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Determination of Young's Modulus through Virtual Laboratory-Based Wire Stress-Strain Simulation

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Abstract. Elasticity is a fundamental topic in physics, yet students often find stress, strain, and Young's modulus difficult to understand because these concepts are abstract and require precise measurement. This article describes the use of a virtual laboratory-based computer simulation to determine Young's modulus through stress-strain measurements. The simulation was designed as a student practice medium that allows users to vary tensile force, initial wire length, wire diameter, and material type. This study used a descriptive computational simulation approach consisting of variable exploration, virtual measurement, data tabulation, graphical analysis, and mathematical modeling. The practice results show that wire elongation is directly proportional to the tensile force and the initial wire length, but inversely proportional to the cross-sectional area and Young's modulus. The relative uncertainty of this virtual laboratory is 0.036%. This value is very small, so the simulation results can be considered consistent. The graph of wire elongation versus tensile force is linear, indicating that Young's modulus can be determined from the gradient of the curve. These findings suggest that virtual labs provide visual, interactive, measurable learning experiences and a practical alternative for elasticity practice activities when access to laboratory equipment is limited.

1 Introduction

Physics requires not only mastery of formulas, but also the ability to connect concepts, data, and physical phenomena [1]. One important concept in the mechanics of materials is Young's modulus. This concept describes a material's stiffness under tensile or compressive forces [2]. The concept of Young's modulus is often difficult to grasp because students must simultaneously visualize the relationship between force, cross-sectional area, change in length, and material properties [3,4].

Theoretically, Young's modulus is defined as the ratio of tensile stress to tensile strain [1,2]. Young's modulus applies to tensile or compressive deformation in the linear-elastic

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region, as described by a commonly used mathematical formula [5]. This formula shows that Young's modulus can be determined by measuring force, cross-sectional area, initial length, and increase in length [6]. This concept is well-suited to teaching through practical work because students can directly observe changes in each variable's value.

However, real-world elasticity experiments require fairly precise measuring instruments [5,6,7]. Micrometer reading errors, limited materials, and the risk of permanent deformation of the wire can hinder learning [8]. A virtual laboratory can address some of these challenges because students can change variables safely, quickly, and repeatedly [9,10,11]. Research on virtual laboratories in science learning shows that these media can support conceptual understanding, laboratory skills, scientific literacy, critical and analytical thinking, and questioning [12,13].

Computer simulations also provide opportunities for students to learn through exploration [14]. Students not only receive a final equation but also discover patterns in the data. The virtual laboratory used in this article guides students in varying the load mass, initial length, diameter, and type of wire. From this process, students are asked to determine whether the increase in wire length is affected by the tensile force, initial length, cross-sectional area, and Young's modulus.

In this context, the article focuses on the use of computer simulation as a virtual laboratory medium for determining the Young's modulus of various materials. This article emphasizes the stress-strain measurement approach to help students understand that Young's modulus is not simply a constant value but rather the result of the relationship between stress and strain in elastic materials.

This article aims to describe the design of a virtual lab to determine Young's modulus using computer simulations; explain how tensile force, wire length, diameter, material, and elongation relate; show how to find Young's modulus through stress and strain measurements and explain how computer simulations are safe, interactive, and easy for physics practice.

2 Mathematical Formulation

The Young's Modulus practicum using a virtual lab aims to determine the magnitude of Young's Modulus by looking at the functional relationship between the increase in the length of the metal wire (Δl) with the magnitude of the tensile force on the wire (F), the diameter of the wire (A), the length of the wire (l) and the Young's modulus of the wire (E). In general, the relationship between the five physical quantities can be written as follows:

$$\Delta l \propto F^a\ lo^b A^c E^d \quad (1)$$

$$m \propto (kg\,m\,s^{-2})^a\ m^b\ m^{2c}\ (kg\,m\,s^{-2}m^2)^d \quad (2)$$

$$m \propto (kg)^{a+d}(m)^{a+b+2c+-2d}(s)^{-2a-2d} \quad (3)$$

$$kg^0 m^1 s^0 \propto (kg)^{a+d}(m)^{a+b+2c+d-2d}(s)^{-2a-2d} \quad (4)$$

$$0 = a+d, \quad a=-d \text{ and } 1 = a+b+2c-d$$

$$0 = -2a-2d, \ a=1, \quad d=-1$$

$$1 = a+b+2c+d, \ 1 = 1+b+2c+1, \ so\ that\ 1-2 = b+2c$$

$$-1 = b+2c, \quad \text{if } b=1, \quad so-1 = 1+2c$$

$$-2 = 2c\,, c=-1$$

Got it $\mathrm{a} = 1, \mathrm{b} = 1, \mathrm{c} = -1$ dan $\mathrm{d} = -1$

So, we get the form of a hypothetical equation for increasing the length of the metal wire.

$$\Delta l \propto F^1\ lo^1 A^{-1} E^{-1} \quad (5)$$

$$\Delta l \propto \frac{FLo}{AE} \quad (6)$$

If the proportionality sign is replaced with an equal sign, we get:

$$\Delta l = C\frac{FLo}{AE} \quad (7)$$

The arbitrary constant C can be determined through practical activities by determining the gradient value of the virtual lab result curve using equation 8.

$$M = \frac{y_2 - y_1}{x_2 - x_1} \tag{8}$$

Then the general linear equation is determined using equation 9.

$$y = Mx + B \tag{9}$$

To determine the value of C and obtain the Young's modulus value from virtual laboratory data, the linear equation (9) is compared with the hypothesis in equation (8).

3 Numerical Methods

This study uses a quantitative descriptive approach based on computational simulation. The focus of the study is not on testing the effectiveness of experimental learning, but on utilizing computer simulation to generate elasticity lab data and help students determine Young's modulus.

3.1 Objects and Media

The lab object is a virtual metal wire with several input variables. These variables include tensile force, initial wire length, wire diameter, and material type. The virtual lab to simulate Young's modulus is shown in Figure 1.

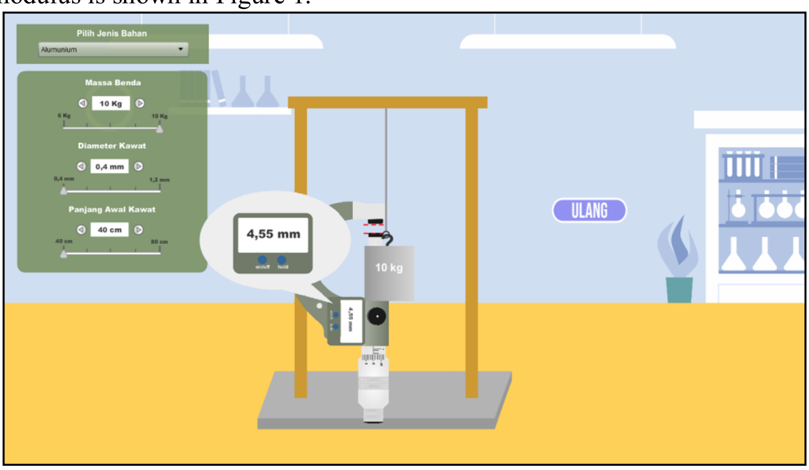

Fig. 1. Computer simulation for determining Young's modulus

The lab media in Fig. 1 is a computer simulation that displays a wire system, a load, a hanger, and a length-measuring tool. The virtual laboratory displays a variety of material types, diameters, wire lengths, and load masses, as well as a virtual screw micrometer to measure the wire's length increase.

3.2 Practical Variables

The independent variables in this lab are tensile force, initial wire length, wire diameter, and material type. The dependent variable is the increase in the wire's length. Students are instructed to use a worksheet to examine the relationship between the increase in length and tensile force, initial length, cross-sectional area, and Young's modulus.

3.3 Procedure

The procedure using a virtual laboratory is carried out in several stages. First, select the type of wire material consisting of aluminum, iron, steel, nickel, copper, and brass. Second, determine the initial length (40, 50, 60, 70, and 80 mm) and the wire diameter (0.4, 0.6, 0.8, 1.0, and 1.2 mm). Third, attach a load to the end of the wire (6, 7, 8, 9, and 10 kg). Fourth, read the increase in length using a virtual micrometer screw. Fifth, repeat the measurement by varying one of the variables, while the other variables are kept constant.

Before carrying out the practical activities, the practicum proposes a hypothesis about the form of the functional relationship between the magnitude of the increase in the length of the metal wire (Δl) with the magnitude of the tensile force on the wire (F), the diameter of the wire (A), the length of the wire (l), and the Young's modulus of the wire (E) on the elastic wire. To formulate the hypothesis, use the analysis of the units of the physical quantities involved.

4 Code Validation

The Young's Modulus Virtual Laboratory produces data on variations in the increase in wire length (Δl) due to variations in the load (tensile force) (F), while the wire length, diameter, and type of wire material remain as shown in Table 1.

Table 1. Virtual laboratory results data obtained by varying the load mass while other variables remain constant.

Wire length	Wire diameter	Types of wire	Load Mass (kg)	Tensile Force (F)	Increase in wire length (Δl)
50 cm	0.4 mm	Aluminum	6	60 N	3.41 mm
			7	70 N	3.98 mm
			8	80 N	4.55 mm
			9	90 N	5.12 mm
			10	100N	5.69 mm

Based on the data in Table 1, a curve is obtained that satisfies the linear function between Δl and F in Figure 2.

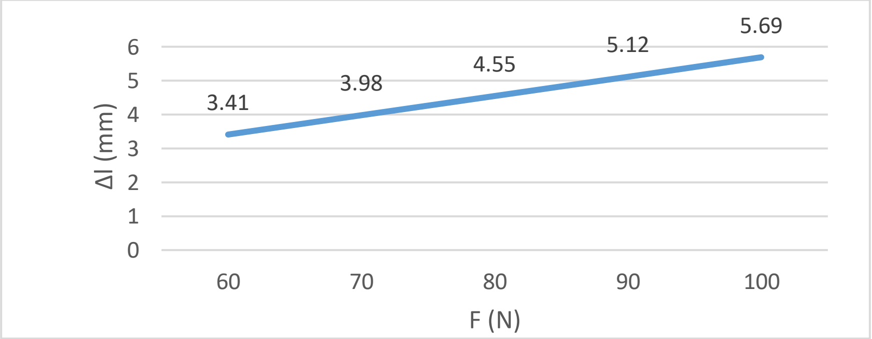

Fig. 2. Relationship curve between Δl and the F from virtual lab results

5 Results and Discussion

The Young's Modulus virtual laboratory displays a relationship consistent with the hypothesis. $\Delta l$with load variation (F) whereΔl ≈F, the relationship between length and length $\Delta l$of $\Delta l$the original wire(lo) ≈ lo, the relationship between $\Delta l$the area of the wire (A)whereΔl ≈1/A, the connection between $\Delta l$the type of wire (E) whereΔl ≈1/E.Based on Figure 2, the gradient value is obtained as follows:

$$M = \frac{y_2 - y_1}{x_2 - x_1} = \frac{4{,}55 - 3{,}98}{80 - 70} = 0{,}000057 m/N$$

The general linear equation is: y = Mx + B, where M is the gradient or slope of the graph. From the relationship equation between Δl and F, the gradient of M is obtained as $0{,}000057m$. The value of the proportionality constant C in the hypothesized equation can be determined by comparing the linear equation of the graph with the hypothesized equation. Based on the graph, the equation obtained is $\Delta l = M\ F$
from the hypothesis obtained:

$$\Delta l = C\frac{FLo}{AE}$$

By comparing the two equations for Δl, the following relationship will be obtained:

$$M = C\frac{Lo}{AE}$$

by entering the value of lo = 50 cm, d = 0.4 mm and the value of E (aluminum) = 7 x 10^{10} N/m 2, we will get:

$$A = \frac{22}{7} 0{,}2x0{,}2x10^{-6}\ m^2 = 0{,}125x10^{-6} m^2$$

$$C = \frac{MAE}{Lo} = \frac{0{,}57x\ 10^{-4} m/N\ x0{,}125x10^{-6} m^2 x\ 7x10^{-6} \mathrm{N}/m^2}{0{,}5\ m} = 1$$

By obtaining the value C = 1, an equation is obtained that connects the increase in the length of the metal wire (Δl) with the magnitude of the tensile force on the wire (F), the area of the wire (A), the length of the wire (l), and the Young's modulus of the wire (E) $\Delta l = \frac{FLo}{AE}$, and the Young's Modulus value can be determined using the equation $E = \frac{FLo}{A\Delta l}$.

Young's modulus for Table 1 is 70.009 GPa, 69.980 GPa, 69.958 GPa, 69.941 GPa, 69.927 GPa. The average Young's modulus of aluminum is 69.963 GPa. The absolute uncertainty (ΔY) is calculated from the average of the differences of each value with respect to the average value using equation 10. The Relative Uncertainty (RU) is obtained by comparing the absolute uncertainty to the average value using equation 11.

$$\Delta Y = \frac{\sum Y_i |\bar{Y}|}{n} \quad (10)$$

$$RU = \frac{\Delta Y}{\bar{Y}} x100\% \quad (11)$$

The calculation results are ΔY =0,025 GPa and RU= 0,036%. The relative uncertainty is 0.036%. This value is very small, so the simulation results can be considered quite consistent. This also shows that the relationship between tensile force and wire elongation is nearly linear. Based on the description above, the Young's Modulus virtual lab, utilizing computer simulation, makes an important contribution as a physics practicum medium because it offers an interactive, safe, and easy-to-use learning experience, especially for abstract concepts.

Computer simulations serve as interactive lab media because students not only see conceptual explanations but can also change variables, observe changes, and analyses relationships between physical quantities directly [11]. In the Young's Modulus lab, for example, students can vary the tensile force, wire length, wire diameter, and material type. These changes are immediately displayed as increases in length, data tables, or graphs. In this way, students more easily understand that the increase in wire length is influenced by the applied force, initial length, cross-sectional area, and the material's elastic properties.

Computer simulations help create safer labs [9,11]. Some physics activities require specific tools, materials, or conditions that pose risks if performed directly, such as high voltages, extreme temperatures, fragile materials, or sensitive measuring instruments [12,13]. Through simulations, students can still learn physics principles without the risk of injury, equipment damage, or dangerous procedural errors [11,14]. In elasticity labs, simulations can also prevent the risk of broken wires, falling loads, or incorrect use of measuring instruments.

In terms of convenience, computer simulations are a practical, easy-to-use laboratory tool because they can be accessed on a computer or digital device without requiring extensive laboratory equipment [15]. Students can perform experiments repeatedly at their own pace. Errors in data entry or variable selection can also be quickly corrected without restarting the equipment setup. This is particularly helpful for schools or educational institutions with limited physics laboratory facilities.

Computer simulations also strengthen students' analytical skills [11]. Lab data can be displayed numerically and processed into tables, graphs, and mathematical models. Students can observe patterns of relationships between variables, such as the linear relationship between tensile force and the increase in a wire's length. Thus, simulations not only help understand concepts but also hone the ability to read graphs, interpret data, and draw conclusions based on evidence.

Thus, the primary contribution of computer simulations to physics labs lies in their ability to provide more visual, active, safe, cost-effective, and flexible learning. Computer simulations can be an alternative when laboratory equipment is limited and can also complement real-world labs, enabling students to gain a stronger, more systematic understanding of concepts.

6 Conclusion

Determining Young's Modulus through stress and strain measurements can be done effectively using a computational approach. Virtual lab simulations allow students to vary the tensile force, initial wire length, wire diameter, and material type, enabling a more concrete understanding of the relationships among variables in the concept of elasticity.

The results of the virtual lab show that the increase in wire length is directly proportional to the tensile force and the wire's initial length, but inversely proportional to the cross-sectional area and Young's Modulus. The linear relationship between the increase in wire length and the tensile force indicates that Young's Modulus can be determined from the gradient of the graph of the measurement results. Thus, the virtual laboratory can be a learning medium that helps students understand the concept of elasticity visually, interactively, and measurably, especially when physical laboratory facilities are limited.

7 Suggestion

While virtual laboratory simulations facilitate learning, several drawbacks should be considered. First, simulations do not fully represent real-world experimental conditions because factors such as measurement error, instrument imperfections, friction, non-ideal material behavior, and environmental influences are not always present in virtual systems.

Second, simulation-based practical activities tend to limit students' manual skills, such as using measuring instruments, setting up experimental materials, reading scales, and directly controlling experimental variables. Third, the results obtained are highly dependent on the program design and mathematical model used in the simulation. If the model is too idealized, students may obtain an overly simplistic understanding of real-world elasticity phenomena.

Furthermore, empirical testing of its effectiveness in improving students' conceptual understanding and thinking skills remains necessary. This article is primarily descriptive-computational in nature, so it cannot yet confirm the extent to which the use of virtual labs actually improves learning outcomes compared to conventional practical methods.

8 Recommendation

The development of this virtual laboratory should be continued by adding features that more closely approximate real-world experimental conditions, such as measurement errors, material elastic limits, variations in measuring instrument accuracy, and the possibility of less-than-ideal experimental data. This is crucial so that students not only understand the mathematical relationships between variables but also the characteristics of experimental data in real-world physics practice.

Further research is recommended to test the effectiveness of using a virtual lab on improving conceptual understanding and other thinking skills. Testing can be conducted through experimental or quasi-experimental designs by comparing classes using a virtual lab with classes using conventional learning methods.

Furthermore, virtual labs should be used not only as a substitute for physical labs but also as a complement to them. Simulations can be used before the actual lab as a conceptual preparation activity, or after the actual lab to strengthen data analysis. This way, learning about elasticity becomes more comprehensive by combining conceptual understanding, mathematical analysis, interactive visualization, and experimental experience.

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