The experience in teaching mathematical disciplines using information technologies

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Abstract. The presented material is devoted to the long-term experiment on the introduction of computer technologies in the process of teaching students of technical (and not only technical) specialties and lectors in various courses and disciplines at MAI. The experiment was carried out in teaching completely different courses, such as: combinatorial analysis, operations research, computational mathematics, as well as in the course of information technology, designed to improve the qualifications of teachers.

1 Introductions

The development, search and implementation of innovative ways in organizing of the educational process, which that meets the trends of modern education, are mentioned in the Federal Law "On Education in the Russian Federation" and has become a standard practice at the Moscow Aviation Institute.

The direction, which began to develop actively in the 20th century under the names "computational mathematics", "numerical methods", "operations research" and etc. is aimed at introducing the theoretical possibilities of higher mathematics, both in modern engineering and in the field of production management.

The pandemic has accelerated the process of introducing computer technologies. Two years of the pandemic have shown that it is quite possible to give lectures in a remote format, for example, using the LMS.MAI platform, although conducting practical classes and laboratory work in a remote format is still not available for all disciplines. This is reflected in the current training programs. Such tactic should continue in the future.

Classical mathematical disciplines are certainly important for the formation of an engineer's worldview. They open up the possibilities of interaction between objects and explain the principles of their existence in the real world. But the solution of practical problems is impossible without the use of computer technology.

We will share the experience of conducting a number of courses that were taught at the aerospace institute and other technical institutes both before the pandemic and during the pandemic. This approach was certainly liked by students when lectures were presented in the form of presentations.

2 Experience first. Combinatorial analysis

The course "Combinatorial Analysis" is taught to students if two faculties: "Aerospace institute" and "Aviation technology institute". Despite the fact that this course is devoted to the

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study of the basics of modern mathematics, namely: set theory and combinatorics, topology and graph theory, as well as the theory of algorithms and logic, there still is the possibility of using and implementing the basics of computer technologies even in such a course [1]. Computer technologies, which are used in this course:

- MS Word is taught in order to write term papers and essays correctly. Students need to gain basic knowledge and working skills in MS Word (document structuring, lists, through numbering, insertion of literature sources, etc.) regardless of what and how they were taught at school.
- MS Excel must be taught in order to get skills in possibilities to perform complex calculations (autocomplete, working with formulas, etc.). Students use spreadsheets to solve all combinatorial problems, also they use spreadsheets to order graphs for the purpose to reduce an arbitrary graph to the form of Koenig graph, which obtains the recursive property.
- MS Visio is taught in order to get skills in for the competent creation of almost any illustrations for present and future term papers. Students learn to draw graphs, matrices and various diagrams, which the will need in their future study.

All these computer technologies are integrated into the practice of the course along with gaining theoretical knowledge, and all the tasks of the Combinatorial Analysis course are solved exclusively with the help of information technologies. Students write essays, solve combinatorial problems and problems of graph theory using tools of MS Office (Word, Excel, Visio).

3 Experience second. Computational mathematics

Unfortunately, not much time is given to combine the solution of applied mathematics problems with the use of programming capabilities in high-level languages, in the engineering faculties of many universities, for almost any specialty, in accordance with the curricula.

The objective of the course "Numerical Methods" is to acquaint future masters, specialists and bachelors with the basic rules for solving engineering problems: interpolation, approximation, optimization and solution of differential equations, without which modern technical developments are impossible [2–4].

For the numerical solution of ordinary differential equations, a sufficient number of marching explicit and implicit, one-step and multi-step methods of various orders have been developed, which allow you to effectively build calculation schemes in the spreadsheet environment. A large number of numerical schemes make it possible to organize calculations according to individual options for each listener.

Thus, the course covers 24 explicit methods of different orders from 1 to 6 for solving first-order ordinary differential equations based on Runge–Kutta computational schemes, including eight nested schemes that correct the choice of the integration step. Students can solve even stiff differential equations by reviewing the collection of 18 implicit circuits.

In addition, for the final stages of calculations, it is proposed to use sets of multi-step methods. Why are there so many methods offered for study? Only so that future engineers have a choice of methods, and there is confidence that you can always build your own computational scheme that will be able to solve a new separate problem.

Problems leading to the solution of linear partial differential equations have always been included only in term papers or computational papers due to certain difficulties in modeling physical processes, choosing the equations themselves, and also in selecting computational procedures.

It makes sense to abstract from the semantic and physical loads that are assigned to equations built according to the laws of classical physics. It is quite possible to work only with

well-classified [5] model types of equations. Then the decision problem passes into the plane of choosing a specific computational method and into algorithms for calculating the accompanying parameters.

At the same time, plane and even axisymmetric problems of mathematical physics can be modeled and analyzed within the framework of practical or laboratory work, where it is convenient to illustrate the algorithms in spreadsheets, which can later serve as a source of control calculations in cases where it is necessary to debug the developed software products.

So, for example, for equations of parabolic and hyperbolic types with linear coefficients and with any initial and boundary conditions, the finite element method is most often used, which leads to a marching integration scheme. Due to the certain complexity of such tasks, programs should be written in arbitrary programming languages, when implementing the selected algorithms.

At the same time, for explicit finite-difference schemes it is necessary to simulate the calculations in Excel tables, and tabular calculations can be used to debug the corresponding programs. For the implicit difference schemes, which are usually solved using methods for solving systems of linear algebraic equations, computing also can be done with the help of tabular calculation, using simplified methods for solving systems.

So, the study of partial differential equations in the spreadsheet environment can be included in the plans of practical and laboratory classes in order to develop skills in performing numerical calculations and parametric studies, as well as for graphical interpretation of the results.

The solution of linear differential equations in partial derivatives has always been included only in term papers or computational-graphic works. But it is impossible to conduct classes without mass calculations. Undoubtedly, computing systems have been created and are currently actively used, such as Matlab or Mathcad. They are positioned as universal applications for researchers.

Such complexes, which run on modern operating systems, including Linux, MacOS, Solaris and Windows, belong to the class of computer-aided design systems and are intended only for calculations using algorithms selected for each specific task. However, these systems do not have a training link. Most of these systems are based on the “black box” principle, which indicates its answer (calculation result) for any question (source data option).

Such systems are good for mass standard parametric calculations or for multiple statistical processing, but are not suitable for initial acquaintance with numerous engineering problems that can be solved by methods of applied computational mathematics.

In these cases, spreadsheets come to the rescue as a learning tool. It is possible to train students in almost all most common methods in a fairly short time, with the help of such an application. In the future, students easily will switch to creating programs for such methods in high-level languages, which will be available to them in other applications.

Thus, we can offer a spreadsheet environment (Excel) as a modern universal computing platform, because it has a large mathematical content and is easy to use. The main advantage of spreadsheets is the availability of this application, since it is included with MS Office by default.

Thanks to the widespread use of Excel, as well as learning the basic skills of working with MS Office in high school, most students already used spreadsheets for simple calculations, and therefore had some experience, although they considered spreadsheets like a large calculator. It should be noted that there is a great opportunity to use spreadsheets for other, more complex, engineering tasks, for example, for processing statistical data obtained in natural experiments.

The input and output of data is clear and simple in spreadsheets, and the possibility of a simple and high-quality graphical representation of the obtained results, allows students

quickly to acquire the necessary computing skills. In addition, iterative processes are well modeled in spreadsheets.

The visibility of calculations in spreadsheets makes it possible not to hide solution algorithms in subprograms, but to show its step-by-step execution, while graphic support in tables illustrates even a small change in parameters. In addition, within the framework of one calculation, it is possible to perform parametric studies, which, for example, may be required when discussing the problem of launching a payload by a multistage vehicle into a given orbit.

The disadvantages of spreadsheets include the following situations: solving problems of small dimensions and working with relatively simple functions. Naturally, these shortcomings narrow the scope of spreadsheets for scientific research, but this software product is quite suitable for teaching students and completing term papers. Subsequently, even partial calculations performed using Excel can be used to test the performance of programs written in high-level languages.

4 Experience third. Operational research

Spreadsheet programming is also quite possible to apply in some other engineering courses. The courses, under general name of "Operational Research" are studied by students not only of two faculties: "Aerospace institute" and "Aviation technology institute", but also by some other technical institutes. In particular, there is experience in using the option "Search for a solution" in order to work with problems related to linear and non-linear programming, as well as extreme programming and solving probabilistic and game problems in courses of disciplines called "Operations Research".

Of course, outside the programming environment in high-level languages, and using only spreadsheets, we can only solve small tasks.

In such disciplines, the essence of the use of spreadsheets is as follows. The student creates problem models, using the spreadsheets and solves them without programming [6, 7]. On the one hand, this seems to be a disadvantage, but there are also advantages: it becomes possible to show the student a wide class of operations research problems [8–10].

The course contains the following tasks:

1. Linear tasks of operational research:
    a) distributive tasks (this section includes various tasks of production planning, subject to the variation of the model range of similar tasks);
    b) tasks, which apply transport models (mainly logistical tasks);
    c) assignment tasks (efficient organization of transport routes, distribution employees by vacancies);
    d) tasks, which are based on the guillotine cutting.
2. Non-linear tasks of the operational research:
    a) tasks, which apply inventory management models;
    b) financial tasks (Markowitz and Sharp models with different variations, and many others);
    c) the tasks of queuing systems;
    d) game tasks, including games with nature;
    e) the statistically distributed (stochastic) tasks with application of Monte-Carlo method.

3. Extremal problems:

    a) various tasks based on the salesman problem;

    b) scheduling tasks;

    c) tasks, based on the knapsack problem, etc.;

4. Tasks of searching and monitoring.

In addition we can say that since by now there are a huge number of proposals on the Internet for programming simple tasks of operations research (not the fact that they are created without errors). And presented approach with applying MS Excel (subject to the possibility of checking the student's work by the teacher for plagiarism) creates good conditions for fixing the material of practical classes and laboratory work.

The course also contains term papers, where model tasks can be solved not only applying spreadsheets, but also using high-level languages. The use of graphic technologies is also required to create illustrations accompanying term papers.

In the future, the transition to the programming of individual tasks is carried out as part of the work on course projects. However, spreadsheets allow program verification for course projects created in high-level algorithmic languages.

Three semesters of studying different tasks of operational research are combined by a common and single ideology of solving practical problems.

5 Experience fourth. Training in MS Office products for teachers of various disciplines MAI

For many teachers, the transition to distance education was accompanied by the need to create presentation lectures. And this is a kind of art. Some of the teachers needed to introduce spreadsheet calculations into the discipline. Almost everyone needed to transform their lectures into electronic format and create tutorials and textbooks also into electronic form. Many of them needed to provide lectures and textbooks with graphic illustrations. It requires the ability to use the MS Visio (graphic vector editor).

For these purposes, a two-semester advanced training course for MAI teachers was developed, which has been in existence for three years [11, 12]. This course, which is intended for teacher's training, combines the publishing functions of MS Word, the drawing tools of MS Visio, the computing power of MS Excel, and the demonstration tools of MS Power Point, which corresponds to the rules of a seminar or colloquium. This allows teachers not only quickly create presentations of their lectures for LMS.MAI, but also practice the layout of both monographs and study guides, in conditions of strict regulation of the number of printed sheets.

Transition from paper technology of knowledge transfer to paperless is currently important and opens up additional opportunities for knowledge acquisition. A possibility to create textbooks in the form of an original layout, which is ready to run on a printing press, in addition, such technology allows to do without a printing machine at once creating electronic textbooks.

6 Conclusions

Based on the methods already developed, digital technologies should be introduced not only to transfer information, as was done during the pandemic and, apparently, will remain with us, but also in face-to-face communications with students.

In the future, it is advisable that practical and laboratory work should be carried out not so much in a notebook using a calculator, but on a computer using appropriate software applications.

Various forms should be used for calculations: from spreadsheets to building programs in any available programming languages. It is best to integrate one computing environment into another and/or combine different technologies with each other.

The variety of existing technologies makes it possible to expand the scope of existing courses of disciplines, adding not only the formulation of new topical problems, but also offering various modern methods for solving them.

References

[1] N.L. Malinina, O.L. Demidova, *Combinatorial Analysis* (MAI Publishing House, Moscow, 2021)

[2] I.B. Petrov, A.I. Lobanov, *Lectures on computational mathematics* (Internet University of Information Technologies, Moscow, 2006)

[3] O.L. Demidova, N.L. Malinina, *Solution of systems of linear equations, algebraic and transcendental equations in spreadsheets* (MAI Publishing House, Moscow, 2017)

[4] O.L. Demidova, N.L. Malinina, *Nonlinear systems. The theory of approximation of functions. Practice of calculations in spreadsheets* (MAI Publishing House, Moscow, 2021)

[5] A.D. Polyanin, *Handbook of linear differential equations* (FIZMATLIT, Moscow, 2001)

[6] N.L. Malinina, O.L. Demidova, *Solution of extremal problems of operations research in spreadsheets* (MAI Publishing House, Moscow, 2021)

[7] N.L. Malinina, O.L. Demidova, *Solution of non-linear problems of operations research in spreadsheets* (MAI Publishing House, Moscow, 2017)

[8] H.M. Markowitz, *Mean-variance analysis in portfolio choice and capital markets* (Blackwell, Oxford–Cambridge 1992)

[9] J. Sharpe, F. William, *Investments* (Prentice Hall, Upper Saddler River, NJ, 1998)

[10] M. Pattnaik, *Inventory Models: A Management Perspective: Methods & Application of EOQ and Fuzzy EOQ Models* (LAP LAMBERT Academic Publishing, 2014)

[11] O.L. Demidova, N.L. Malinina, *Programming in spreadsheets. Excel 2010* (Buki Vedi, Moscow, 2013)

[12] O.L. Demidova, N.L. Malinina, *Programming of text documents. Word 2010* (Buki Vedi, Moscow, 2013)