The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42210

The Physics of Gym Elastic: Elastic Force and Energy of a Non-Linear Material

Prof. Rodrigo Cutri, Maua Institute of Techonology

Cutri holds a degree in Electrical Engineering from Maua Institute of Technology (2001), MSc (2004) and Ph.D. (2007) in Electrical Engineering - University of SÃ£o Paulo. He is currently Titular Professor of Maua Institute of Technology, Professor of the

Dr. Nair Stem prof., Instituto Mauá de Tecnologia

- Associate Professor at Instituto Maua de Tecnologia - CEUN-IMT - Graduated at Physics (Bachelor) at IFUSP, Master at Electrical Engineering and Doctor at Electrical Engineering at EPUSP.

Dr. Octavio Mattasoglio Neto, Instituto Mauá de Tecnologia

Undergraduate in Physics (1983), master in Science (1989) and phd in Education (1998) all of them from Universidade de São Paulo. Professor of Physics at Mauá Institute of Technology, since 1994 and President of Teacher's Academy of the same Institute,

The Physics of Gym Elastic: Elastic Force and Energy of a Non-Linear Material

Aiming to analyze first-year engineering students' previous knowledge regarding elastic force and energy, we chose to characterize an everyday material: gym latex elastics and to compare it to a linear spring characteristic curve. This choice aimed to contextualize the concept being taught, establishing a connection between the students and a familiar non-linear material. There were four types of elastic tubes that were provided to the students, each color can be associated to a specific level of resistance: a) The minimum resistance – yellow one b) Low-intermediate resistance – blue one c) Upper-intermediate resistance – red one, and d) The maximum resistance – black one, according to the manufacturer. The purposed activity can be divided into four stages: pre-class, during class, post-class, and student´s perception. The pre-class and post-class activities (equal for both phases) involved a quiz about elastic force and energy. This quiz included questions that tested low-order thinking skills related to elastic forces (Hooke's Law), high-order thinking skills involving graph interpretation and the non-linear behavior of materials, as well as elastic potential energy. Approximately 350 students participated in this activity. This comparison was necessary because students often enter high school with the misconception that all elastic materials strictly obey Hooke's Law for a long interval of deformation. During the class step, the students were divided into groups of three or four members; each group was assigned to only one specific type of elastic band to discover its level of resistance by means of the characteristic curve (elastic force as a function of deformation) and a spring.

The elastic forces in the elastic tubes and in the spring were measured using a PASCO force sensor. The spring constant was about 8.0 N/m, and the characteristic curve was completely linear. For the elastic tubes the forces were measured with an elongation range from 0 to 40 cm in 2.0 cm increments. A comparison among third-degree, second-degree polynomial function and linear fits was performed. The results indicated that, despite achieving a better fit with a third-degree polynomial, it is not the most suitable method for physical interpretation and modeling. According to the literature, these gym elastic curves exhibit three asymptotic lines, allowing for the definition of three different elastic constants for specific regions. To simplify the problem for a first-year course in an introductory graph analysis class, the students approximated the trend line and obtained the elastic constant only for the region of elongation from 2.0 cm to 6.0 cm. The analysis of the three asymptotic regions was not asked in order to not lose the focus on elastic force and the different behavior for linear and non linear materials. A collective construction took place, where

each group shared their assigned elastic constant with the entire class, ensuring that all types of elastic tubes were characterized. A qualitative comparison was made between the measured elastic constants (obtained in the interval 2.0 cm to 6.0 cm) and those provided by the manufacturer. The teachers provided explanations about elastic tube behaviors such as elastic hysteresis, the influence of wall thickness on the resistance force. They also compared the results to linear spring. According to our results (utilizing descriptive statistics), a comparison was performed between the scores obtained in the pre-quiz and post-quiz, as shown by the presented data distribution histogram. There was a general improvement from 69.1% to 78.7%. Subsequently, the data were filtered using only the highest scores clusters in the analysis performed by employing data mining (using a software called Orange); otherwise, it wouldn't be possible to interpret the results due to the sparse distribution of clusters and their overlap. Focusing on having a detailed analysis of the types of the questions from both quizzes (elastic forces and high-order thinking skills) and elastic potential energy, an analysis of the students' development was performed by using tree algorithm. Additionally, a qualitative comparison between the measured elastic constants and the manufacturer's predictions showed good agreement, with approximately 97.0% of students correctly identifying the maximum resistance for the black tubes. Regarding student perception, we asked about their thoughts on the activity: a) how much new information they felt it brought, and b) how interesting they found it. Students could rate their responses on a scale from 1 (not interesting or no new information) to 5 (very interesting or a lot of new information). Out of the 246 students who responded, 82.6% found the activity either very interesting or interesting, and approximately 72.4% considered it to have provided new information.

Introduction

The Physics subject is applied to the First-Year students of the Engineering courses at the Mauá Institute of Technology - University Center and has one theory class and one laboratory class per week, each with 100 minutes, observing the following syllabus:

Theory: a) Physical quantities and their measurements; b) Motion in two or three dimensions; c) Applied forces; d) Newton's laws; e) Equilibrium of particle; f) Dynamics of particle; g) Work and kinetic energy; h) Potential energy and energy conservation; i) Power; j) Momentum; k) Impulse and Collisions; l) Center of mass and m) Equilibrium of rigid bodies.

Laboratory: a) Physical quantities and their Measures; b) Measuring instruments; c) Graph analysis and Interpretation and d) Experiments and Physical modeling.

The Physics subject aims to develop the following Physics modeling competencies and soft skills of First-Year Students in engineering courses:

- Being able to model phenomena, physical and chemical systems, using mathematical, statistical, computational and simulation tools, among others.

- Predicting system results through models.

- Checking and validating the models using appropriate techniques;

Thus, based on previous academic experiences [1-8] and an active learning approach [9], [10]; [11] and [12], in the Physics laboratory, aiming to analyze the understanding of first-year engineering students regarding elastic force and energy, we chose to characterize a day-by-day material: gym latex elastic tubes. This choice aimed to contextualize the concept being taught and to establish a connection between the students and a familiar non-linear material [13, 14, 15]. The only prerequisite for this class is to know how to build up a graph and to analyze straight line relationships. Despite the fact that most students are already familiar with Hooke's Law, it is demonstrated during the course. The properties of elastic materials are used to model physics exercises aiming to study practical case of Newton Second Law, Work and Energy during the course. There are innumerable applications of the usage of springs in our routine: cabinet hinges, car shock absorbers, and so on.

According to figure 1 from reference [7] a typical characteristic curve of an elastic material can be divided into elastic region (either obeying Hooke’s Law or not), permanent deformation and fracture.

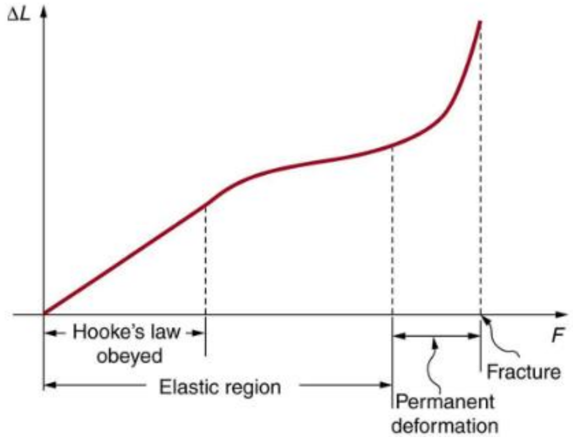


Figure 1. *[7] A graph of deformation **ΔL** versus applied force **F**. The straight segment is the linear region where Hooke's law is obeyed. The slope of the straight region is **1 / k**. For larger forces, the graph is curved but the deformation is still elastic—**ΔL** will return to zero if the force is removed. Still greater forces permanently deform the object until it finally fractures. The shape of the curve near fracture depends on several factors, including how the force **F** is applied. Note that in this graph the slope increases just before fracture, indicating that a small increase in **F** is producing a large increase in **L** near the fracture.*

Methodology:

Table 1 ([16], [17]) presents the evidence that the proposed approach intends to collect in relation to the competences to be developed by the students.

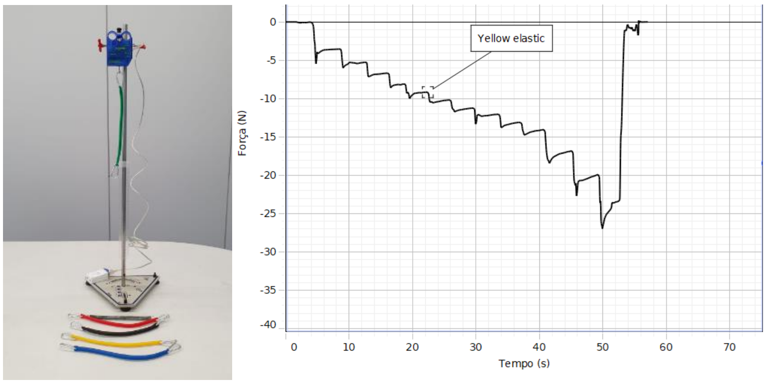
Table 1 – Competences and evidences

Competences	Evidences
To develop knowledge	The students will collaborate with their peers and teachers to conduct a survey
To synthesize knowledge	The students should understand the difference between linear and non linear material characteristic curve.
To think critically and reflectively	The students should make a comparative and critical analysis of the expected results with the theoretical model and the experimental results obtained.

In the laboratory classes, the students were divided into teams of three or four members. Each team was provided with a spring and one type of an elastic bands (each one can be associated with a specific color): a) The minimum resistance – yellow one; b) Low-intermediate resistance - blue one; c) Upper-intermediate resistance - red one; and d) The maximum resistance – black one. Both materials were characterized for an interval ranging from 0 to 40 cm with a 2.0 cm step. Then the characteristic curves (force as function of elongation) were obtained and the data was analyzed using Excel. It is important to note that no previous information about the elastic resistance was given, so the students were able to qualitatively compare and to classify them.

The activity can be divided into four stages: pre-class, during class, post-class, and student perception. Pre-Class and Post-Class Activities consisted of providing equal quizzes before and after the class (they can be seen in the appendix), with questions covering both low-order and high-order thinking skills related to elastic forces (Hooke's Law and non linear ones) and energy. The purpose of these quizzes was to assess and compare students' understanding before and after the class. Approximately 350 students participated in this activity. The comparison was necessary because students often enter high school with the misconception that all elastic materials strictly obey Hooke's Law.

The experimental apparatus is depicted in Figure 2a, and in Figure 2b, an example of the obtained curve for the yellow elastic is shown. In this figure, it can be observed that there is a different force pattern each time the deformation is increased by 2.0 cm. Since this measurement is manual, average values were obtained for each force pattern and recorded in a table. Following that, the students were required to fit three types of trends (third-degree polynomial, second-degree polynomial, and linear one) and to determine the best mathematical model that fits the data in the interval from 0 to 40 cm by analyzing the R-squared value. The best mathematical fit for the typical measured curves is found for the closest squared R values to 1 (100%). In the case of the spring, they only fitted the linear equation and obtained the elastic constant.



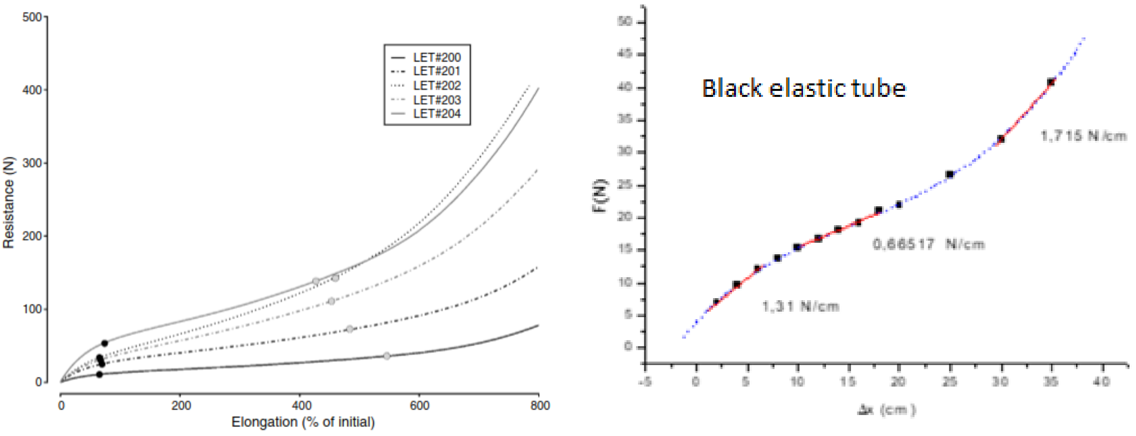
(a) ***(b)***

Figure 2. *a) Experimental apparatus (Pasco force sensor; Gym Elastic) b) Example of a measurement performed with force sensor for yellow elastic*

The obtained results showed that the best fit was obtained for a third-degree polynomial function, consistent with previous work [18]. According to the cited work, these gym elastic curves exhibit three asymptotic lines, allowing for the definition of three different elastic constants for specific regions.

In Figure 3a), the first asymptotic line is shown between the zero point and the black dot region, the second one between the black and grey dots, and the last one for elongation greater than 600% of the initial length.

In Figure 3b), a typical characteristic curve obtained by the authors for a black elastic tube of about 20 cm is presented. In this figure, three different elastic constants can be fitted for each region: 1.31 N/cm, 0.665 N/cm, and 1.72 N/cm. However, it should be noted that these elastic constants are only qualitative since the elastic tubes were manually stretched and not by a machine, as depicted in Figure 3a [18]. Additionally, the elastic tubes may also differ in their initial length. Note that due to the significant differences in resistance forces required by each elastic color, different intervals of hang weights are necessary for deformation. For instance, the black ones would need a wide range of hang masses to achieve the deformation presented in Figure 3b. Therefore, to simplify the experimental procedure, the proposed activity was based on deforming the elastic tubes in the same manner they would be worked out in a gymnasium (by pulling them until the desired deformation was obtained).



(a) (b)

Figure 3. *a) [18] A graph of resistance as a function of percentual elongation for LET#200 to #204 Lemgruber® elastic tubing. Black dots represent the 1st inflection point and Grey dots represent the 2nd inflection point. b) the author's obtained curve*

To simplify the problem for a first-year engineering course, the students approximated the line trend and obtained the elastic constant only for the region of elongation from 2 cm to 6 cm. A collective construction took place (Table 2), where each group shared their assigned elastic constant with the entire class, ensuring that all types of elastic tubes were characterized.

At the end of the activity, the teachers showed the predicted elastic force by the manufacturers aiming that students could perform a comparison between their results to the manufacturer´s ones. The force measured by the manufacturers were black one (50 lbs), red (30 lbs), blue (20 lbs), and yellow (10 lbs), considering a 100% elongation of an initial length equal to 1 meter. The students could compare the manufacturers' results with the table obtained through collective construction among the groups. They could debate why they had gotten the same qualitative resistance classification or not and what went wrong in the method of obtaining an elastic constant in the chosen region. In this way, they could develop knowledge with their peers and critically analyze their results. Besides, they could compare the results to the characteristic curve of the spring, and conclude it was linear for all measured elongation interval, differently from the elastic tubes.

Table 2- Please consult your colleagues from other teams in your class and note down the constants found adjusted in the range of 2 cm to 6 cm.

Elastic color	Experimental Elastic constant (k) (N/cm)	Four Qualitative Resistance Classification
Yellow		
Blue		
Red		
Black		

Results

To present the results, we will divide them into three parts: during class, a comparison between the answers for the pre-class and post-class quizzes, and students' perceptions.

During class, a qualitative comparison was made between the measured elastic constants and those provided by the manufacturer for different resistance levels: the lowest resistance yellow elastic, low intermediate resistance blue elastic, upper intermediate resistance red elastic, and the highest resistance black elastic. Figure 4 displays the results measured by the students from 20 groups. “Yes” represents that found results consistent with the manufacturers' predictions, while "No" represents different results attributed to experimental errors.

It can be observed that some groups did not obtain the predicted results. Since the exerted force was manually performed and not done by a machine, they had difficulty maintaining a constant force and obtaining a suitable average value. Some groups were also concerned about the peaks in their measurements. However, it is noteworthy that the majority of groups found the expected results predicted by manufacturer, with nearly all groups identifying the black elastic tube as the most resistant (97.2%).

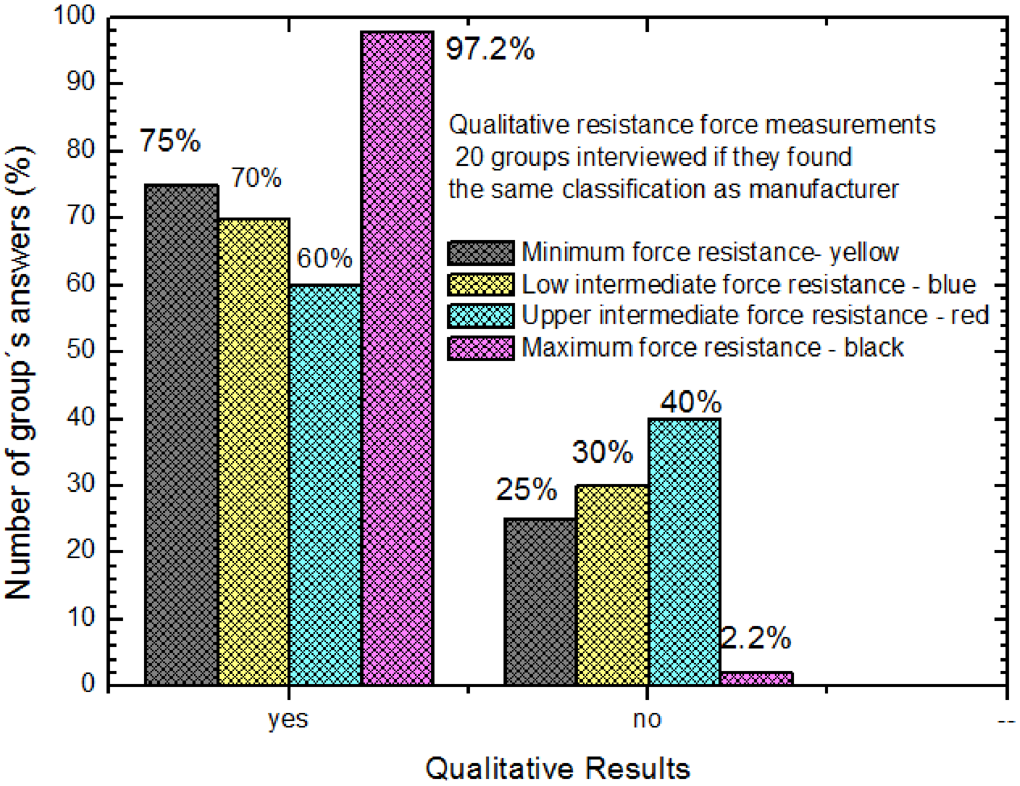


Figure 4. *Qualitative results four found by 20 groups about the qualitative classification of elastic tubes: yes (the group results that agreed to manufacturer) and no (the groups that didn´t have success in their classification due to experimental error)*

Pre-class and post-class quizzes: The pre-class and post-class quizzes were identical, covering topics including elastic forces (objective and higher-order thinking skills) and elastic potential energy, as shown in the appendix. However, the post-class quiz was completed after performing the experiment and participating in an in-class collective construction and analysis, both conducted on the blackboard by the professor. Three additional questions were answered individually by the students in order to check if they had understood the blackboard discussion and developed satisfactory the three proposed competences presented in table 1: a) they had to answer if the spring on their table was linear or not for the analyzed range, b) which elastic was the most resistant one and c) the cause of the different resistance forces in the tested elastic tubes.

To compare the results, we considered only the answers from students who responded to both the pre-class and post-class quizzes. Cases where students answered only one of the quizzes were disregarded. The analysis of the pre-class and post-class quizzes is divided into two parts: a general view of the grade marks and a question-by-question analysis. In the case of the last three questions about comprehension of discussions and data interpretation, a simple statistic was performed.

General view

Figure 5 shows the number of students as a function of the difference between the post-class final grade and pre-class final grade. Based on this initial analysis, it can be observed that, in general, there was an increase in the total quiz grade, resulting in a positive difference, supporting the idea of developing knowledge and critical thinking after performing the experiment, the analysis in the group, and taking part in the collective construction.

Descriptive statistics analysis of the data shows that the average value is (0.086 $\pm$ 0.01), with the minimum value being -0.430 and the maximum value being 0.570. The kurtosis of the histogram is 0.237, indicating a Platykurtic distribution [19], and the Pearson skewness coefficient is 0.518, indicating a positive skewness. The tail of the distribution is longer on the right side, indicating that the majority of students increased their total quiz grade. There were few students who decreased their grade in the post-class quiz, indicating the necessity to repeat the concept taught in other activity in the future, in order to improve their learning too.

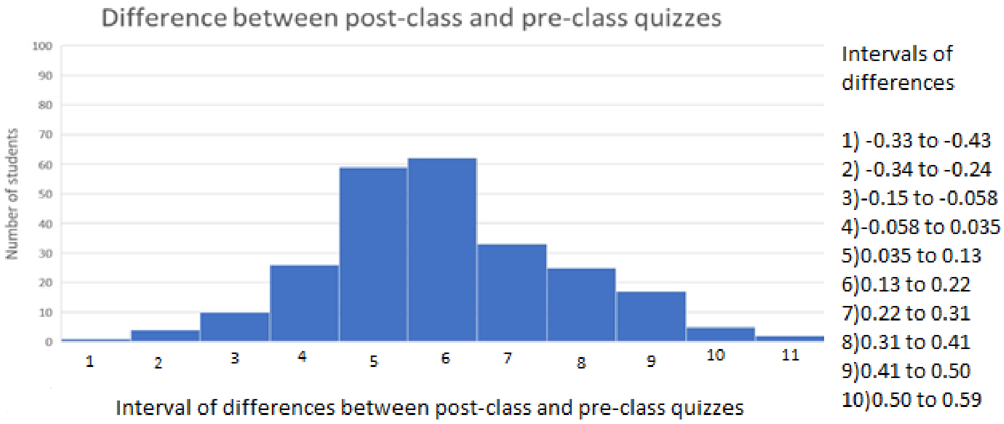
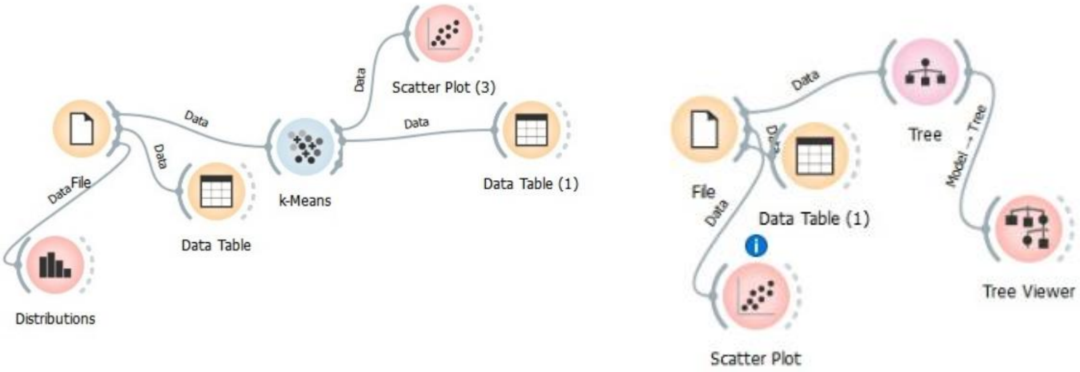


Figure 5. *Number of students as function of the difference between the post-class final grade and pre-class final grade*

Using Orange Data Mining software [20], the analysis was performed by constructing a structure as depicted in figure 6 (this is a print screen of the software command arrangements for analysis). The analysis involved two different approaches:

6a) The first approach utilized the k-means algorithm to identify clusters of similar cases. This allowed for grouping based on the performance of students in the pre-quiz and post-quiz. It was considered the clusters identified included a higher pre-quiz group (0.33 to 0.78 grade interval), a higher post-quiz group (0.65 to 1.0 grade interval), and cases with equal results. This analysis was performed following the sequence of commands in orange data mine software (file, data table, k-means, and scatter plot or distribution analysis). It was necessary to filter the data and to consider only the highest scores in order to not overlap the clusters, because they were too sparse.

6b) The second approach involved tree model, with the target variable being the post-class quiz. A comparison was made for each individual question, examining the performance and differences among the students. This analysis was performed following the sequence of commands in orange data mining software (file, data table, tree and tree viewer).



(a) ***(b)***

Figure 6. *The mounted structure in order to perform the analysis by using the Orange data mining software: (a) k-means analysis structure (b) Tree algorithm structure*

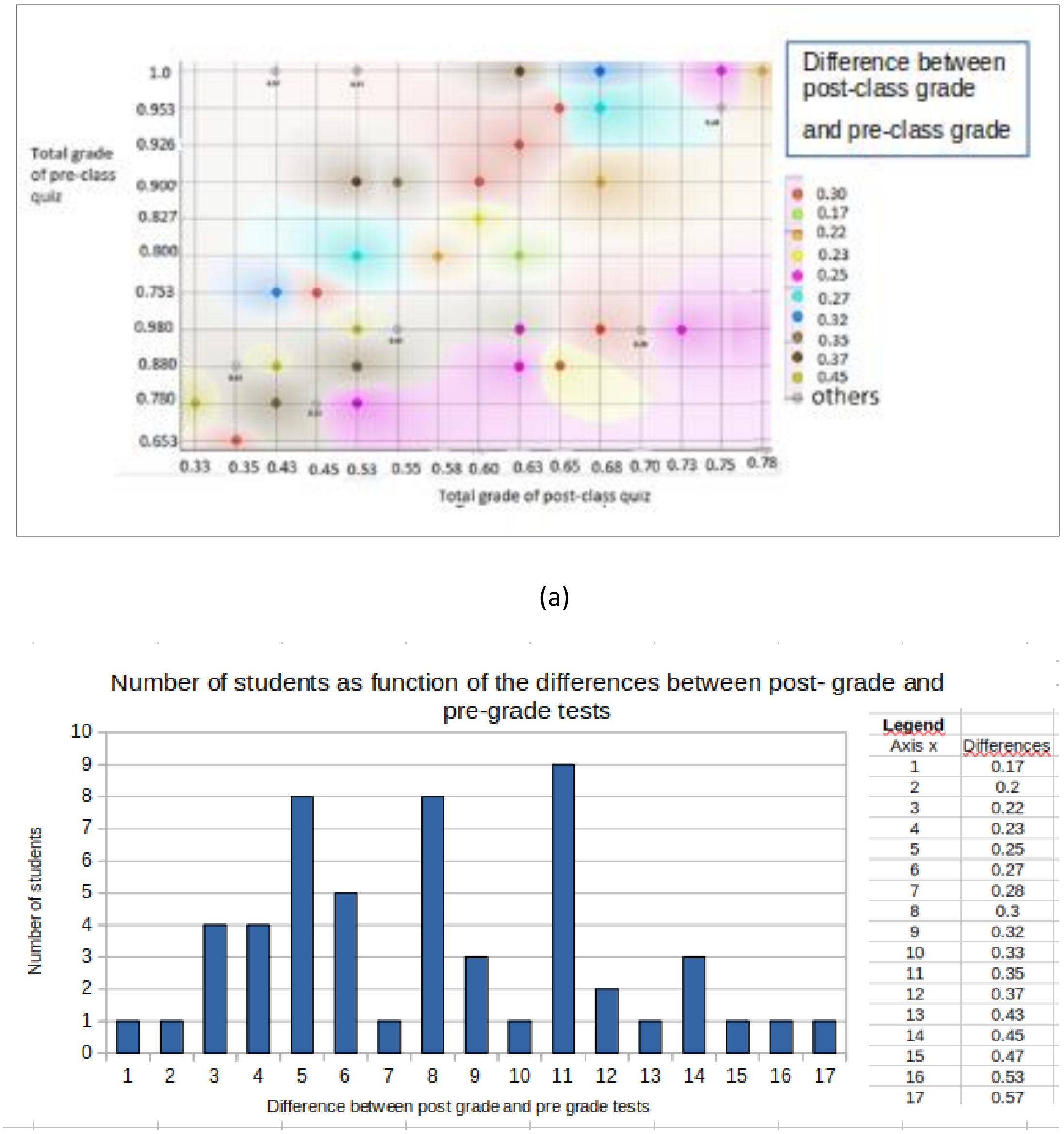
Considering only the cases where the difference between the post-class and pre-class grades is higher than 20% and positive, it was found that this accounts for approximately 22% of the total number of students. The K-means algorithm was used to analyze the distribution of improvements, correlating the pre-class grades with the post-class ones.

In Figure 7a, the distribution is displayed, showcasing clusters of post-class grades cases as a function of the pre-class grades. The improvements (differences between post-class grades and pre-class grades) are indicated in the legend. Simultaneously, Figure 7b illustrates the number of students in each cluster represented in Figure 7a. According to figure 7b, the most frequent improvement observed was 0.35, with approximately 9 cases. It is also noteworthy that the highest post-quiz final grade (1.0) was achieved by students with various pre-class grades, ranging from 0.35 to 0.78.

These results highlight the necessity for a detailed analysis of the progress, focusing on the variation of question by question. This approach allows for the identification of the specific questions that contribute the most to the observed grade changes.

Question by Question analysis

The comparison of performance between the answers of a specific question before and after class was conducted using the tree algorithm of Orange Data Mining. The tree was constructed with 5 levels and 4 leaves, with the post-class quiz grade as the target variable, as it can be seen in the figures 8 and 9. A total of 245 answers were analyzed for both quizzes.



(a)

(b)

Figure 7: *a) number of student's post class grades as function of pre-class grades with the differences in legend for improvements higher than 20% in final quiz b) distribution of improvements for differences higher than 20%. Each cluster of figure 7a corresponds to a difference posted in figure 7b.*

Figure 8 shows the percentage of number of students that maintained their grades, improved and decreased as function of the objectives questions (Q1 to Q5). This figure presents the results for the objective questions, showing that the majority of students answered these questions correctly both before and after the class. Notably, the highest improvement in grade was observed for question 4, which addressed the concept of elastic materials always obeying Hooke's Law. Approximately 44% of students were not aware that materials could exhibit different behaviors. Meanwhile, the presence of a certain percentage of students who experienced a decrease in their grades in individual evaluations after this group lab activity points out the necessity of reinforcing the study of the taught concepts by means of other activities. In the particular case of Q3, the most probable cause of misconception was the construction of the sentence due to the inclusion of the word "always." Figure 9 focuses on the higher-order thinking skill questions showing the number of the percentage of students that maintained the grades, the ones that improved and the ones that decreased. The questions Q6, which involved graph interpretation of non-linear materials, and Q9, which covered elastic hysteresis, showed the highest learning gains with improvements of approximately 39% and 37.1% respectively. These results support the initial hypothesis that in high school, students are primarily exposed to Hooke’s law, but no previous idea about non-linear material. Once again the percentage of students that decreased grades points out the necessity to develop activities to reinforce the taught concepts.

In order to check if they had developed the three proposed competences individually (presented in table 1), they had to answer three analysis question as it was mentioned previously, a) whether the spring on their table was linear, b) what the most resistant elastic was, and c) if the cause of the different resistances depended on the elastic color. According to the results, 80% of the students who answered the questions concluded that the spring elastic constant was linear, and 93.5% of them concluded that the cause of the difference in elastic resistance was not the color, but in fact the differences in resistance force is dependent on the thickness of the elastic wall, the higher thickness the higher resistance. Additionally, 83.3% of them concluded that the most resistant elastic was the black one, demonstrating the development of an individual knowledge and critical thinking and corroborating as well the improvement observed in questions 6 and 9 of the quizzes. The competence of synthesizing knowledge was checked by means of questions 1-5 and questions 7 and 8 as well. In the following, their perception about the acquired knowledge will be presented.

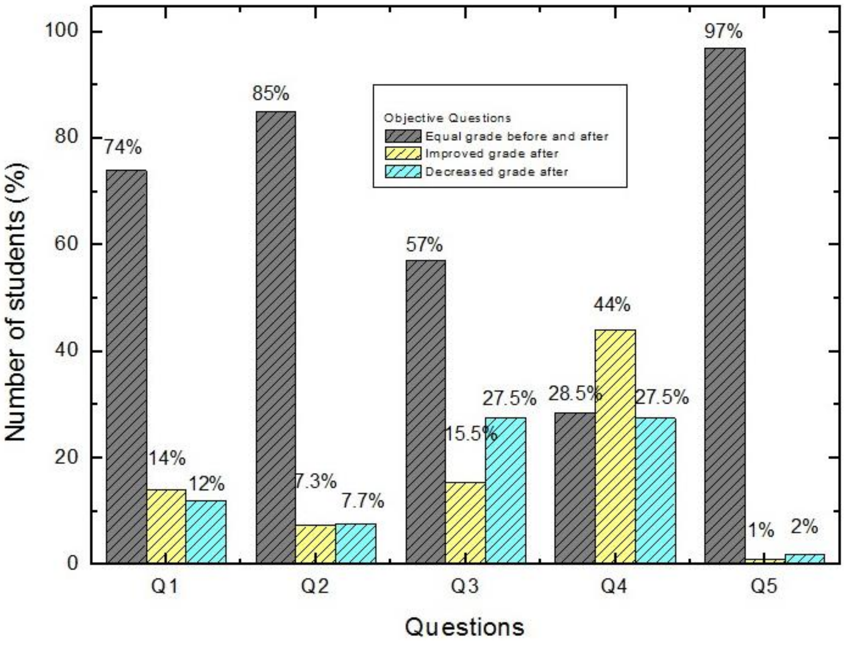


Figure 8. *Percentual number of students considering the ones who got the same grade, the ones who got an improvement in objective questions presented in appendix, and the ones that decreased the grades.*

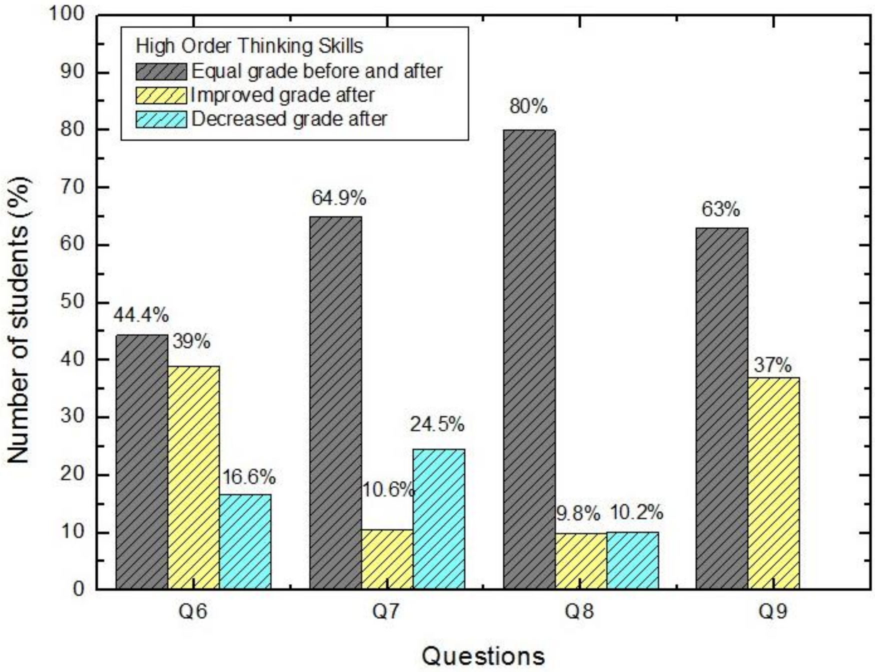


Figure 9*. Percentual number of students considering the ones who got the same grade, the ones who got an improvement in higher order thinking skills questions presented in appendix and the ones that decreased the grades.*

Students´ perceptions

Regarding student perception, we asked about their thoughts on the activity: a) how much new information they felt it brought, and b) how interesting they found it. Students could rate their responses on a scale from 1 (not interesting or no new information) to 5 (very interesting or a lot of new information). Out of the 246 students who responded, 82.6% found the activity either very interesting or interesting, and approximately 72.4% considered it to have provided new information.

In general, the students expressed the following perceptions:

“Different from previous experiments, I liked it! “

“I found the experiment very interesting, thank you. “

“The experiment helps to better understand springs and Hooke's Law.”

“ I enjoyed the class and what I learned. “

“The experiment is very good and very useful because, by knowing the material in practice, it helps students build a memory of it, making it easier to apply what was taught in theory classes.”

“Interesting experiment to discover that not all elastic materials obey Hooke's Law at all times, although I am not familiar with everyday elastics to understand better. Personally, this experiment was very good as it allowed me to notice the difference between a spring that approximately follows Hooke's Law and an elastic material that does not obey the same law. Additionally, the reason behind this is very interesting! ”

Final Considerations

The development of applied Physics activities that integrate Physics studies into everyday life allows students to gain a better understanding of elastic force and the behavior of non-linear materials. It also allows for a more immersive experience in physical modeling problems, with teachers acting as mediators and students taking the lead in making discoveries. This highlights the importance of creating accurate mathematical models for Physics phenomena and the need for approximations to better analyze them, such as dividing the characteristic curve into three different regions. It was demonstrated that a third-grade polynomial curve is not always the best approach when a physical model and interpretation are required.

Based on the steps taken during the class, the results obtained were satisfactory. The majority of groups were able to qualitatively classify the elastic tubes and discuss the approximation used in the model, as well as the sources of experimental errors. A comparison between the pre-class and post-class quizzes showed the highest improvement in objective question Q4 and the higher-order thinking skills questions Q6 and Q9. This supports their perception that they previously lacked knowledge of the characteristics of elastic materials, such as changes in the characteristic curve, mathematical modeling, and hysteresis.

Finally, based on student feedback, the proposed experiment was described as simple and engaging, providing an immersive experience where the student acts as the investigator. Additionally, the sharing of discoveries and group discussions helped foster the ability to work collaboratively.

Acknowledgment

The authors are grateful for the support provided by technicians of Physics Laboratory of Institute of Technology in carrying out the experiment, and the financial support of Mauá Institute of Technology.

References

[1] OLIVEIRA, Benjamim Nunes de. O uso da simulação Massa-Mola do PhET como auxílio para a aprendizagem da força elástica (Lei de HOOKE). 2019. 103 f. Dissertação (Mestrado em Ensino de Ciências e Matemática) – Centro de Educação, Programa de Pós Graduação em Ensino de Ciências e Matemática, Universidade Federal de Alagoas, Maceió, 2016. - Available: http://www.repositorio.ufal.br/handle/riufal/5577 [Accessed Nov. 14, 2023].

[2] Ramos, T. C., & Vertchenko, L. Uma abordagem experimental das propriedades dos corpos deformáveis no ensino de física geral para os cursos de engenharia. Revista Brasileira de Ensino de Física, 33, 01-09. 2011. - Available: https://www.scielo.br/j/rbef/a/kvV4cNM8H5SsWRzGbbXCDjg/?lang=pt&format=pdf [Accessed Nov. 14, 2023].

[3] Aranha, N., Oliveira Jr, J. M. D., Bellio, L. O., & Bonventi Jr, W. A lei de Hooke e as molas não-lineares, um estudo de caso. Revista Brasileira de Ensino de Física, 38, e4305. 2016 - Available: https://doi.org/10.1590/1806-9126-RBEF-2016-0102 [Accessed Nov. 14, 2023].

[4] Nascimento, L. Análise experimental do sistema massa-mola através da Lei de Hooke. Revista Multidisciplinar Pey Këyo Científico-ISSN 2525-8508, 1(2). 2016

[5] Urbano, D., de Fátima Chouzal, M., & Restivo, M. T. Feeling the elastic force with a haptic device: A learning experience with K12 and first year engineering students. In 2015 3rd Experiment International Conference (exp. at'15) (pp. 306-309). IEEE.

[6] Urbano, D., Marques, J. C., de Fátima, M., Restivo, C. T., & Andreatta-da-Costa, L. Experimental training in engineering. In 2016 IEEE Global Engineering Education Conference (EDUCON) (pp. 1046-1050). IEEE.

[7] x-Douglas College Physics 1107 Fall 2019 Custom Textbook - Authors:Department of Physics and Astronomy at Douglas College and OpenStax – Available: https://pressbooks.bccampus.ca/introductorygeneralphysics1phys1107/ [Accessed Nov. 14, 2023].

[8] Uchida, M.C.; Nishida, M.M.; Sampaio, R.A.C.;T. Moritani; H.Arai. Thera-band® elastic band tension: reference values for physical activity J. Phys. Ther. Sci. 28: 1266–1271, 2016 The Journal of Physical Therapy Science

[9] Dori, Y. J.; Belcher, J.; Learning Electromagnetism with Visualizations and Active Learning. Visualization in Science Education. Models and Modeling in Science Education. Volume 1, 2005, pp 187-216

[10] Du.X; De Graaff,E.; Kolmos, A. Research on PBL Practice in Engineering Education. Sense Publishers. 2008

[11] Fraser,J.M.; Timan,L.A.; Miller,K. ; Dowd,J.E.; Tucker,L.; Mazur,E. IOP Publishing – Reports on Progress in Physics – Doi 10.1088/0034-4885/77/3/032401 , 2014.

[12] A Setiawan et al Effect of Higher Order Thinking Laboratory on the Improvement of Critical and Creative Thinking Skills 2018 IOP Conf. Ser.: Mater. Sci. Eng. 306 012008

[13] Krause, S. J., & Waters, C., & Stuart, W. J., & Judson, E., & Ankeny, C. J., & Smith, B. B. (2016, June), Effect of Contextualization of Content and Concepts on Students' Course Relevance and Value in Introductory Materials Classes Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.26894

[14] Picardal, M.T., Sanchez, J.M.P. Effectiveness of Contextualization in Science Instruction to Enhance Science Literacy in the Philippines: A Meta-Analysis international Journal of Learning, Teaching and Educational ResearchVol. 21, No. 1, pp. 140-156, January 2022 Available: https://doi.org/10.26803/ijlter.21.1.9 [Accessed Nov 22 2023].

[15] Lopes, J. & Viegas, Clara & Cravino, José. Improving the Learning of Physics and Development of Competences in Engineering Students. International Journal of Engineering Education. 26. 612-627 (2010).

[16] Cutri, R.; Gil, H. A. C. ; Freitas, P. A. M. . Avaliação por competências? Uma proposta de aplicação em disciplinas de engenharia. In: XLVII Congresso Brasileiro de Educação em Engenharia (COBENGE), 2020. XLVII Congresso Brasileiro de Educação em Engenharia (COBENGE), 2020.

[17] Stem, N., Mattasoglio Neto, O., C. Hector, A., Cutri, R. Avaliação por competências - uma proposta de aplicação nos laboratórios das disciplinas de ciências básicas da engenharia. In: XLVII Congresso Brasileiro de Educação em Engenharia (COBENGE), 2022. L Congresso Brasileiro de Educação em Engenharia (COBENGE), 2022. DOI:10.37702/COBENGE.2022.3767

[18] de Lima, F.F., Camillo, C.A., dos Reis, E.A.P., Job, A.E., Silva, B.S. de A., Topalovic, M., Ramos, D., Ramos, E.M.C. Mechanical properties, safety and resistance values of Lemgruber® elastic tubing, Brazilian Journal of Physical Therapy, Volume 23, Issue 1, 2019, Pages 41-47, ISSN 1413-3555, https://doi.org/10.1016/j.bjpt.2018.07.001.

[19] Platykurtic Distribution Published: April 27, 2022 by Ken Feldman https://www.isixsigma.com/dictionary/platykurtic-distribution/

[20] Orange Data Mining - Available: https://orangedatamining.com/

Appendix QUIZ (Pre-Class and Post-Class)

Type 1– Objective questions

Question 1: Elasticity is the ability of a material to return to its original shape after being stretched or compressed. When an elastic material is stretched or compressed, it exerts an elastic force. The elastic force has many uses, from hair elastics to bed springs.
True or False: When a material is stretched or compressed, its elastic force increases.
Answer: True

Question 2: The potential energy due to the shape of an object is called elastic potential energy. This energy results when an elastic object is stretched or compressed. True/False: The more the object is stretched or compressed, the greater its elastic potential energy.
Answer: Falso

Question 3: True or False: Elastic force is always positive because it wants to restore the object to its original position.
Answer: True

Question 4: True or False: Elastic force is always linear (proportional) to the deformation.
Answer: False

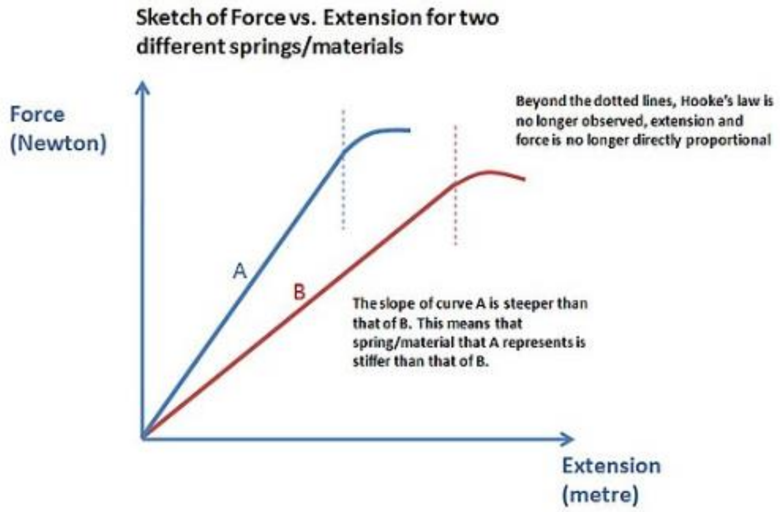
Question 5: The physical law that states that deformation is directly proportional to the applied load or force up to the limit of proportionality is known as:

a. Hooke's Law
b. Newton's Law
c. Pascal's Law
d. Boyle's Law

Answer: a. Hooke's Law

Type 2 – Elastic force and High order thinking skills

Question 6:
Observing the following graphs, can we say that:
I - Up to the dotted sections, both body A and body B obey Hooke's Law (Elastic force is proportional to deformation).
II - After the dotted sections, the bodies have undergone permanent deformation and do not return to their original position.
III - The deformation constant (elastic constant) is higher in body B than in body A.
Are the following statements true?

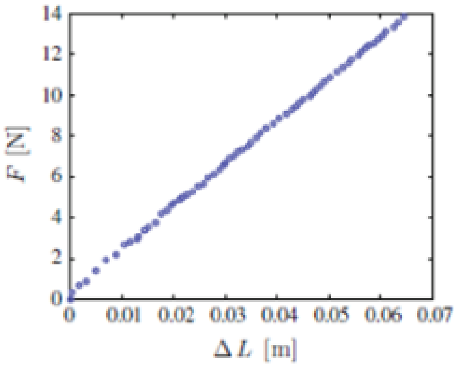


Boodoo, Ranjit. 2020. Hooke's Law. Image/jpeg. Wikimedia Commons, the Free Media Repository.

a. I, II e III
b. I e III
c. I e II
d. II e III

Answer: c. I e II

Question 7: Based on the given graph, we can say that the value of the spring constant is approximately:



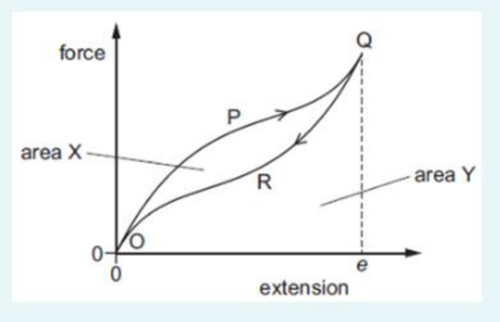
a. 0 N/m
b. Cannot be determined.
c. 0.005 N/m
d. 200 N/m

Answer: c. 0.005 N/m

Question 8: If we assume that each change adds a weight of mass M to the hook, and in the last image, there is a weight of mass 6M, then we can say that the deformation of the spring will be:

a. 6 times greater than the first
b. 3 times greater than the first
c. 6 times smaller than the first
d. Equal in all cases
Answer: a. 6 times greater than the first

Question 9: In an elastic, it is observed that there is a curve P of force as a function of displacement when it is stretched and another curve R when it is released. Can we say that it obeys Hooke's Law for any region of the graph?
Answer: False



Reference:https://physics-ref.blogspot.com/2019/05/a-rubber-band-is-stretched-and-then.html