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Original paper

The problems with the mathematics during laboratory exercises in physics – how to solve them?

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ABSTRACT
The aim of this paper is to point out to a problem of mathematics, which now a physics teacher has to face and the possibilities of its solution. For quantity processing of dates and visualisation of experimental data, a program IP COACH is used. Students, however, do not want to know only the "no software" solution to the problem. They are also interested in the answers to questions, such as: Why has this approximate function been selected? What is the principle of approximation of measured data in an appropriate function? Answers to these questions will be provided by numerical mathematics. It is taught only in the 2nd year of their study. This means that a finding a solution to this problem requires a cooperation of a mathematician and a physicist.

KEYWORDS: Interdisciplinary relations, measurement at the physics, interpolation, approximation, software *Mathematica*®

JEL CLASSIFICATION: N50, M50

INTRODUCTION

The quality of teaching of mathematical subjects is an important determinant of the quality of the vocational education at universities of technology. In addition to the comprehensive education of mathematics in engineering, physics and descriptive geometry also play an important role [1]. The role of these subjects in university education is understood by the future engineer only when they realize their usefulness and usability in their own technical field.

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Therefore, a role of the teacher of mathematics is to prevent the future engineer from isolating theoretical knowledge from practical skills and habits. This fact highlights the importance of interdisciplinary relations in the teaching at university of technology.

MATERIAL AND METHODS

Problem with mathematics - where and way

Physics, as well as mathematics, fulfils its role in university education at the Slovak university of technology in Bratislava at the Faculty of Mechanical Engineering. Part of the physics teachings are the lab exercises. Laboratory exercises of physics are included in the 1nd year of Bachelor's degree studies at the Faculty of Mechanical Engineering. They are carried out in the summer term in the range of 26 hours – 2 hours/week.

These exercises are designed to measure different characteristics, for example the measurement of the characteristics of the magnetron (interpolation); analysis of the process of charging and discharging a capacitor; validation of the Steiner's theorem; etc. Students measure the necessary data, which need to be further processed, quantitatively and qualitatively. For the quantitative processing and visualization of experimental data a program IP COACH is used. IP COACH provides as follows:

- saving the measurements in the Excel file,
- graphical representation of the measurements,
- selecting an appropriate approximate function in the general shape and consequently the parameters of the solution.

The problem for the laboratory exercises in physics is in the conclusion of the exercise at the time reserved for discussion. Students want to know not only the "no software" solution to the problem. They are also interested in the answers to questions, such as: Why has this approximate function been selected? What is the principle of approximation of measured data in an appropriate function? Answers to these questions will be provided by numerical mathematics. It integrates various mathematical disciplines in itself and has an interdisciplinary nature with regard to the determination of the application. It belongs to obligatory subjects of the Bachelor's degree study. It is taught only in the 2nd year in the summer term. The cause of the problem is thus very simple – the lab exercises in physics precede the numerical mathematics one academic year.

Solution to the problem with mathematics

From the above, it can be followed that for a physics teacher it is not sufficient that they master the program but they also should be familiar with mathematical machinery needed to solve this problem. This requires cooperation with one of the mathematicians.
Due to time utilisation rate, the exercise is moved to the nearest seminar during which the answers to the questions of physics. The seminar provides greater scope for different discussions. The possible solutions are as follows:

1. a physics teacher answers students' questions.
2. on a voluntary basis students are set a paper on the topic of the approximation of functions.
3. students get themselves to study functions and during the seminar on the approximation, they discuss it with a teacher of physics or numerical mathematics.
4. physics teacher is invited to a seminar a numerical mathematics teacher who will solve the problem and clarify the principle of approximation of functions briefly – interpolation and approximation in the meaning of the method of least squares approximation, or function fit

and by using the software system Mathematica®, realizes the calculations and graphical display of data.

A physics teacher gives priority to the fourth solution because the solutions to other laboratory measurements - for example, the measurement of the characteristics of the magnetron, analysis of the process of charging and discharging a capacitor - "hides" in itself knowledge of approximation of functions.

Numerical mathematics teacher will solve the problem smoothly. First, they explain the principle of approximation of functions (interpolation and approximation in the meaning of the method of least squares approximation, or function fit) briefly and by using the software system Mathematica®, realizes calculations and graphical display of data. (A more detailed knowledge of the approximation of functions, the students become aware only in the 2nd year in the subject of Numerical Mathematics.)

We demonstrate an elegant solution to this problem in one of the laboratory exercise of physics. The topic of the laboratory exercises: validation of the Steiner's theorem.

RESULTS AND DISCUSSION

Laboratory exercises

One of these tasks is also a laboratory exercise [2] aimed at measuring with the pendulum. The motions can be broadly categorized into two classes, according to whether the thing that is moving stays near one place or travels from one place to another. Examples of the first class are an oscillating pendulum, a vibrating violin string, electrons vibrating in atom, etc. The physical pendulum consists of any rigid body suspended from a fixed axis that does not pass through its centre of mass. Consider a rigid body pivoted at a point *O* (see fig.1) that is the distance *a* from the centre of mass.

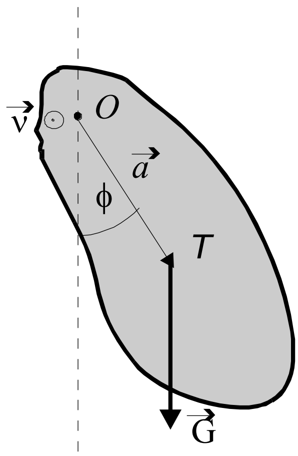

Fig. 1 Physical pendulum

Motion such as body gives by the formula

$$\boldsymbol{\tau} = I\boldsymbol{\varepsilon}, \qquad (1)$$

where: $\boldsymbol{\tau}$ is the torque of the force to the axis of rotation defined as $\boldsymbol{\tau} = \boldsymbol{a} \times \boldsymbol{G}$, I is the moment of inertia about an axis through the pivot, defined by $I = \int a^2 dm$, a is the distance from the mass element dm to the axis of rotation, $\boldsymbol{\varepsilon}$ is the angular acceleration given by $\boldsymbol{\varepsilon} = \dfrac{\mathrm{d}^2\Phi}{\mathrm{d}t^2}\boldsymbol{\nu}$.

The general solution of equation (1) is: $\Phi(\boldsymbol{t}) = A\cos(\omega t + \alpha)$, where: A is the amplitude of the motion, α is the phase constant. The period T of the physical pendulum is

$$T=2\pi\sqrt{\frac{I}{mga}} \qquad (2)$$

We note that I is the moment of inertia of the rotating body about the fixed axis that not pass through the centre of mass. When we use the parallel-axis theorem

$$I = I_{c.m.} + ma^2, \qquad (3)$$

where: $I_{c.m.}$ is the moment of inertia of the rotating body to the axis of rotation passing through the centre of mass, m is the mass of the body and a is the perpendicular distance between both axis then eq.2 is in form

$$T = 2\pi\sqrt{\frac{I_{c.m.} + ma^2}{mga}} \quad \text{or} \quad a^2 - g\frac{T^2}{4\pi}a + \frac{I_{c.m.}}{m} = 0 \qquad (4)$$

From the eq. (4) we see that the period of physical pendulum varies with the distance a. We can observe that there is the distance $a_{\min}$ of which is the period $T_{\min}$. This minimum may be determine mathematically taking the derivative of the period given by eq. (4) with respect to distance a. Then we have

$$a_{\min} = \sqrt{\frac{I_{c.m.}}{m}} \qquad (5)$$

$$T_{\min} = 8\pi\sqrt{\frac{a_{\min}}{g}} \qquad (6)$$

Using constant q and k we have

$$aT^2 = q + ka^2, \qquad (7)$$

where constants q and k are given by

$$q=\frac{4\pi^2 I_{c.m.}}{mg}, \ k=\frac{4\pi^2}{g}.$$

The verification the parallel - axis theorem means the verification linearity of eq. 7. Using eqs.5, 6, and 7 calculate $I_{c.m.}$, g, $a_{\min}$ and $T_{\min}$ as

$$I_{c.m.} = \frac{q}{k}m, \ g = \frac{4\pi^2}{k}, \ a_{\min} = \sqrt{\frac{q}{k}}, \ T_{\min} = \sqrt[4]{4qk} \qquad (8)$$

Determine the slope of the T versus a. The slope finds out $a_{\min}$ and $T_{\min}$. Compare these values with the values obtaining from eq. 5 and 6. Value of acceleration of gravity g compare with accepted table's value.

Solution by system Mathematica®

The formulation of this problem in mathematics: *measurement of period T the pendulum plate depending on the distance and from the axis of rotation of this board, and were relatively accurately measured the following values.* (Table 1).

Table 1. The measured values for *a* and *T*

i	1	2	3	4	5	6
a	0,281	0,176	0,170	0,108	0,086	0,036
T=T(a)	0,593	0,539	0,537	0,542	0,562	0,770

a) Definitely a local minimum of the function $T = T(a)$.

b) Definitely slope of line $aT^2 = aT^2(a^2)$,which approximates data $\left\{\left[a_i^2 ; aT_i^2\right]\right\}_{i=1}^{6}$.

An elegant solution to the problem, which will provide numerical mathematics using Mathematica® system software after the explanation of approximation of functions (in the meaning of the method of least squares approximation, or function fit) students is given on the fig.2, fig.3 and on the table 2.

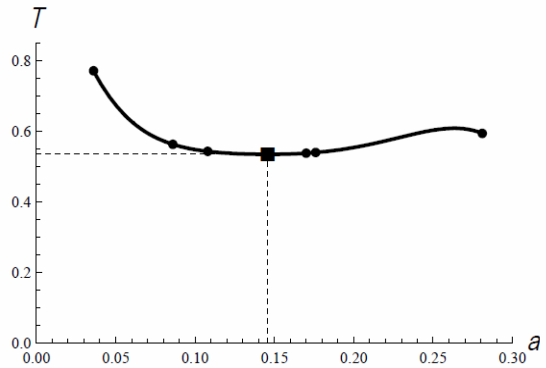

Fig. 2. Graph of measured values, interpolation polynomial *IP*(x) and local minimum

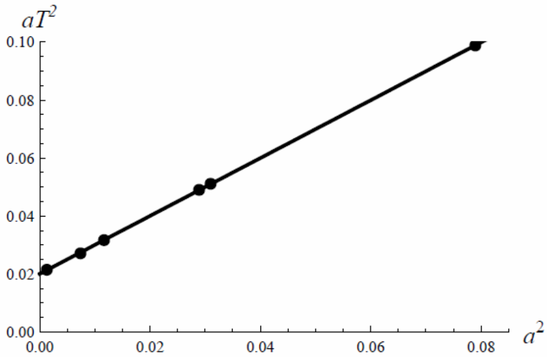

Fig. 3. Graph of measured values, interpolation polynomial *AP*(x)

Table 2 An overview of the measured data, the interpolation polynomial, approximation function and physical search parameters

a	T	a^2	aT^2
0.281	0.593	0.078961	0.0988134
0.176	0.539	0.030976	0.0511317
0.17	0.537	0.0289	0.0490227
0.108	0.542	0.011664	0.0317265
0.086	0.562	0.007396	0.0271626
0.036	0.77	0.001296	0.021511
$IP(x) = 1,2987 - 22,543x + 271,869x^2 - 1665,26x^3 + 5104,71x^4 - 6116,66x^5$			
Lokal minimum *IP*(*x*): [0,145735 ; 0,533727]			
$AP(a) = 0,0200865 + 0,997837x$ => slope of line: k = 0,997837			

CONCLUSIONS

By the simple solution of the technical problem, we can see that natural but also technical subjects at the University of Technology cannot be taught in isolation. They are connected to each other. Cooperation with "physicists" enriches both sides of the mathematicians. Some of the tasks of the laboratory exercise of physics can be also used in the teaching of numerical mathematics – they point to the possibility of its practical use or they can be set as a project within the framework of the student scientific and professional activity in the first cycle of university education.
We expect that the future will bring consistency in teaching both subjects – mathematics and physics.

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