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Software Support for the Higher Mathematics Course at the Technical University

Part 1. Basic questions

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Abstract—The paper addresses the challenges of training modern engineers in mathematical disciplines. It emphasizes the need for graduates to possess theoretical knowledge and be capable of using modern software solutions for efficient mathematical calculations. The article discusses the importance of incorporating mathematical software into higher education to enhance the teaching of mathematical disciplines. Explores the potential benefits and challenges of using mathematical software in the learning process, such as the need for coordination among teachers and the importance of familiarizing students with the interfaces of mathematical packages. The paper recommends using specific mathematical software packages, such as Scilab, for scientific and engineering calculations. It also highlights the necessity of guiding students in understanding the practical applications of mathematical software in solving complex mathematical problems. Furthermore, the paper addresses the issue of preventing students from inappropriately using online calculators for tasks, emphasizing the importance of mastering theoretical foundations before utilizing mathematical software packages. The paper generally advocates for a balanced approach that incorporates both traditional theoretical exposition and practical application of mathematical programs in higher education to promote effective teaching and learning of mathematical disciplines.

Keywords — educational technology; hybrid learning; electronic learning; engineering education; electrical engineering; calculus; mathematical programming.

I. Introduction

Training modern engineers in mathematical disciplines is becoming an increasingly difficult task [1]. The requirements for graduates of higher education institutions [2] lie not only in the level of knowledge of existing theoretical methods and the use of specific formulas — but also in the ability to analyze the tasks, choose the necessary calculation method, and... not calculate the data with the help of a calculator or spreadsheets, but use modern software solutions to obtain the fastest possible result. [3]

Of course, the numerical calculation can only be done correctly with an understanding of the theory. But do we correctly build a training program using only "pen and paper," limiting ourselves to analytical transformations? Should the learning process be focused on testing the student's ability to perform standard mathematical procedures on paper?

Such questions cause and will cause much controversy. We do not try to provide a universal solution but offer to consider one of the possible models: a combination of traditional theoretical exposition of the material with demonstrations and practical application of mathematical programs; in turn, control measures should be focused not on conducting standard calculations, but on analyzing the chosen method and understanding its features.

Professional mathematical packages are usually understood as programs (program packages) that perform various numerical and analytical (symbolic) mathematical calculations, from simple arithmetic calculations to solving partial differential equations, optimization problems, testing statistical hypotheses, etc. In a slightly expanded sense, such packages usually have the following functions:

- editing mathematical texts;
- construction of graphs of functions, images of geometric objects, sets, construction and manipulation of graphs, reproduction of dependence (signal), the graph of which is specified by an analytical function or a set of points, import and export of graphics and sound;

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- execution of symbolic transformations and corresponding calculations;
- implementation of numerical and numerical analytical methods.

It is clear that when students apply the methods learned in the course of higher mathematics, all these functions can be used with high efficiency, but the practical use of these functions is associated with several problems; the analysis of some of them is devoted to this work.

II. Selection of Specialized Software for Teaching Higher Mathematics

Firstly, in our opinion, given the current level of development of graphic tools, on the one hand, and the level of knowledge and skills of students acquired from a school geometry course, on the other hand, the use of additional software packages such as GeoGebra in the educational process is indispensable. It should be noted here that the course of higher mathematics, in this sense, is only forced to follow the example of the course of applied geometry, which in most cases known to us now contains computer graphics instead of traditional engineering graphics. The capabilities of the software packages mentioned above allow, among other things, viewing spatial geometric images from different angles and analyzing their sections. At the same time, for example, when constructing graphs of functions, the vast majority of existing packages do not contain the function of a detailed demonstration of a complete study of functions, the scheme of which is a fundamental element of the course of mathematical analysis, as a result of which the students' understanding of the validity of the form of the graph is lost.

Secondly, as evidenced by, for example, the study [4], the use of mathematical packages is effective when considering "mass" tasks in practical classes, such as finding limits, calculating derivatives, integrals, etc. In these cases, under proper guidance from teachers, students have the opportunity and must even use such software tools as a simulator, which allows them to learn the following:

- classify the type of specific task (limit, derivative, integral, etc.);
- learn the procedure for its implementation;
- to learn to adhere to a certain standard of design solutions to such problems.

With such an approach to the educational process, it is necessary to have software tools that ensure the "generation" of a sufficient number of tasks for students.

When students study mathematics courses, it is essential to refer to the relevant functions of the mathematical package chosen for use in studying each topic, if possible, a detailed explanation of the fundamental difference between the formal mathematical approach and the implementation of mathematical methods in practical tasks.

The most common include packages such as Maple, MathCAD, MATLAB, Scilab, Wolfram and others [5], [6]. Such packages differ in the interface, capabilities, platforms (available for use by operating systems), and, most importantly, their distribution freely or through a paid license. Accordingly, the first problem that arises when using them in the educational process is the choice of a specific package, which requires coordination of the positions of all "internal consumers" — teachers of mathematics, programming, general engineering, and special disciplines, probably deciding on the use of a specific such package on levels of the higher methodological council, or at least the methodological commission of each faculty (institute), which is its structural subdivision.

As a possible software package, Scilab version 2024.0.0 was chosen. This mathematical package is free, can be used without legal problems, and provides extensive possibilities for scientific and engineering calculations.

The second problem, in our opinion, is the distribution of functions between the aforementioned "consumers." The fact is that when students study computer science (programming) courses, their opportunities to familiarize themselves with such packages are usually minimal. To an even greater extent, this applies to mathematics courses themselves. At the same time, even the presence of a course (not at all mandatory!), which can be conventionally called, for example, "Introduction to Computational Mathematics," usually does not solve the problem of students' timely and conscious mastering of the applications of mathematical packages! The fact is that considering the curricula, such a course is usually taught somewhat late and turns out to be overloaded. According to the authors, a way out of such a situation is possible only if the teachers' actions in the three courses above are maximally coordinated. For example, the computer science course program must include familiarization with the interfaces of mathematical packages, teaching students how to edit mathematical texts, and entering data in numerical and symbolic forms when using specific programs. Accordingly, in higher mathematics, there is an opportunity, based on the knowledge and skills acquired by students, to illustrate the study of each course topic with examples of software tools.

Let us turn, for example, to the course of analytical geometry (or the corresponding sections in the course of higher mathematics). One of its main elements is the theory of matrices, which is considered from the point of view of the algebra of such objects. Students' thorough understanding of mathematical calculations with matrices and tensors is the basis for further mastery of specialty 171 Electronics. In addition, it is

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a fundamental element for working with systems of linear algebraic equations (SLAE).

When studying systems of linear algebraic equations, in our opinion, it is necessary to draw students' attention to the dependence of the number of arithmetic operations required by each of the standard methods of solving SLAE on the number of its equations, which makes their "manual" implementation impossible with enough large dimensions of systems, it is also advantageous to demonstrate the effect of the accumulation of computational error, which leads to the appearance of a significant discrepancy — the difference between the left and right parts of the equations of the system obtained as a result of its solution. In this way, the practical necessity of using iterative methods in this case is substantiated, i.e., replacing exact methods with approximate ones! Of course, it is handy to familiarize students with specific algorithms for solving "sparse" systems, which are most often found in practical applications.

The Scilab 2024.0.0 software package offers a huge number of ready-made solutions for such calculations, but we will list only a small number of them [7], [8]:

- carrying out calculations using methods of numerical algebra;
- built-in libraries for solving algebraic equations;
- possibility of obtaining numerical solutions of differential and integral equations;
- presentation of functions in various coordinate systems, both two-dimensional and three-dimensional;
- optimization of mathematical functions and much more.

III. EXAMPLES OF USING SCILAB IN THE EDUCATIONAL PROCESS

Let's consider several traditional problems that students of the Electronics 171 specialty should be able to solve while fully understanding the meaning of their actions and their consequences.

A. Work with matrices

We are determining the determinant and rank of a matrix. Let's generate a random matrix of size 6*6, which consists of 2 significant numbers. For example, we deliberately chose the matrix size of 3*3, which is not traditional for lectures, since this limitation is caused by the complexity of calculations on the board.

```
--> A = round(100*rand(6,6))
 A  =

   4.    78.   84.   56.   39.   26.
   48.   21.   41.   59.   92.   50.
   26.   11.   41.   69.   95.   26.
   41.   69.   88.   89.   34.   53.
   28.   15.   11.   50.   38.   54.
   13.   70.   20.   35.   73.   12.

-->
```

Now consider the result of calculating the determinant of such a matrix:

```
--> det(A)
 ans  =

   1.740D+10

-->
```

The result is provided to students immediately. You can discuss its content and dimensions. You can immediately show students what the presence of linear dependencies in rows or columns leads to.

```
--> B = [A(1:4,:); 6*A(4,:); A(6,:)]
 B  =

   4.     78.    84.    56.    39.    26.
   48.    21.    41.    59.    92.    50.
   26.    11.    41.    69.    95.    26.
   41.    69.    88.    89.    34.    53.
   246.   414.   528.   534.   204.   318.
   13.    70.    20.    35.    73.    12.
```

```
--> det(B)
 ans  =

   0.0000125
```

```
--> C = [A(:,1:4) 6*A(:,3) A(:,6)]
 C  =

   4.    78.   84.   56.   504.   26.
   48.   21.   41.   59.   246.   50.
   26.   11.   41.   69.   246.   26.
   41.   69.   88.   89.   528.   53.
   28.   15.   11.   50.   66.    54.
   13.   70.   20.   35.   120.   12.
```

```
--> det(C)
 ans  =

   0.0000124
```

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The results should indicate to students the need to consider machine errors during calculations. A serious problem here is that many users of mathematical programs trust the obtained results unconditionally without checking their compliance with the conditions of the issues that were solved with their help.

Let's look at the results of calculating the ranks of the matrices:

```
--> [xA, dimA] = range(A,1)
 xA  =

  -0.4226498  -0.4428189  -0.4100097  -0.5239288  -0.2691015  -0.3320447
   0.5628471  -0.4624363  -0.4643955   0.439494   -0.2451389  -0.0210854
  -0.2162569   0.093634   -0.103033    0.4516329   0.3968023  -0.756588
   0.2486887  -0.0075971   0.59445    -0.0485344  -0.5857482  -0.4891512
  -0.0726919   0.7247171  -0.4667224   0.0858097  -0.4931462  -0.033388
   0.6250385   0.2366942  -0.185506   -0.5644931   0.3517743  -0.276573
 dimA  =

   6.
```

```
--> [xB, dimB] = range(B,1)
 xB  =

  -0.1273342  -0.1126497  -0.1012755  -0.160561   -0.9633658  -0.0835814
   0.0159027  -0.6145075  -0.6475695   0.0282086   0.1692516  -0.4163408
  -0.5992934   0.2978546   0.184787    0.0141007   0.084604   -0.7145818
  -0.6051349   0.2734671  -0.5674157   0.0106689   0.0640135   0.4825509
   0.5081262   0.6679738  -0.4629149  -0.0117823  -0.070694   -0.2760291
  -1.803D-16   1.315D-16  -3.003D-16   0.9863939  -0.164399   -7.895D-18
 dimB  =

   5
```

```
--> [xC, dimC] = range(C,1)
 xC  =

  -0.6052646  -0.3064416  -0.3024982  -0.6435542  -0.0958072  -0.1578044
   0.5183411  -0.4621981  -0.2660884  -0.0331191  -0.6664298  -0.0408276
  -0.048426    0.1576645   0.3229367   0.0731467  -0.224355   -0.901567
  -0.1883143  -0.3167871   0.8274113  -0.0967691  -0.2713565   0.3107662
   0.3863269  -0.5529538   0.1542966  -0.2100286   0.6475343  -0.2403613
  -0.4218075  -0.5113672  -0.1580721   0.7251996   0.0584997  -0.0791112
 dimC  =

   5.
```

Students visually receive quick information about the orthogonal matrix and the rank of the original matrix. In this way, it is possible to significantly reduce the time for routine calculations during practical classes, to allow students to explore various variations of matrices, and to emphasize the analysis of the obtained results. It is a thorough analysis that will show the student's understanding of the material, not the performance of standard calculations (often passed down "by inheritance" from senior to junior courses).

B. Study of functions

Similarly, it is handy to demonstrate the problems that arise, for example, when solving extremum problems that require finding solutions to non-trivial equations and their systems.

Consider an example of using Scilab to find the extremum of a function $y = \dfrac{x^3 + 3x^2 - 2x - 2}{\sqrt{x^2 - 2}}$. The list of relevant teams will be as follows (the language of the comments is aimed at students of Ukrainian higher education institutions):

```
// Визначення функції
function [y, g, ind] = myfun(x, ind)
    y = (x^3 + 3*x^2 - 2*x - 2)/sqrt(x^2 - 2); //function
    g = (2*x^4 + 3*x^3 - 6*x^2 - 10*x + 4)/(x^2 - 2)^(3/2); //gradient
endfunction

// Крок 2: Встановіть початкове значення
x0 = 2;

// Крок 3: Запустіть алгоритм оптимізації
[fopt, xopt] = optim(myfun, "b", 1.5, 20, x0);

// Крок 4: Проаналізуйте результати
disp(['Знайдений мінімум: x = ' string(xopt)]);
disp(['Значення функції в мінімумі: y(x) = ' string(fopt)]);
```

The results of the script execution give the result for the argument – 1.67 (Fig. 1) and for the function – 8.65 (Fig. 2). You can view the behavior of the function under investigation at a given interval in the form of a graph and make sure that the obtained result is correct:

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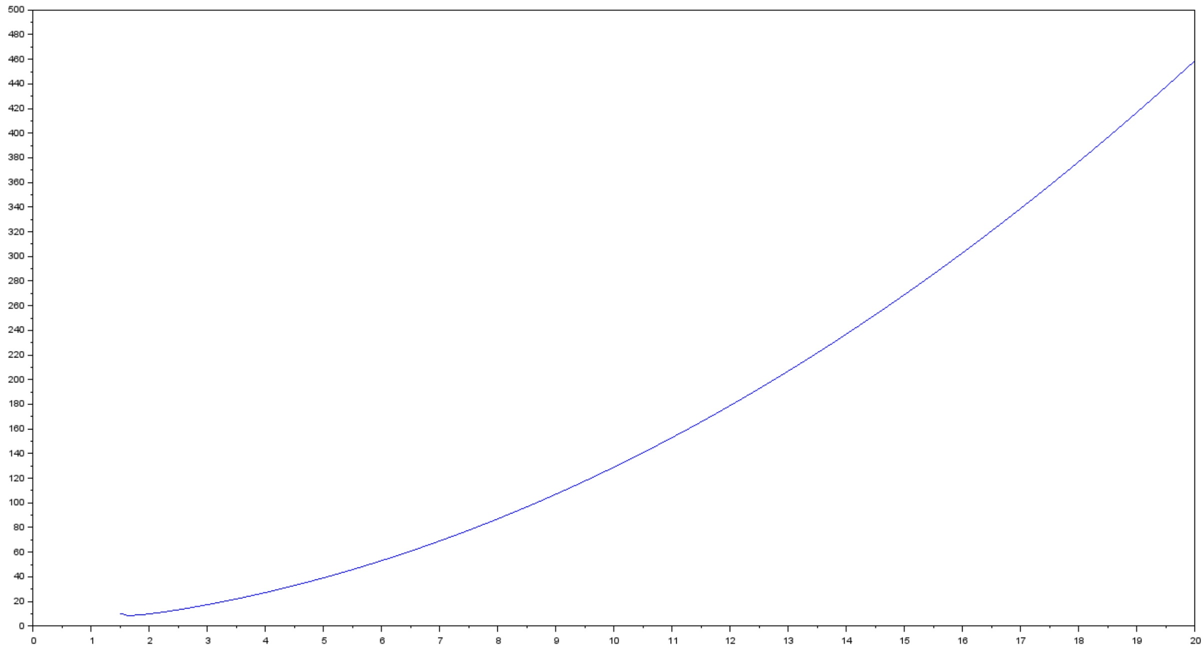

Fig. 1 Results of the script execution give the result for the argument - 1.67

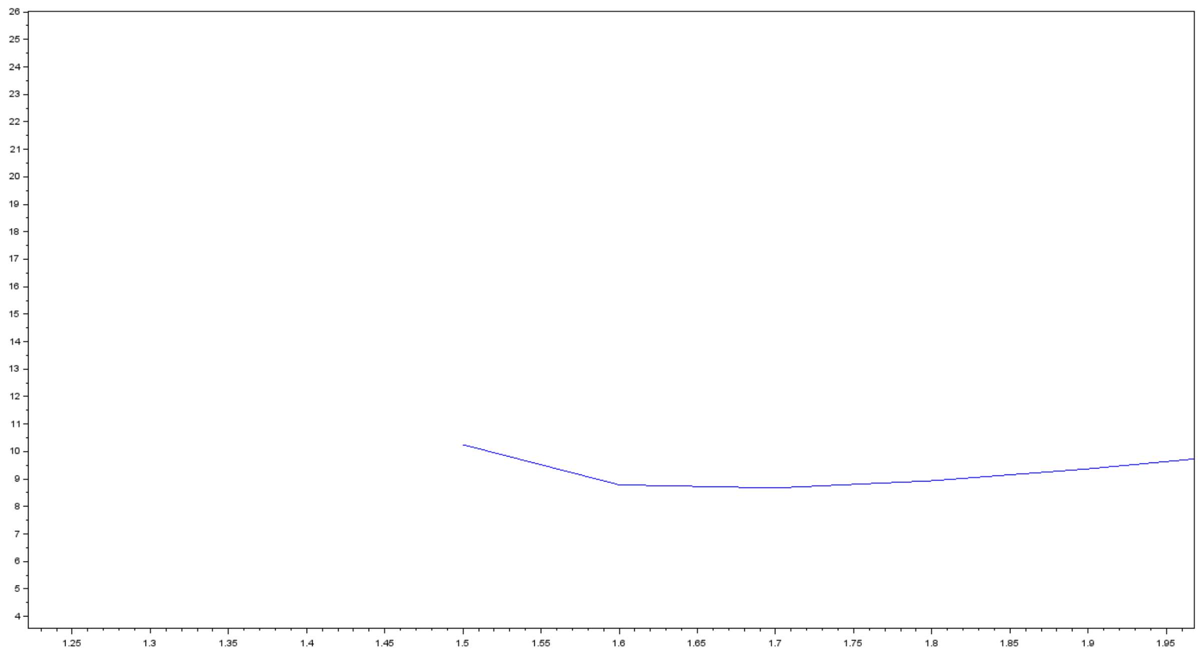

Fig. 2 Results of the script execution give the result for the argument - 8.65

As you can see, the student will not only be able to quickly get the result of the calculations but also visually confirm the correctness of the answer found. It should also be noted that the student will practice the functions defined by the differential. This action is necessary for the correct functioning of the *optim* command. However, it can be replaced by a numerical search for the differential of the function at the following stages of mastering the theoretical material.

C. Features of integral and differential calculus

Turning to the teaching of integral calculus, we note that explaining to students that only a few classes of even elementary functions are integrable in the traditional sense is fundamentally essential. That is, they allow

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writing out their primitives in terms of elementary functions again. And this, in turn, makes it impossible to use the Newton-Leibnitz formula! Again, such an explanation allows students to understand the relevance of quadrature formulas and, later - the corresponding numerical analytical methods. Of course, the list of emphases when studying different sections of the higher mathematics course can be very diverse depending on the direction of student training, but very significant from the point of view of mastering the use of mathematical packages is the mandatory reference to the possibility (or rather, the necessity!) of their use in the practical application of mathematical methods in each case.

IV. *Ethical issues*

The third problem well known to every mathematics teacher, and not only that, is the need to fight against students' unauthorized use of mathematical packages as online calculators when completing tasks for independent work and, especially, when they pass control measures. It should be noted that in such cases, there is not only the evasion of students from the normal learning process (acquiring appropriate knowledge, skills, and abilities) and a flagrant violation of the principles of academic integrity but also the creation of the illusion that they are acquiring skills and abilities to master the possibilities of using mathematical packages, which is impossible without thorough mastering of the mathematics course! Usually, the following measures are used to avoid this kind of excesses:

- carrying out explanatory work with students, aimed at explaining to them the consequences mentioned above of the use of mathematical packages not agreed with the teachers of mathematics;
- mandatory interviews ("defenses") when students perform independent tasks - homework, typical calculations, calculation, and graphic works, control of the works as mentioned earlier regarding the presence of specific signs of the use of online calculators well known to teachers: absence of intermediate transformations, non-standard markings, etc.;
- if possible, conducting control events only offline, with appropriate monitoring of students' work;
- in the case of conducting control measures online, by selecting the tasks offered to students to perform, try to avoid the possibility of using online calculators.

Conclusion

Only after students have mastered the theoretical foundations of basic calculations and understand the content of transformations possible for a specific task can we see the possibility of wide application of the mathematical software package. The authors know that teaching requirements are pretty challenging to implement in the conditions of a certain number of higher mathematics disciplines. Therefore, we suggest supplementing the standard training plans with additional short-term video materials on using Scilab for relevant lecture topics.

Finally, the last (in order of consideration, but not in order of importance!) of the topical problems of this topic is a set of issues related to the "directly didactic" use of mathematical packages, that is, their use by students not instead of traditional methods of acquiring knowledge, skills, and abilities, and in the process of obtaining the latter. It should be noted that the Scilab mentioned above package cannot act as a "didactic tool" since it is not an aid. Mastering it is one of the goals of the educational process. Moreover, it does not include the possibilities of symbolic transformations in its functionality, which, in our view, is necessary for use in practical classes with students.

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Програмні засоби супроводження курсу вищої математики у технічному університеті

Частина 1. Основні питання

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Анотація—У статті обговорюються проблеми підготовки сучасних інженерів з математичних дисциплін, наголошується на необхідності балансу між теоретичними знаннями та практичним застосуванням за допомогою програмних засобів. Розглянуто використання професійних математичних пакетів, таких як Scilab, у викладанні вищої математики, оскільки вони надають необхідні інструменти для візуалізації та розуміння складних математичних концепцій. У статті також обговорюється використання Scilab у розв'язанні традиційних задач зі спеціальності 171 Електроніка, таких як робота з матрицями та аналіз властивостей функцій. Підкреслюється необхідність розуміння студентами основних математичних принципів.

Розглядаються такі етичні питання, як можливість академічної нечесності та хибне відчуття набуття навичок, коли студенти використовують математичні пакети як онлайн-калькулятори. Для пом'якшення цих проблем пропонуються такі заходи, як роз'яснювальна робота, обов'язкові співбесіди, офлайн-оцінювання та ретельний вибір завдань. Вибір програмного забезпечення має бути скоординований між педагогами, щоб забезпечити узгодженість методів навчання.

Ключові слова — освітня технологія; гібридне навчання; електронне навчання; інженерна освіта; електротехніка; обчислення; математичне програмування.