ISSN 1870-4069

Kinematics Learning in Engineering Students through Low-Cost Prototypes and 3d Printing

Fidel Córdoba-Valdés, Carlos Daniel Ramírez-Hernández, Daniel Sánchez-Guzmán, Juan Carlos Martínez-Espinoza

Instituto Politécnico Nacional,
UPIIG. Silao de la Victoria Guanajuato,
Mexico

dsanchez@ipn.mx

Abstract. Derived from the reincorporation to activities in person after the confinement situation caused by the SARS-COV-2 virus (COVID-19), an important challenge is to resume learning physical concepts for the training of engineers at the national as international. However, considerable progress has been made in learning through online platforms, and using various software based tools, for example, simulations, virtual reality, augmented reality, virtual laboratories and remote laboratories. The return to a face to face scheme implies new challenges that partially implement technological tools, both in virtualand face to face models, establishing effective hybrid learning. Together, 3D printing has led to an increase in its use and application for the learning process at different educational levels, the foregoing derived from its low cost and easy acquisition. The present work is the proposal for the design of a prototype basedon 3D printing to be adapted in Physics laboratory material, which tends to be obsolete over time, and with the aim of promoting engineering students to learn concepts of physics. Kinematics and Dynamics. It consists of a set of sensors and actuators so that students can carry out experiments physically, but with thesupport of the prototype to carry out measurements in a semiautomatic way. Currently, there is a prototype proposal and an application proposal in a real scenario in a physics laboratory with new students entering an engineering academic program.

Keywords: Kinematics learning, engineering students, 3D printed low cost prototypes.

1 Introduction

The pandemic caused by the SARS-CoV-2 virus (COVID-19) meant a radical change in society in general, because of confinement in most countries worldwide. A social activity, such as education, underwent a revolutionary change, which caused a resonance effect, starting from a total uncertainty in the way that the educational process would be resumed at the beginning of the confinement until the adaptation of the online educational process of most of the academic community, students, teachers, and administrators.

Although students are considered as digital natives for handling electronic devices, such as smartphones, tablets, laptops, etc., this does not mean that they will naturally adapt to the change in the educational model, the foregoing derived from the fact that students learning processes that led prior to confinement were face to face and with direct expository approaches.

During the process of adaptation to a virtual model by students and teachers, all kinds of digital and technological tools were experienced that led to their adoption or rejection to be implemented within the different educational processes. Thus, digital, and technological tools, such as virtual reality, augmented reality, reproducible or interactive simulations, online exams, virtual reality glasses, remote controls for re mote laboratories, 3D printing of Physical and Chemical models, etc.

They were incorporated to be applied and demonstrate concepts that were necessary for continuity in learning at different educational levels. UNESCO [1], through the Commission for the Future of Education, presented a report presenting nine ideas for the adaptation of educational processes in a post-COVID-19 era. These ideas in general are:

1. **Commitment to strengthen education as a common good.** Consider the educational process as a development process for society, collectively and individually.
2. **Extend the concept and definition of the Right to Education.** Not only in the field of access as a service but with the right to have the digital resources to be able to be connected.
3. **Value the profession and teaching collaboration.** It is worth noting the extraordinary adaptation that occurred in the teaching communities, both individually and collectively.
4. **Promote the exercise of their rights in youth, students, and children.** A fundamental part of intergenerational relations and democratic principles.
5. **Protect social spaces inside schools.** Not only return to the concept of physical space but also the different school settings that can be developed.
6. **Generate educational technological resources, free and open for teachers and students.** Education is no longer just the face to face and expository process, but sharing knowledge and technology developed to promote meaningful and high impact learning using technological resources.
7. **Ensure scientific literature within the curricula.** With the confinement situation, the prevailing need arose for scientific and well-founded explanations to help society understand what was happening, hence the need to include more scientific content in basic to professional training programs.
8. **Protection of local and international economic resources to ensure the operation of education.** During the pandemic it became evident that the lack of financing for education led to a delay in educational systems, in some cases it is considered a setback in decades, which affected all educational systems. These resources are required to be secured by local governments and international associations to continue the development of society in general.

9. **Advance global solidarity to end current levels of inequality.** COVID-19, evidenced the inequalities and inequities that exist within society, it is the responsibility of governments and non-governmental organizations to support development to achieve greater equity and less inequality for people who suffer from these vulnerabilities.

Starting from these proposed ideas, this research work is framed in ideas 1, 5, 6 and 7. Since through the physical spaces the learning process will be ensured in person; With the development and use of technology at low cost, such as the use of 3D printed prototypes, almost universal technological tools can be promoted and the learning of Physical concepts in students of different levels, allows the vision of what happens around students is something that requires an analysis and reflection regarding the world that surrounds them.

Electronic systems for several decades have been afundamental part in simplifying tasks that mainly involve a longer execution time. Recently, the incorporation of compact embedded systems and 3D printing designs have led the way in the implementation of low-cost prototypes with aesthetic and functional designs for different applications in various areas of knowledge [2-4].

A particular situation for this research work was that the basic science laboratories, specifically Physics, did not have an update on the Education 4.0 approach or under the requirements of the STEM model (Science, Technology, Engineering and Mathematics), for its acronym in English), promoting technological obsolescence, to mitigate this situation, the design of a prototype was carried out that can be adjusted to the material available and that allows the manipulation and operation of low-cost laboratory devices and with a STEAM or Education 4.0 approach.

Taking into account the scenario presented in this research work, it was possible to identify that there are similar scenarios and similar contexts that allow the proposed action to be implemented in similar scenarios.

1.1 Research Objectives

General Objective

Design, develop and implement a low-cost and 3D-printed prototype to measure time on a laboratory rail, to propose a didactic sequence with an Education 4.0 approach, which efficiently promotes the learning of concepts in Kinematics and Dynamics. in laboratory practices for engineering and science students.

Specific Objectives

1. Design the prototype that will be printed in 3D, both the electronics, the mechanical systems, and the adjustment to a laboratory rail in Physics.
2. Develop and implement the prototype in the testing phase to validate that the adjustment to the rail and the sensors are making the corresponding measurements and calibrations.
3. Propose a didactic sequence that involves the use of the prototype developed to encourage students, newly admitted to an engineering program, to learn concepts in Kinematics and Dynamics.

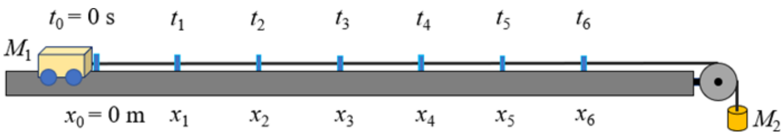

Fig. 1. The experimental set up is shown. The car started at 1 mm just before the optical sensor, located atx0 = 0 detected it, then a signal was sent to a display. A second sensor was located at different distances. The separations between xi and xi+1 is 10 cm for i from 0 to 5.

2 Methods and Techniques

2.1 Design and 3D Printing of the Molds and Electronic Measuring System

The design of each piece of the proposed system was created using Solid works vx.0 software and transformed into a coordinate system for 3D printing (STL, Stereolithography). For 3D printing, a 1.75 mm PLA filament supplied to a Flashforge finder printer was used under an operating temperature of 210 ºC. For the electronic detection system, two reflective optical sensor modules were used, compatible with the embedded Arduino nano system based on the ATmega328P microcontroller. The readings were shown through a 16x2 LCD display.

2.2 Prototype Testing

In Fig. 1. the experimental setup is shown. A M1 = 50 g car was accelerated from rest by a hanging mass of M2 = 20 g, both were connected by a thread of negligible mass. The starting point corresponds to x0 = 0 m where a fixed optical sensor was located.

The car started its movement approximately 1 mm just before the sensor detected it, hence we expected a zero-initial velocity. When the car passed in front of the second optical sensor, located at x1 = 10 cm, the time was read from the display. To analyze the variation among several measurements we repeated the experiment 100 times, obtaining the data set shown in table 1 and its corresponding histogram in fig. 2.

Considering ideal conditions, a movement with constant accelerations is expected. To find out a relationship between position and time, we placed the second optical sensor at positions ranging from x_2 to x_6 which are separated by 10 cm between two successive points. For these positions only 30 measurements were carried out as well as the mean time for every position and its standard deviation were calculated. Fig. 3 shows the car's position as function of time where error bars are defined by the standard deviation of the measurements.

A polynomial function of order 2 was fitted to the data as shown in Fig. 3. As we can see, there is a good agreement between experimental results and theoretical approach given by the kinematic equation for constant acceleration [5]:

$$x = \frac{1}{2}at^2 + v_0 t + x_0. \quad (1)$$

able 1. The frequency for 100 measurements. The mean value is 0.293 s with standard deviation of 0.013 s. display is required.

***t*(s)**	**Frequency**
0.27	5
0.28	24
0.29	35
0.30	20
0.31	6
0.32	10

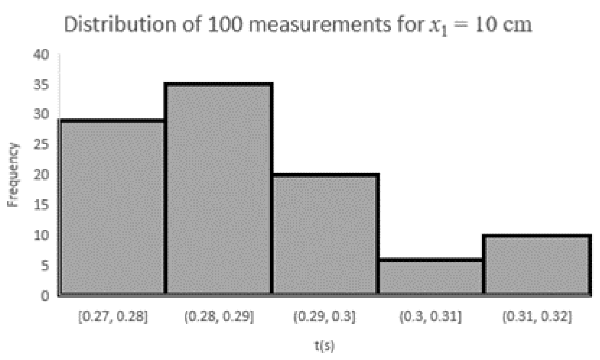

Fig. 2. The distribution of the measurements. A normal distribution is expected, however a better precision in the where g = 9.81 m/s2 is the magnitude of the acceleration due to the gravity. If we plug into equation (2) the values of the masses, we get that the acceleration should be a =2.80 m/s2.

Which compared to the numerical fit we conclude that in our experiment there was an average initial position x_0 = 3.2 mm, an initial velocity v_0 = 0.0224 m/s and a constant acceleration a = 2.18 m/s^2. These values for the initial position and the initial velocity come from the fact that the car was located at a small distance before the firstoptical sensor. On the other hand, considering ideal conditions like neglecting the effects of friction and the weight of the pulley, the accelerations can be calculated by applying the second Newton law, which lead us to:

$$a = \frac{M_2}{M_1+M_2} g, \quad (2)$$

where g = 9.81 m/s^2 is the magnitude of the acceleration due to the gravity. If we plug into equation (2) the values of the masses, we get that the acceleration should be a =2.80 m/s^2. This means that in our experiment we underestimated the acceleration roughly 22% below the ideal situation.

More measurements, varying the masses and distances, would let us conclude whether this difference comes uniquely due to factors like friction, discarding the possibility of malfunction of the prototype.

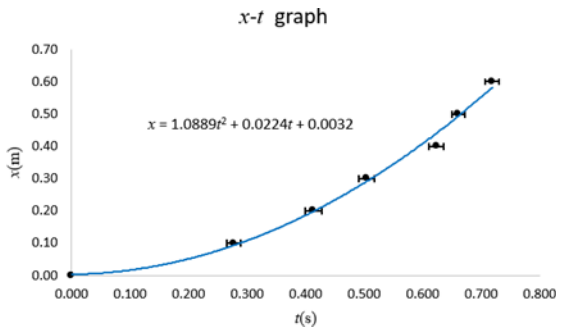

Fig. 3. x-t graph. Dots represent the experimental data. The size of error bars corresponds to the standard deviation for every set of measurements. Solid line represents a polynomial fit of order 2, also the equation obtained from the numerical fit is shown.

2.3 Didactic Sequence Design Proposal for Learning Kinematics and Dynamics

Starting from the developed and manufactured prototype, it can be taken as an element within the learning process for carrying out laboratory practices in Physics subjects, the didactic sequence proposed for the use of the developed prototype wouldbe:

1. Application of pre-test [6, 7] or evaluation instrument that identifies the previous ideas of the students in relation to the concepts of Kinematics, Dynamics, generation, and interpretation of graphs that relate different variables within a physical system.
2. Assembly of the prototype developed based on a laboratory practice reconditioned with the use of the proposed system.
3. Feedback from the teacher regarding the values that must be measured and give continuity to the laboratory practice.
4. Development of the practice by the students with the accompaniment by the teacher or teachers who participate in the learning activity.
5. Application of the post-test or data collection instrument to quantitatively measure the understanding of the concepts addressed within the practice.
6. Application of the corresponding statistics to evaluate the Normalized Conceptual Gain and the Concentration Factor.

3 Conclusions

Derived from the new approaches that must be considered, based on the training of students at the engineering level, from the perspective of Education 4.0 and the STEM model, it can be concluded that this type of development contributes to the training and learning processes in incoming students at the level of an engineering program. The proposal is in accordance with the ideas formulated by UNESCO for the adaptation of educational systems and models in a post-pandemic scenario.

References

1. UNESCO. Education in a Post-COVID World: nine ideas for public action. UNESCO (2019)
2. Axtmann, C., Boxriker, M., Braun, M.: A custom, high-performance real time measurement and control system for arbitrary power electronic systems in academic research and education. In: 2016 18th European Conference on Power Electronics and Applications, EPE'16 ECCE Europe, pp. 1–7 (2016)
3. Takács, G., Gulan, M., Bavlna, J., Köplinger, R., Kováč, M., Mikuláš, E., Salíni, R.: HeatShield: a low-cost didactic device for control education simulating 3D printer heater blocks. In: 2019 IEEE Global Engineering Education Conference (EDUCON), pp. 374–383 (2019) doi: 10.1109/EDUCON.2019.8725201
4. Rua-Ramirez, E. B., Jimenez-Diaz, F., Gutierrez-Arias, G. A., Villamizar, N. I.: 3D Printing as a didactic tool for teaching some engineering and design concepts. Producción Editorial Universidad Distrital Francisco José de Caldas (2018) doi: 10.14483/23448393.12248
5. Halliday, D., Resnick, R., Walker, J.: Fundamental of physics. 10th Edition, Wiley and Sons, New York (1988)
6. Zavala, G., Tejeda, S., Barniol, P., Beichner, R. J.: Modifying the test of undertstanding graphs in kinematics. Physical Review Physics Education Research, vol. 13, no. 2, pp. 020111 (2017) doi: 10.1103/PhysRev PhysEducRes.13.020111
7. Thornton, R., Sokoloff, D.: Am. J. Phys., vol. 66, no. 4, pp. 338 (1998)