

Fundamental Algebra in the Training of Developers of Digital Economy Software Product

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Abstract—The article analyzes the basic problems of the fundamental mathematical training of IT students as highly qualified developers in the digital economy sphere. These include creation and maintenance of a high level of motivation to study fundamental mathematical disciplines, development of highly productive independent work skills in obtaining and mastering new knowledge in the professional field of developing digital resources based on fundamental mathematical disciplines, and creation of a psychological commitment to lifelong learning. To solve these problems, a technique is proposed using modifications of blended learning technology, including elements of a flipped classroom technology. In the experimental training, we use various computer platforms that combine on-line and off-line approaches. The organization and results of the experiment conducted by the proposed technique are discussed.

Keywords—training of software developers, computer training platforms, blended learning technologies.

I. INTRODUCTION

The transition to a digital economy dramatically increases a need for specialists in the field of digital technologies, although even in spite of this their demand today significantly exceeds the output capacity of universities that train such specialists. But even a more severe shortage is felt in a cluster of high-level specialists. As for the companies involved in the development of software for processing digital resources, they are faced with heightened requirements in the field of fundamental mathematical education.

Upon the initiative of SKB Kontur, the company specializing in the development of software products for economic purposes, with the participation of specialists from other IT companies and teachers of fundamental mathematical disciplines of universities, we began modernization of these disciplines. The main problems that needed to be solved as a result of modernization were identified as follows:

1) Improving the orientation of fundamental mathematical courses (algebra, mathematical analysis, discrete mathematics, probability theory and mathematical statistics, etc.) to train high-level specialists in digital resource development.

2) Creation and maintenance of a high level motivation of students to study fundamental mathematical disciplines.

3) Development of high-performance independent work skills in obtaining and mastering new knowledge in the professional field of digital resource development based on the fundamental mathematical disciplines.

4) Creation of a psychological commitment to lifelong learning.

The basis for solving these problems was the following:

- Creation of motivation to study fundamental mathematical courses by setting tasks for modern digital technologies (machine learning, Big Data, 3D modeling, etc.) through demonstration of how to apply means and methods of fundamental mathematics to solve these tasks;
- application of educational technology of blended learning, as well as the “Flipped Classroom” technology, in which a certain amount of material is studied by students independently, they themselves independently carry out a predetermined set of tasks with subsequent discussion in laboratory and practical classes;
- part of the student’s academic time is regularly devoted (i.e. during the educational process, and not as a final form) to students’ educational activities implemented through using computer technologies, during which students use mathematical tools and methods studied by them when performing the tasks which look like real development of digital technology products.

This approach allows the students to demonstrate the conceptual unity of mathematics and programming as a sphere of scientific and industrial activity. In turn, the use of blended learning educational technology significantly increases the share of independent work in obtaining and mastering new knowledge.

II. LITERATURE REVIEW

The flipped classroom educational technology, proposed by J. Bergmann and A. Sams [1], is currently one of the most actively studied. Originally proposed for teaching a chemistry course, it began to be applied in a wide range of disciplines - both in natural sciences [1,2] and humanitarian disciplines, including socio-political ones. However, as is indicated in the works related to teaching the humanities, transfer of the flipped classroom technology from natural sciences to

The study was supported by the grants from SKB Kontur and Naumen.

teaching disciplines in another sphere has certain limitations [3,4,5]. It has led to emergence of mixed pedagogical technologies, in which, along with the flipped classroom technology, various other technologies of active learning are presented. As for teaching mathematics, what is of a particular interest for our study is the opinion which is expressed in [6, p. 4442] that "not all topics are suitable for a flipped classroom." In particular, they believe that preference should be given to algebraic topics. As for geometry and, in general, for those sections where mathematical proofs are present, according to the authors of [6], their study should be carried out in a traditional way. We do not share this point of view, and in our experimental training with application of the methodology we have proposed, there are also geometric topics and a number of proof-based arguments. At the same time, we support the point of view expressed in [3] that it is the mixed technologies of the flipped classroom that allow us to build effective training, including in such abstract disciplines as mathematics and philosophy.

III. RESEARCH METHODOLOGY

The research methodology is based on a student-centered approach in teaching with the leading role of the individualized educational activity of each student. To implement this approach, we widely and diversely use the means of information and communication technologies. At the methodological level, we fully follow the basic principles [7], which characterize the basic competencies of the student as a person in an information-oriented society:

- student is a person with an internal motivation to learn;
- student is a person who realizes himself/herself as a citizen of an information-oriented society;
- student is a person that is open to new knowledge;
- student is a person with developed algorithmic and engineering thinking;
- student is a person who is open to creative interaction with other people;
- student is a person capable of cooperation and teamwork.

It is easy to see that these competencies correspond to the problem field that is given in the introduction to this work.

At the level of educational technology for development of the course, we follow the guidelines [8], which emphasizes that course development should "include four main steps:

- a clear wording of the holistic picture of the training course for the students and the teacher;
- determination of learning outcomes describing the changes that will occur with students after completing the course;
- development of a system of "training" evaluation grades, which are part of the learning experience and provide quick and regular feedback;
- development of forms of educational activity for active, practical training."

One of the conclusions of the research [9] is that to follow these principles is an essential factor in successful student learning.

In this regard, in our research, a special role is assigned to the tools that allow us to diagnose changes in the style of students' work with the material studied and to evaluate the skills acquired by them and highly productive independent work in obtaining and mastering new knowledge. These include monitoring tools that allow us to track the work of each student with the materials provided to him on-line, a set of control and measuring materials and questionnaires.

In accordance with the concept of the "flipped classroom", the students independently study theoretical material and perform a number of tasks, mainly of the reproductive type. After that at the laboratory and practical classes, a discussion is held on the basis of the questions that students had in their independent work (about 15% of the total time devoted to considering the topic in practical classes), then solving productive problems on this topic (about 70% of time at the practical class) and finally, fulfillment of individual (at the student's option) tasks of a creative character (up to 15% of time). In general, such a structure corresponds to a standard structure of a lesson conducted according to the flipped classroom technology [1, chapter 2].

One of the fundamental differences from the flipped classroom technology, proposed in [1] and [2], and the blended learning technologies proposed in [3] - [6], is the inclusion in the program of laboratory and practical classes of individual tasks of a creative nature. In this, we follow our research findings described in [10].

IV. RESULTS

The technique of blended learning in the flipped classroom technology is proposed for teaching students to fundamental mathematical disciplines with computer methods applied in the digital economy. On-line and off-line support is designed and developed for the course of fundamental algebra and geometry for the first-year students in IT specialization.

The developed training system has been tested and pilot implementation has been carried out in the professional field of "Fundamental Informatics and Information Technologies".

V. RESULTS OF EXPERIMENTAL RESEARCH

The pilot experiment involved 65 first-year students in the professional field of fundamental informatics and information technology.

To study theoretical material, students were given video lectures and textual versions of lecture material. However, they were not literally matching. Only the definitions and formulations of the main statements were uniform in them. As for the given examples explaining the introduced concepts and proofs, here we strove for a sufficient variety. This approach, on the one hand, allows the student to look at the same material from several different points of view, prompting him to compare different options and thereby contributing to the development of a critical understanding of the material being studied. We consider it to be a fundamental point in our educational approach, since in traditional teaching of mathematical disciplines a student, as a rule, uses only one version of the material presented, i.e. the one read by the lecturer.

Besides, the students were encouraged to compile a compendium of the theoretical material being studied, the use of which was welcomed during laboratory and practical classes. The compendium was required to be concise,

structured, and complete. However, a compendium was not a mandatory requirement, the student himself had to assess the degree to which he needed such a compendium for further academic work.

The technological basis for implementation of this course is the Ulearn network platform developed by SKB Kontur, and the Jupyter notebook system.

Each topic of the course under study, is represented on the Ulearn platform by the following objects:

- video lecture;
- text version of the lecture material;
- tasks for individual training;
- tasks designed to be performed at the laboratory and practical lesson on this topic.

Individual tasks of a creative nature were not placed on this platform, so that students did not have an opportunity to proactively search for their solutions.

For most of the tasks intended for students to independently solve before conducting laboratory and practical classes, an automatic check of solution correctness is provided. For a task where such a check is not provided, the student himself/herself in a separate form notes whether he/she, in his/her opinion, coped with this task or not. All the information about the students completing assignments for independent solving is available to the teacher conducting laboratory and practical classes in the group, and he/she takes this into account when planning the next lesson on this topic. If less than 70% of students have completed the task, then it is analyzed at the practical lesson, with a student at the board, whose task is marked as a solve done. It allows us to speed up the analysis of individual tasks for independent solving, and as for those tasks where automatic check is not provided, to establish correctness or incorrectness of the solution proposed by the student.

The Ulearn platform provides the teacher’s feedback. This allows students to quickly answer the questions that arise, as well as provide on-line explanatory comments on the course materials.

In general, the Ulearn platform implements all the basic functions of on-line training, which are present in the well-known and widely used Coursera system. In particular, the tools are provided for regular assessment of the student’s material acquisition, they contain feedback elements; even knowledge assessment is provided directly during viewing video lectures in the format of one or two questions. Yet, there are additional features. Each student is registered in the Ulearn system, and all his/her actions are logged. Therefore, the teacher can learn information not only about whether this or that problem has been solved or not solved by this student, or how the decision process went (how many attempts he/she needed and whether he/she addressed the guiding questions), but also how thoroughly he/she studied the theoretical material in video lectures, whether he accessed it or the textual material repeatedly when completing assignments.

Every third laboratory and practical lesson is conducted using the Jupyter notebook system. 10 days before the lesson, the students receive through the network service the next task, which they should try to complete before the lesson in the classroom. To complete it, a student must be familiar with the

basics of the Python language, which he learns in a parallel programming course. In reality, in order to solve the problems we offer, it is enough for the student to know the basic constructions of the language, since the main purpose of the classes is to demonstrate the tasks of the IT sphere in which the studied methods of fundamental algebra and geometry are used, and not to improve knowledge of the programming language. The Jupyter notebook system was chosen by us precisely because the entire routine part can be presented in it ready-made, and the student only needs to write directly in Python that fragment of the program code in which there is the algorithm which uses the studied algebraic or geometric methods.

Here is an example of a task offered for one of such classes (its number shows that it was preceded by 3 more tasks, which included step-by-step preparatory elements for completing this task).

Projective image. Complete the following function. On entry you are given an image with dimensions w by h and four points p_0, p_1, p_2 and x . Each pixel of the image (image $[i,j]$, where $0 \leq i < w$ and $0 \leq j < h$) is a number from 0 till 255, that defines the gradation of gray from black till white. The image “is stretched” over a parallelogram with the apexes p_0, p_1, p_2 , as in the picture (the fourth apex of the parallelogram p_3 is not shown, but is implied):

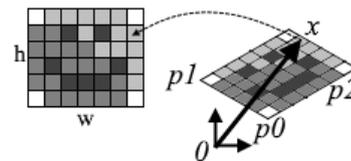


Fig. 1. Image conversion

The left and right lower pixels of the image are located, respectively, in image $[0, 0]$ and image $[w - 1, 0]$. Return 0, if point x does not lie in this parallelogram, and return the corresponding image pixel, otherwise,

```
def get_pixel (p0, p1, p2, x, image):
```

“Pixel corresponding to x in the image stretched over p_0, p_1, p_2, p_3 ”

```
w = image.shape [0]
h = image.shape [1]
# your code could be here
return 0
```

Verify that your solution generates the projective image correctly.

After inserting the desired code (instead of the phrase “your code could be here”), the student sends the program for a test verification. If all the tests are passed with a positive verdict, the student tells the teacher the algorithm by which the problem was solved. Only an algorithm is discussed with the student, issues related to the programming language are not discussed, since this is beyond the scope of the subject being studied. Thus, the student outlines the area of his personal responsibility for his/her preparedness in related disciplines (in this case, programming).

According to the results obtained by means of an objective measurement of learning outcomes, we note:

- More than 70% of the students cope with at least 80% of the tasks (as part of independent work before the laboratory and practical classes);
- from 50% to 65% of the students independently cope with tasks of a productive level (in laboratory and practical classes), depending on the topic;
- 15-17% of students independently cope with individual tasks of a creative level.

As part of the objectives of our study, it is important for us to evaluate the significance of each component of the learning process, both within the flipped classroom technology and other elements of blended learning. The information received through the Ulearn platform is integratively presented in Table 1.

TABLE I. VARIOUS FORMS OF ON-LINE PRESENTATION OF THEORETICAL MATERIAL FOR INITIAL ACQUISITION BY STUDENTS

Presentation form	Ratio of student who watched...			
	...more than 95% of lectures	...from 70% till 95% of lectures	...from 30% till 70% of lectures	...less than 30% of lectures
Video	63.1%	24.6%	9.2%	3.1%
Text	24.6%	23.1%	38.5%	13.8

As we can see, the majority of students as the first acquaintance with the theoretical material preferred video lectures, but more than 45% were getting acquainted with the material to a great extent using text format (some the text only). Of course, various factors can influence such a distribution. An assessment of some of them is presented in Table 2, which shows the percentage of students (percentage) who have rated lecture material according to the indicated quality indicators (personal data).

TABLE II. STUDENTS' ASSESSMENT OF SOME FACTORS OF PERCEPTION OF LECTURES IN VIDEO FORMAT WHILE GETTING ACQUAINTED WITH THEORETICAL MATERIAL FOR THE FIRST TIME

Quality indicator	Always	Often	Rarely	In very rare cases
The material delivered is easy to understand	23.1%	67.7%	9.2%	0%
Key aspects are emphasized	36.9%	55.4%	7.7	0%
Practical demonstration is offered	4.6%	33.9%	41.5%	20.0%
It was clear how to apply the lecture material in practice	15.4	55.4%	24.6%	4.6%
Lectures were interesting	20.0%	55.4%	20.0%	4.6%

Indeed, practical application has been demonstrated to a greater extent in the text format of lecture material. All this encouraged students to use a text format. At the same time, we see that students can and are willing to independently transform the studied theoretical material into an ability to solve practical problems.

The reaction of students to our proposal to create a compendium of theoretical material was as follows: 50.7% of the students had compendiums for the entire material, 20.0% of the students had compendiums for the most part of the

material (from 50% to 90%), and compendiums (for less than 50%) had 16.9% of the students and 12.4% of the students did not do compendiums at all. The Students who had notes, regularly used them in laboratory and practical classes amounted to 39.4%, often used - 30.3% and rarely used - also 30.3%.

Only those who did not have notes did not use the compendiums. Although only 15-17% of the students coped with the tasks of a creative orientation, more than 80% of the students considered it useful to work with them at laboratory and practical classes. They were dissatisfied with the fact that, in their opinion, little time was devoted to solving such problems.

VI. CONCLUSION

The results of the experiment show that the proposed method of blended learning allows us to achieve our goals quite effectively. It develops the students' skills of independent work with educational material, skills to compare different ways of presentation of the same educational material and evaluate them critically, to create problem-solving algorithms based on the methods studied.

We also observe that the educational technology that we have proposed for most of the students increases their motivation to study methods of fundamental algebra and geometry, the ability to critically evaluate their own academic achievements.

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