlike other commercial educational resources, offers a low implementation cost and, by applying different areas of knowledge, students with diverse interests in scientific areas (physics, mathematics, programming, design, etc.) can be motivated to use and modify this tool, as well as to implement new resources for other physical phenomena.

Finally, it worth mentioning that the variations in the speed and time shown in Figures 8 and 9 are due to voltage variations from the source, which modifies the speed of the car launcher.

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CI-6742A Motion sensor II and ME-5708A Basic smart cart metal track 1.2m system (PASCO) [Apparatus and software] (available at: https://www.pasco.com/products/lab-apparatus/mechanics/dynamics-systems/me-5708).

SW471 Law of motion kit (INDOSAW) [Apparatus and software] (available at: https://www.inspirephysics.com/law-of-motion-kit/).

SOBRE O ORGANIZADOR

Dr. José Luis Escamilla Reyes- Profesor del Tecnológico de Monterrey, Campus Ciudad de México desde 1998. Doctor en Física por la Universidad Autónoma Metropolitana, Unidad Iztapalapa. Cuenta con una experiencia docente de 32 años. Es coautor de Manuales de Física II y Física III, así como de dos ebooks, uno sobre Física General y otro sobre Óptica y Física Moderna. Está certificado en el Programa de Desarrollo de Habilidades Docentes del Tecnológico de Monterrey. Ha participado con varios trabajos en Congresos Nacionales e Internacionales relacionados con la Física de Semiconductores de los grupos IV y III-V. Sus áreas de interés son: fuentes alternativas de energía, Física del Estado Sólido, diseño y aplicaciones de los MEMS y modelación matemática de Sistemas Complejos. Ha publicado más de 15 trabajos arbitrados y memorias en congresos. Colaboró en el diseño y construcción de láseres pulsados de N2 en el Laboratorio de Óptica Cuántica de la Universidad Autónoma Metropolitana Iztapalapa (UAMI). En el Tecnológico de Monterrey Campus Ciudad de México, participó en el desarrollo de un prototipo de Celda de Combustible con membrana de intercambio protónico (PEMFC) de alta eficiencia. Obtuvo la Medalla al Mérito Académico por el mejor promedio de Maestría otorgada por la UAMI. Fue líder de la Cátedra de Investigación "Micro Sistemas Electromecánicos: Diseño y aplicaciones" del Tecnológico de Monterrey, Campus Ciudad de México y miembro del SNI.

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