P-ISSN: 1693-1246
E-ISSN: 2355-3812
December 2023

Jurnal Pendidikan Fisika Indonesia 19 (2) (2023) 101-107
DOI: 10.15294/jpfi.v19i2.41802

http://journal.unnes.ac.id/nju/index.php/jpfi

Analyzing The Coin Demonstration of The Framework of Newton's Second Law

H. A. Küçüközer*, H. Küçüközer

Balikesir University, Turkey
*Corresponding author: kucuk@balikesir.edu.tr

Received: 06 September 2023. Accepted: 10 November 2023. Published: 31 December 2023.

Abstract

The study aim to show that some of the examples used in teaching Newton's First Law in textbooks, academic studies, and platforms such as YouTube are in fact examples that comply with Newton's Second Law. For this purpose, in the physics course, an easy-to-make "coin demonstration" from these examples was chosen. To get the data, a video of the demonstration was shot in slow-motion mode with a mobile phone. This recording was transferred to a video analysis program called Tracker and then the movement of the coin was analyzed in this program. First, the information about the coordinate planes, length, and mass required for the analysis was entered the program. Then, the position, velocity, and acceleration-time graphs of the object (coin) tracked in the uploaded video were obtained in detail. The result obtained from these analyzes is that the coin moves with acceleration. Based on this result, this study suggests that the coin example and similar examples are in accordance with Newton's Second Law and that this should be especially considered in textbooks, academic studies, and on platforms such as YouTube.

Keywords: coin demonstration, Newton's laws, physics education, tracker program.

INTRODUCTION

Reviewing the related literature, a considerable number of studies are found on students' conceptions in Newtonian mechanics. The main results of these empirical investigations of teaching and learning in mechanics were that students have many misconceptions and few changes in conceptual understanding appear after teaching (Fadaei & Mora, 2015; Bulunuz & Bulunuz, 2016; Ergin, 2016; Liu & Fang, 2016; Wood, Galloway, & Hardy, 2016; Atasoy & Ergin, 2017; Bani-Salameh, 2017; Khandagale, & Chavan, 2017; Handhika, Cari, & Suparmi, 2017; Roemmele & Sederberg, 2017; Erfan & Ratu, 2018; Nie et al., 2019; Topalsan, & Bayram, 2019; Lei & Fritchman, 2021; Asakle & Barak, 2022; Baring & Berame, 2022). On the other hand, in this study, it has been shown by using the tracker program that the coin representation (and similar examples) used in many studies in teaching Newton's First Law are not suitable examples for the first law. Unlike previous studies, it is thought that some misunderstandings will be overcome with this study, which focuses on a specific situation.

To make Newton's First Law easy to be understood, there are some examples that many physics teachers use in their lessons. These are: in the system consisting of a card and coin standing on a glass when the card is hit quickly, the coin falls into the glass; in a system consisting of dishes and glasses on the cloth, the dishes and glasses remain on the table by rapidly pulling the cloth; and when the bus brakes or accelerates, it moves forward and backward, etc. (Riendeau, 2011; Antwi, 2015; Bulunuz & Bulunuz, 2016; Roemmele & Sederberg, 2017). These examples are frequently used in many textbooks and platforms such as YouTube. Physics teacher candidates mostly mention these three examples in the lessons for the teaching of Newton's First Law. According to the first law, the physics teacher candidates in these examples state that since the net force acting on the coin is zero, it maintains its position and while the card moves, the coin stays where it is and falls into the glass. Similar explanations are provided for other examples. Such explanations are also found in some Physics textbooks (Hsu, 2004; Hewit, 2010; Giancoli, 2014; Young & Freedman, 2016).

In Hewitt's book, the unit on Newton's First Law includes the three examples mentioned above, while Hsu (2011) and Young and Freedman (2016) use the tablecloth and the bus example, Giancoli (2014) only uses the bus example. Although not directly, when these examples are always in the section of Newton's First Law, students and teachers naturally use these examples assuming that they are in accordance with the first law. For example, in Hewitt's book on Newton's First Law, these examples are often given in the form of questions: In the coin example, "Why will be coin drop into the glass when a force accelerates the card?", in the dishes and glasses example, "Inertia in action" and the bus example "Why do you lurch forward in a bus that suddenly slows? Why do you lurch backward when it gains speeds? What law applies here?" Like the tablecloth and the bus examples, Giancoli (2014) and Young and Freedman (2016) are also included in the section of the first law. There are studies in which the first law is taught using such examples (Roberson et al., 2004; Riendeau, 2011; Antwi, 2015; Bulunuz & Bulunuz, 2016; Roemmele & Sederberg, 2017). In these studies, it is stated that the examples used in teaching make positive contributions to students' conceptual understanding.

Can the examples given above be explained by Newton's First Law? The statements made by Jones (1977) years ago about "the tablecloth demonstration" may guide us in this way: "Although often considered an example of Newton's First Law, the demonstration of the tablecloth pull is actually an excellent illustration of Newton's Second Law". In the context of this explanation, the situation is the same in the examples of coins and buses, such as the tablecloth demonstration, in other words, they are examples of Newton's Second Law. Using Newton's Second Law, Jones (1977) calculated the total displacement of a dish on the tablecloth because of accelerated motion:

$$d = \frac{1}{2}\, k_1 g t^2 (1 + \frac{k_1}{k_2})$$

Jones (1977) gave this equation directly in his study but did not specify how the equation was obtained. For the derivation of the equation, you may look at the study of Vollmer and Mollmann (2015). In this equation, "d" is the total displacement of the dish, "g" is the acceleration of gravity, "k_1" is the friction coefficient between the tablecloth and the dish and k_2 is the friction coefficient between the dish and the table). If any of k_1, t, and g is zero, d will be zero, and if k_2 is zero, the dish will never stop after it starts moving (Jones, 1977). This explanation contains the necessary conditions for the tablecloth demonstration to pursue Newton's First Law. In research by Vollmer and Mollmann (2015), analyzed the tablecloth sample with recordings taken using a high-speed camera within the framework of Jones (1977)'s total displacement relation given above. As a result, they calculated the coefficient of sliding friction coefficients in each case using different materials and showed how the total displacement increased over time with the measurements they took.

This study aim to show that some of the examples used in teaching Newton's First Law in textbooks, academic studies, and platforms such as YouTube are in fact the examples that comply with Newton's Second Law. The following are the actions taken to achieve this goal; "Coin demonstration" was recorded in slow motion mode using a smartphone. This recording was transferred to the Tracker program. Only the parts of the recording where the coin moves were selected. The movement of the coin was analyzed in the Tracker program (First, the information about the coordinate planes, length, and mass required for the analysis was entered into the program. Then, the position, the velocity, and the acceleration-time graphs of the object (coin) tracked in the uploaded video were obtained in detail). The results of the analysis were visually shared and interpreted (proving that the coin moves with acceleration).

METHOD

During an in-service training with a group of five physics teachers, they were asked what kind of examples they used when teaching about Newton's First Law. The examples they usually gave were the examples mentioned in the introduction. They stated that these examples are also available in textbooks and on YouTube. Most of the teachers also stated that they used the coin demonstration in the classroom. When it was pointed out that these examples were not appropriate examples for the first law, they had difficulty in understanding this situation. This was the starting point of the study.

The study is an instructional resource and is suitable for high school and university levels. In this context, it is thought that a misunderstanding about Newton's First Law will be overcome through the example presented in this study. Physics teachers can easily use the slow-motion video recording of the coin demonstration and the analysis in the tracker program in their classrooms.

Although the study of Vollmer and Mollmann (2015) was effective in analyzing motion, the high-speed cameras they used are not easy for everyone to procure. It is possible to analyze these and similar examples using a mobile phone and an analysis program. This study aims to analyze the "coin demonstration", which can be done easily in the classroom, by using a mobile phone and tracker program.

To simply show that the examples given for Newton's First Law comply with the Newton's Second Law and to overcoming of misunderstanding, this study, discussed the example of the coin, which is easy to make and interesting, which is widely available on YouTube, books, and papers. For this demonstration, a video was recorded in slow motion mode using an iPhone 7 Plus mobile phone (See Figure 1 and video, link https://drive.google.com/file/d/17FWfhupRNyoWYkAEo5OeY2VVLXz_nJmC/view?usp=sharing). This video shows the movement of a coin on a card placed on a glass after a sudden hit to the card. The pink lines in Figure 1 represent the x and y coordinates determined in the Tracker. When looking at Figure 1 and the video, it is seen that the coin does not rest in its position but moves in the positive x direction on the card, and after the card slides completely over the glass, the coin falls into the glass. As mentioned in the introduction, this example given during teaching indicates that the coin should fall directly into the glass. However, before it falls, it moves acceleratively to the right as shown in Figure 1. The focus of the study is to focus on the movement of the coin from the moment it hits the paper until the moment it falls into the glass and to show that it moves with acceleration during this time.

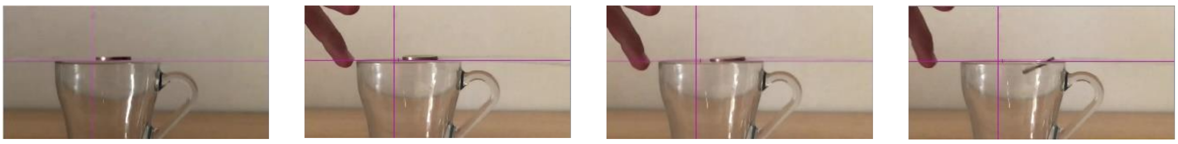


Figure 1. The rightward accelerated movement of the coin just before and after hitting the card, from left to right in the figures.

The analysis of the movement of the coin in this slow-motion recording was carried out using the free tracker program, which was designed for teaching physics and where videos/images can be easily analyzed.

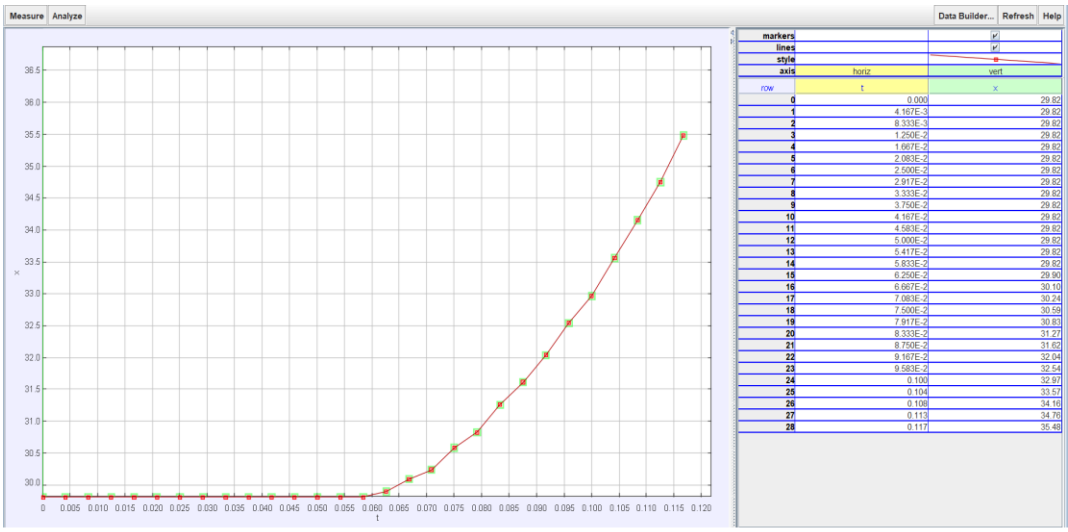
To analyze the recorded video, some data related to the experiment must first be entered into the program. For this purpose, the values for the mass and length of the coin used in the video were determined and entered in the program. In addition, to perform time-dependent analysis, the fps value of the video was learned from the slow-motion features of the mobile phone and entered the Tracker program. The mass of 1 Turkish lira, which was used in the demonstration, was 8.30 g, the diameter was 26.15 mm, and the fps value of the slow-motion video was 240. Then, the x and y coordinate planes of the video were determined, and the analysis phase started. For the analysis of the motion, the coin was first defined as a 'point mass' in the Tracker program. The analysis was performed by marking the positions of the coin in each frame of the video. The position-time, acceleration-time, and velocity-time graphs of the point mass (mass A) on the horizontal axis were plotted to analyze the motion in detail.

RESULTS AND DISCUSSION

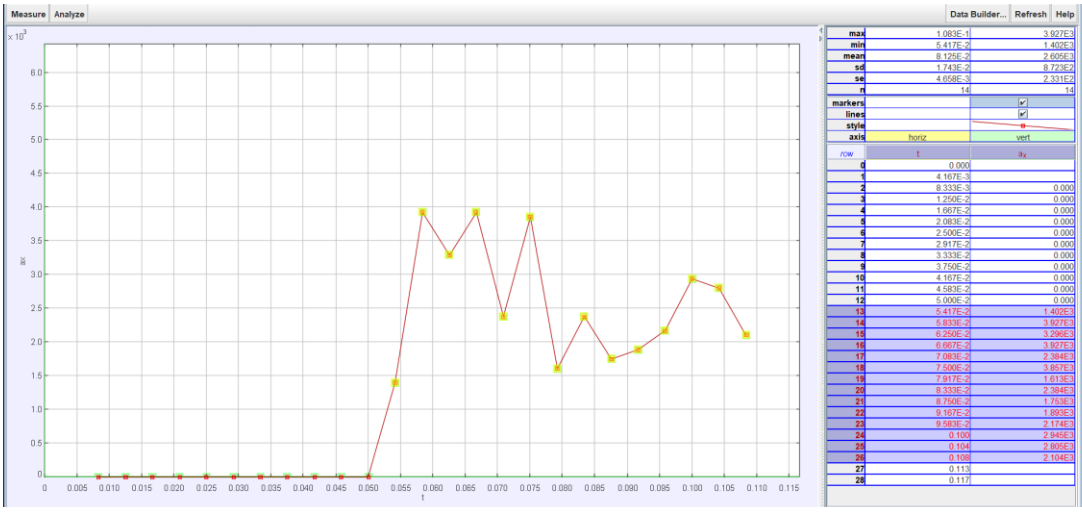
It has been seen that the coin demonstration, which is used as an example of Newton's First Law in the slow-motion video recording, obeys the second law, not the first law. Because the coin does not remain where it is after the card moves and thus it moves with acceleration on the card ($F_{friction} = m_{coin}\ a$).

In addition, the screenshot of the analysis of the slow-motion recording using the Tracker program is shown in Figure 2 (a-b-c). These three graphs were selected from the graph types automatically generated by the program for the purpose of our study. The program offers 25 preferences for the graphs and the table. The x-axis position-time/acceleration-time/velocity-time graphs regarding the movement of the coin after hitting the card are seen in Figure 2 (a-b-c). As displayed in these three graphs, the coin moves with acceleration after hitting the card. As it is visible in the acceleration-time graph, the acceleration value is not constant but changes slightly throughout the motion. When hitting the card, the coin can bounce slightly on the card when there is not a perfectly balanced hit. Due to this jump during the movement, the acceleration value of the coin may differ. Upon noticing this situation in many of the tests, seen that when hit the card a little slowly and from the middle, it made the least jump movement and the acceleration value changed very little throughout the movement.

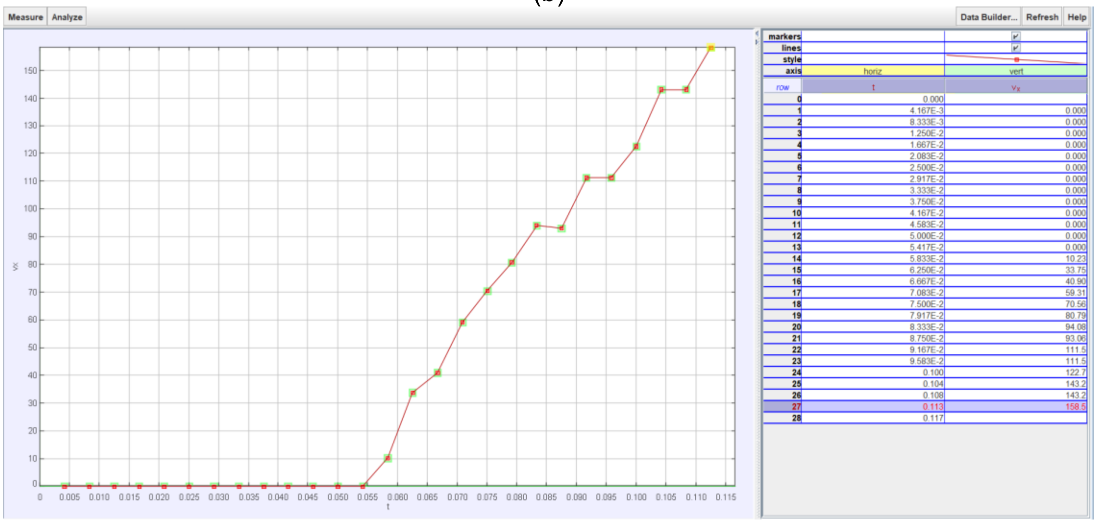
When Figure 2 (a-b-c) is examined, it is seen that the coin makes accelerated movement. The acceleration-time graph (Figure 2-b) shows that the acceleration value changes slightly with time throughout the motion. The data in the Data Tool tab (Analyze-Statistics) of the acceleration-time graph obtained from the Tracker program can be used for calculation. The average acceleration value obtained by this method is a_{avg} = (0.261 ± 0.023) x10^4 mm/s^2. It can be seen in Figure 2-b at the mean and standard error (se) lines.



(a)



(b)



(c)

Figure 2. Analysis of the coin demonstration video with the tracker program

The slow-motion videos presented in this study and the analysis made in the tracker program were enough to convince the group of 20 teachers. All of them accepted that the coin and other examples were related to the second law and that they would use them in their lessons.

These examples are the cases that include Newton's Second Law, not Newton's First Law because the net force acting on the objects is not zero. For example, when the card is hit, there is frictional force acting on the coin. Due to this friction force, the coin moves according to the second law. If these examples are to comply with the first law, as stated by Jones (1977), the friction coefficient and therefore the friction force between the objects must be zero. If the friction force between the objects is zero, the card, cloth, and bus will move with acceleration, while the coin, dishes/glasses, and passengers will remain in their positions. In these examples, due to the friction force, the objects will move in the direction of the force with acceleration proportional to the magnitude of the friction force. While the acceleration that coin, dishes/glasses, and passengers have a limit value due to the frictional force acting on them (Jones, 1977). As a result, in the demonstration, when hitting the card with a very large force, the card moves with great acceleration, but because the acceleration of the coin depends on the friction.

Coefficient between the two surfaces, it cannot exceed a certain limit value. While the card moves with a large acceleration, the coin moves with a small acceleration compared to the card, but since the event takes place in a very short time, it is perceived as if the coin is motionless relative to the card. For this reason, students and teachers may misunderstand this event.

In the video and analyses made with the tracker program, it can clearly be seen that the coin does not rest in its position after hitting the cardboard, but moves with $(2.6 \pm 0.2) \times 10^3$ mm/s^2 acceleration in the positive x-direction. In this case, it can be said that this and similar examples are not suitable to be used to teach Newton's First Law because objects move with acceleration. The coin and other examples will help both students and physics teachers to understand that they are about the second law, not the first law. In these examples, the net force acting on the objects is not zero and therefore the objects move with acceleration. As simply shown in this study, the coin does not rest on the card but moves with acceleration to the right. Therefore, such examples are not suitable for the first law. It would be appropriate to explain these examples using Newton's Second Law or its derivative, the impulse-momentum theorem (Jones, 1977; Simaneck, 2022).

CONCLUSION

Based on the results from this study, Newton's First Law should be taught mostly with thought experiments or simulations where the friction force is assumed to be zero. If coin and similar examples are to be used, it would be more plausible to use these examples where the second law is taught. Otherwise, associating the examples with the first law will also cause misunderstandings. Although the explanation of the motion of objects in such demonstrations is mostly explained by inertia due to the neglect of friction in the pre-high school period it is important to reveal that the object is not actually at rest, by knowing the concepts of friction and acceleration in high school and later. Therefore, it would be more useful to reveal that such demonstrations could be explained by the second law instead of the first law in high school and later periods.

REFERENCES

Antwi, V. (2015). Using Real-Life Activities in an Interactive Engagement Manner in the Teaching and Learning of Newton's First Law of Motion in a Ghanaian University. *Journal of Education and Practice*, 6(12), 48-58.

Asakle, S., & Barak, M. (2022). Location-Based Learning and Its Effect on Students' Understanding of Newton's Laws of Motion. *Journal of Science Education and Technology*, 31(2), 403–413.

Atasoy, Ş., & Ergin, S. (2017). The effect of concept cartoon-embedded worksheets on grade 9 students' conceptual understanding of Newton's Laws of Motion. *Research in Science & Technological Education*, 35(1), 58-73.

Bani-Salameh, H.N. (2017). How persistent are the misconceptions about force and motion held by college students?. *Physics Education,* 52(1), 1-7.

Baring, J.J.A., & Berame, J. S. (2022). Supporting Conceptual Comprehension of Newton's Laws of Motion of Grade 8 Students through Kotobee Interactive E-Module. *Indonesian Journal on Learning and Advanced Education*, 4(3), 209-232.

Topalsan, A.K., & Bayram, H. (2019). Identifying Prospective Primary School Teachers' Ontologically Categorized Misconceptions on the Topic of "Force and Motion". *Journal of Turkish Science Education,* 16(1), 85-109.

Bulunuz, M., & Bulunuz, N. (2016). Using Formative Assessment Probes to Evaluate the Teaching of Inertia in a High School Physics Classroom. *The Journal of Inquiry-Based Activities*, 6(2), 50-62.

Erfan, M. & Ratu, T. (2018). Analysis of student difficulties in understanding the concept of Newton's Law of Motion. *Jurnal Ilmu Pendidikan Fisika*, 3(1), 1-4.

Ergin, S. (2016). The Effect of Group Work on Misconceptions of 9th Grade Students about Newton's Laws. *Journal of Education and Training Studies,* 4(6), 127-136.

Fadaei, A.S., & Mora, C. (2015). An Investigation About Misconceptions in Force and Motion in High School. *US-China Education Review A*, 5(1), 38-45.

Giancoli, D. C. (2014). *Physics: principles with applications*. 7th edition, New York, Pearson Education.

Handhika, J., Cari, C., & Suparmi, A. (2017). Students' representation about Newton law: consequences of "zero intuition". *Journal of Physics: Conference Series, International Conference on Science and Applied Science (Engineering and*

Educational Science). 795. 1-4. 012057

Hewitt, P. G. (2010). *Conceptual physics*. 11th edition, San Francisco, Pearson Education.

Hsu, T. C. (2011). Foundation of Physics. Second edition, Peabody, Massachusetts, CPO Science.

Jones, E. (1977). The tablecloth pull. *The Physics Teacher*, 15(4), 242.

Khandagale, V. S., & Chavan, R. (2017). Identification of Misconceptions for Gravity, Motion and Inertia among Secondary School Students. *Aayushi International Interdisciplinary Research Journal*, 4(11), 197-205.

Lei, B., & Fritchman, J.C. (2021). Knowledge Integration in Student Learning of Newton's Third Law: Addressing the Action-Reaction Language and the Implied Causality. *Physical Review Physics Education Research*, 17, 1-22.

Liu, G., & Fang, N. (2016). Student misconceptions about force and acceleration in physics and engineering mechanics education. *International Journal of Engineering Education*, 32(1), 19-29.

Nie, Y., Xiao, Y., Fritchman, J.C., Liu, Q., Han, J., Xiong, J., & Bao, L. (2019). Teaching towards knowledge integration in learning force and motion. *International Journal of Science Education,* 41 (16), 2271–2295.

Riendeau, D. (2011). Inertia in Action. *The Physics Teacher,* 49(3), 186.

Roemmele, C., & Sederberg, D. (2017). Lazy Days: An Active Way to Put Newton's First Law into Motion (or Rest). *The Physics Teacher*, .55, 285-287.

Simaneck, D. (2022). *Physics Lecture Demonstrations, with some problems and puzzles, too*. Retrived, 09.01.2023 https://dsimanek.vialattea.net/scenario/demos.htm

Vollmer, M., & Mollmann, K.P. (2015). The tablecloth pull revisited. *Physics Education*. 50(3), 324-328.

Wood, A.K., Galloway, R.K., & Hardy, J. (2016). Can Dual Processing Theory Explain Physics Students' Performance on the Force Concept Inventory?. *Physical Review Physics Education Research*, 12, 1-5.

Young, H.D., & Freedman, R.A. (2016). *Sears and Zemansky's University Physics with Modern Physics*. 14th edition, New York, Pearson Education.