ANALYSIS OF STUDENT´S COMPREHENSION OF A NON-LINEAR MATERIAL CHARACTERIZATION ON THE EDUCATIONAL DATA MINING POINT OF VIEW

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Resumo: *In this work it is proposed an activity to analyze non linear characteristics curves obtained with gym latex elastic. Force as function of deformation were characterized for four different types of elastics (the higher resistance force, upper intermediate, lower intermediate and the lowest resistance force). Each group of a class had one type of elastic and one linear spring to characterize. At the end, there was performed a collective construction on the blackboard with the group´s results. The class results were compared to the manufacturer predictions. The majority of students agreed the black elastic presented the highest force resistance. According to the discussions and results of post quiz it could be observed that the students had in mind the Hooke´s law and linear materials; however, it was completely new the behavior of elastics, the linearity presented only in some intervals of deformation, and moreover, the hysteresis of elastics. In general students agreed that the activity was interesting and it could aggregate new information. The teacher staff thinks that it was a good way of practicing graph modeling and developing graph interpretation analysis competence.*

Palavras-chave: *Elastic force. Non linear materials. Educational data mining. Gym latex elastics*

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1 INTRODUCTION

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.

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 (URBANO, D., et al, 2015), (OLIVEIRA, B. 2016), (RAMOS, T. C., & VERTCHENKO, L., 2011), (ARANHA, N., et al, 2016), (NASCIMENTO, L.,2016), (URBANO, D., et al, 2016), (UCHIDA, M.C. et al , 2016) (DOUGLAS COLLEGE, 2019), and an active learning approach (DORI, Y. J.; BELCHER, J, 2005), (DU.X; DE GRAAFF,E.; KOLMOS, A., 2008), (FRASER,J.M. et al, 2014, (A. SETIAWAN, et al, 2018), 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 (LOPES, J. & VIEGAS, CLARA & CRAVINO, JOSÉ., 2010), (KRAUSE, S. J., et al, 2016), (PICARDAL, M. T., SANCHEZ, J.M.P., 2022). 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.

2 METHODOLOGY

Table 1 (CUTRI, R. et al, 2020), (STEM, N., et al, 2022) 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

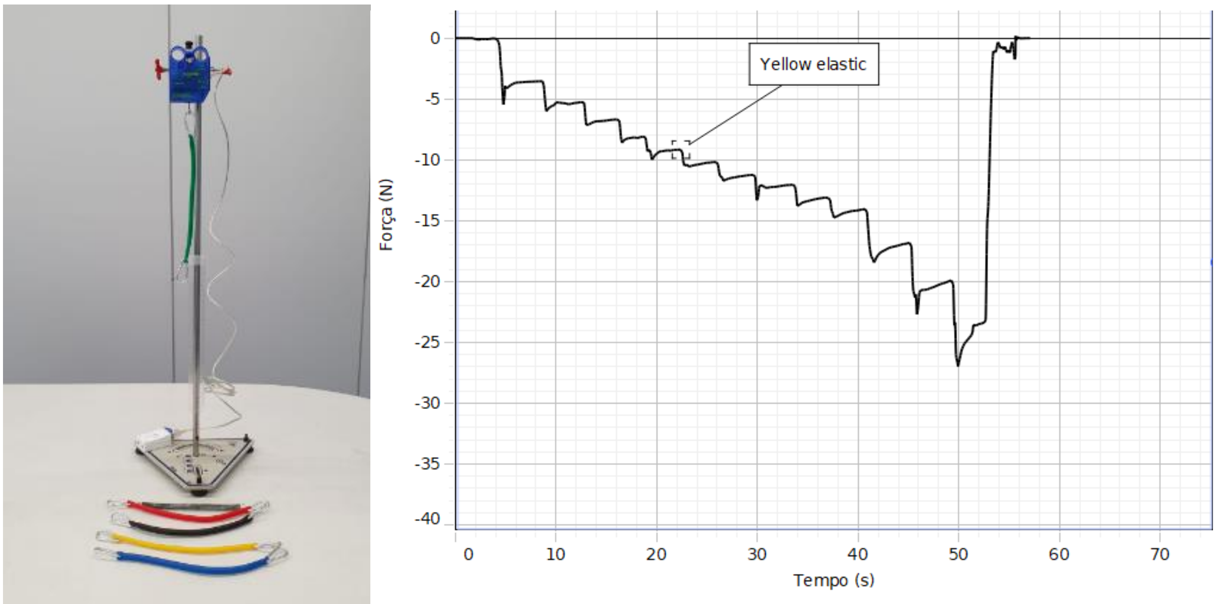
Competences	Evidences
To develop knowledge	The students will collaborate with their peers and teachers to conduct a survey
To synthesize knowledge	The students should understand the difference between linear and nonlinear material characteristic curve.
To think critically and reflectively	The students 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 nonlinear 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.

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



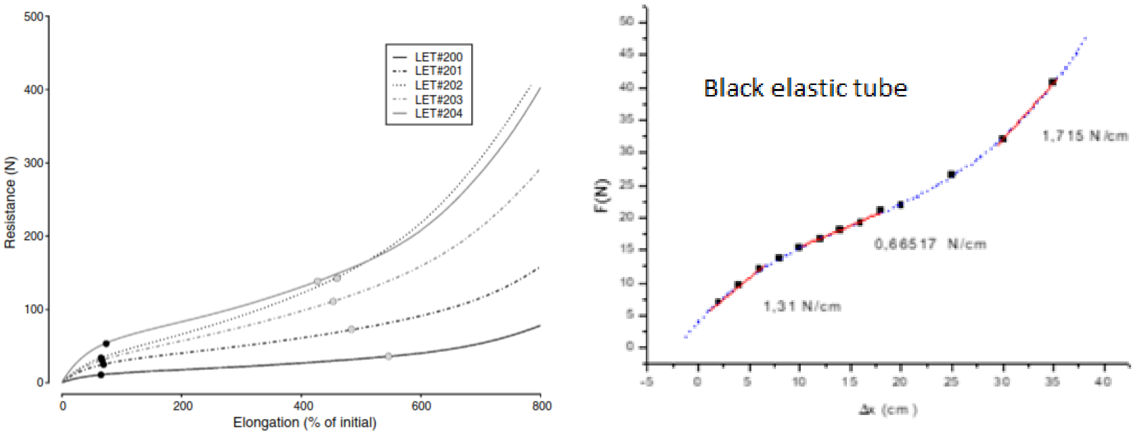
(a) (b)

The obtained results showed that the best fit was obtained for a third-degree polynomial function, consistent with previous work (DE LIMA, F.F., et al, 2019). 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 (DE LIMA, F.F., et al, 2019). 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).

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



(a) (b)

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 on the blackboard 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		

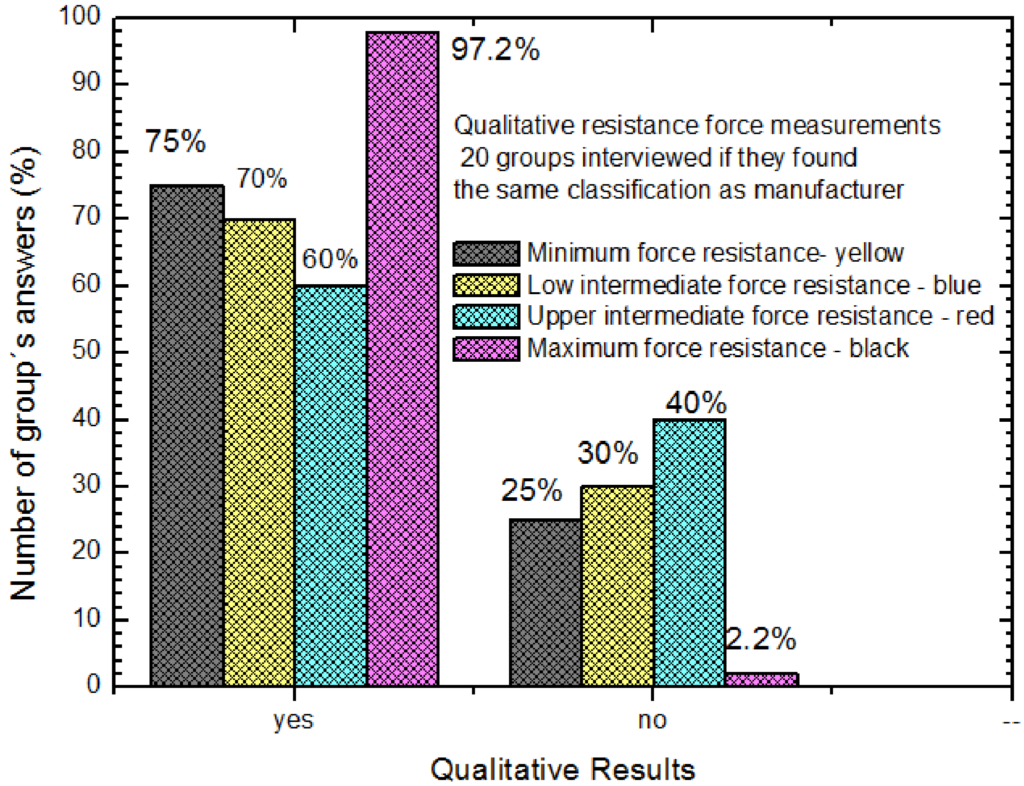
3 RESULTS

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)



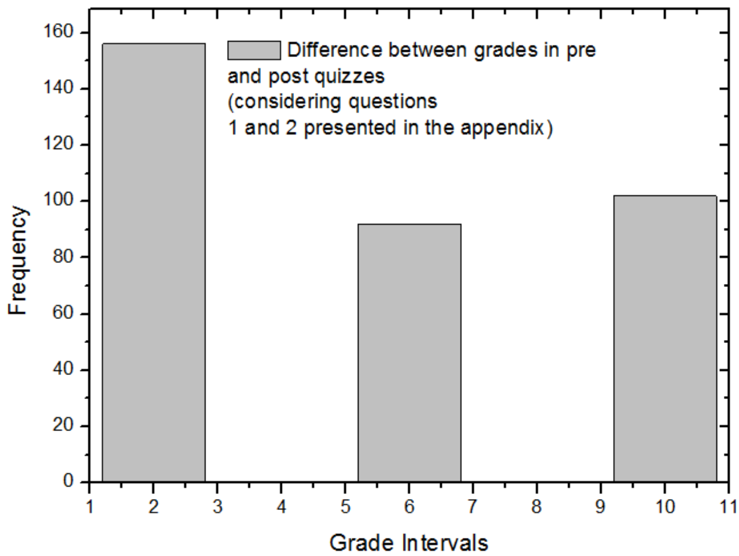
Pre-class and post-class quizzes: The pre-class and post-class quizzes were identical, covering topics including elastic forces (higher-order thinking skills). However, the post-class quiz was completed after performing the experiment and participating in an in-class collective construction and analysis, both conducted on the blackboard by the professor.

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.

3.1 General view

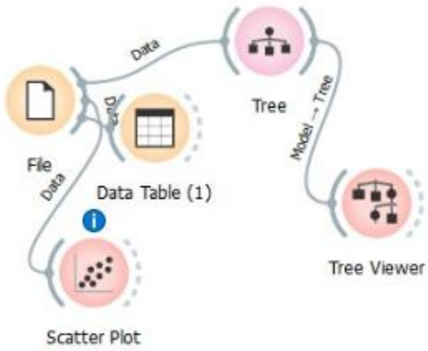
Figure 5 shows the number of students as a function of the difference between the post-class final grade and pre-class final grade. Based on this initial analysis, it can be observed that, in general, there was an increase in the total quiz grade, resulting in a positive difference, supporting the idea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

Figure 5. Number of students as function of the difference between the post-class final grade and pre-class final grade – considering question 1 and question 2



Using Orange Data Mining software (ORANGE DATA MINING, 2022), 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 used 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).

Figure 6. The mounted structure in order to perform the analysis by using the Orange data mining software

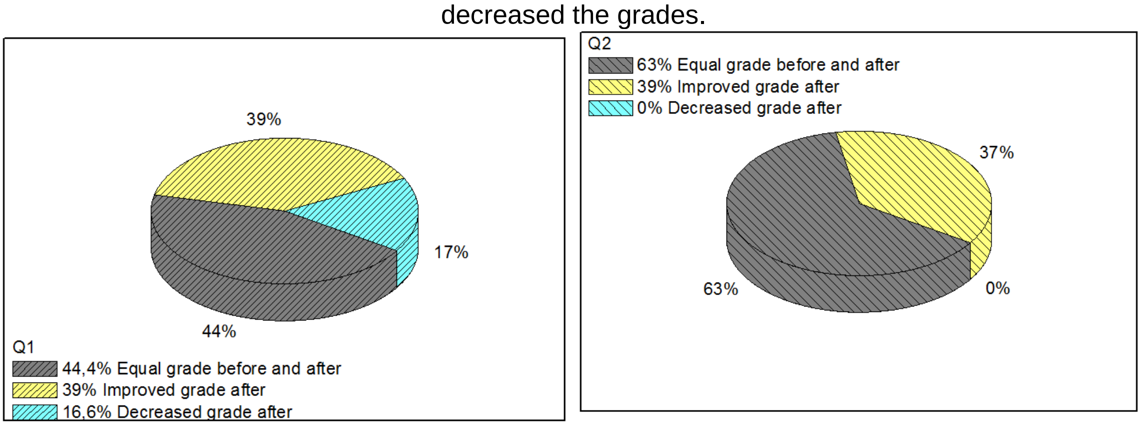


3.2 Question Analysis

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 7 a and 7 b. A total of 245 answers were analyzed for both quizzes.

Figure 7 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 Q1, which involved graph interpretation of non-linear materials, and Q2, 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.

Figure 7. 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.



(a) (b)

4 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. A comparison between the pre-class and post-class questions showed the improvement in the questions Q1 and Q2 (none of them decreased after). 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.

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Keywords: *Elastic force. Nonlinear materials. Educational data mining. Gym latex elastics.*

APPENDIX QUIZ (Pre-Class and Post-Class)

High order thinking skills

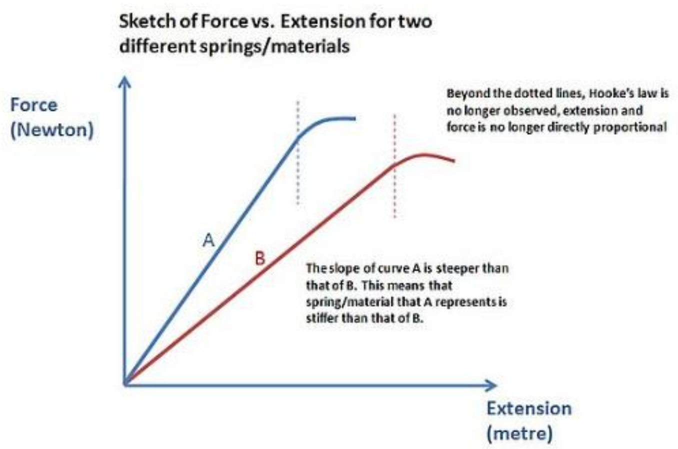
Question 1:
Observing the following graphs, can we say that:

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?



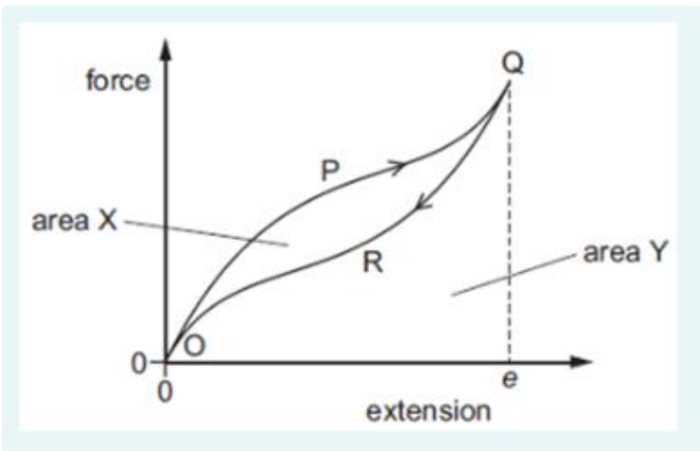
a. I, II e III
b. I e III
c. I e II
d. II e III

Answer: c. I e II

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

Question 2: 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



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