Technologies of distance learning for programming basics on the principles of integrated development of key competences

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Abstract. In the era of the fourth industrial revolution – Industry 4.0 – developing key competences (digital, multilingual and mathematical competences in particular) is of paramount importance. The purpose of this work is to investigate the content of key competences of a secondary school student and to develop a method of teaching for the integrated development of multilingual and mathematical competences in the process of teaching Programming Basics with the help of distant technologies. The objectives of the research include generalizing and systematizing theoretical data on the structure and the content of key competences and the potential of informatics lessons for the development of separate components of multilingual and mathematical competences; generalizing and systematizing theoretical data on the ways of arranging distant support for informatics learning, Programming Basics in particular; to investigate the content and the methods of teaching Programming Basics in 7th-11th grades; to develop the e-learning Moodle course using Python for Programming Basics on the principles of integrated approach to developing separate components of multilingual and mathematical competence with determining some methodical special features while using it. The object of the study is to teach informatics to junior high school and high school students. The subject of the study is the means and the methods of realizing distant support in the process of teaching Programming Basics using Python on the principles of an integrated approach to developing multilingual and mathematical competences.

Keywords: key competencies, digital competence, multilingual competence, mathematical competence, programming basics, integrated approach, Python, Moodle.

1 Introduction

According to the European Commission recommendation [8, p. 7], *the competence* is defined as a combination of knowledge, skills and attitudes where:

- knowledge is composed of established facts and figures, concepts, ideas and theories which are necessary for the understanding of a certain area or subject;
- skills are defined as the ability and capacity to carry out processes and use the existing knowledge to achieve results;
- attitudes describe inclinations, preferences and mentality that form the mode to act or react to ideas, persons or situations.

Law of Ukraine "On Education" [35] defines *competence* as a dynamic combination of knowledge, skills, abilities, thinking methods, views, values, other personal qualities that determines the ability of a person to socialize successfully, to carry out professional and / or further educational activities.

There exists the subject, intersubject and key competences.

The subject competence is the experience gained in the course of study of a specific activity related to the acquisition, understanding and application of new knowledge [35].

The intersubject competence is an ability to apply knowledge, skills, activities and relationships that belong to a certain range of academic subjects (disciplines) and educational areas to an intersubject circle of problems [35].

The key competences are those that all people need for personal self-improvement and development, a great provision of employment, social inclusion, sustainable lifestyle, successful life in peaceful societies, health management and active citizenship. They are developed for the whole life, from the early childhood, through formal, non-formal and informal learning in all contexts, including a family, a school, a workplace, neighbourhood and other communities [8, p. 7].

The key competences are:

- a literacy competence;
- a multilingual competence;
- a mathematical competence and competence in science, technology and engineering;
- a digital competence;
- a personal, social and learning to learn competence;
- a citizenship competence;
- an entrepreneurship competence;
- a cultural awareness and expression competence [8, pp. 7-8].

Taking into account the objectives of this paper, we will examine in more detail the interpretation, structure, and the role of the school subject "Informatics" in forming and/or developing individual components of the three core competences – multilingual, mathematical, and digital.

The multilingual competence is understood as the ability to use different languages correctly and effectively for communicating; the competence is based on the ability to express and interpret concepts, ideas, feelings, facts and opinions, both orally and in writing (listening, speaking, reading and writing) in an appropriate range of social and cultural contexts according to needs.

The multilingual competence manifests itself in:

- the knowledge of the vocabulary and the functional grammar of different languages and awareness of the main types of verbal interaction and language registers; the knowledge of social conventions, cultural aspects and language variability;
- the ability to understand oral messages, initiate, maintain and finish conversations and to read, understand and write texts with different levels of proficiency in different languages according to a person's needs;
- a positive attitude to predicting an appreciation of cultural diversity, an interest and curiosity about different languages and intercultural communication; respect for each person's individual linguistic profile, including respect for the mother tongue of persons belonging to minorities and/or with migratory background, and an appreciation of the official language(s) of the country as a common basis for interaction.

During informatics lessons, such components of multilingual competence are developed:

- the ability to use software tools and resources with an English-language interface;
- the ability to use software tools to translate texts and interpret foreign words;
- the ability to operate the basic international IT terminology;
- awareness of the role of IT in interpersonal communication in a global context;
- understanding of the need for foreign language skills for online learning and active involvement in European and global communities [20].

The mathematical competence is understood as the ability to develop and apply mathematical thinking and intuition to solve a number of problems in everyday life. Based on solid numeracy skills, it relies on process and activity as well as knowledge. Mathematical competence implies, at different levels, the ability and desire to apply mathematical thinking and concepts (formulas, models, structures, graphs, diagrams).

The mathematical competence is manifested in:

- the knowledge of numbers, measures and structures, basic operations and basic mathematical presentations, understanding of mathematical terms and concepts and awareness of the questions that mathematics can offer answers to;
- the ability to apply basic mathematical principles and processes in the context of everyday life at home and at work (e.g., financial skills), and to apply and evaluate logical chains of arguments; the ability to think mathematically, understand mathematical demonstrations, and communicate in the mathematical language; and the ability to use appropriate tools, including statistical data and graphs, for understanding the mathematical aspects of digitalization;
- a positive attitude towards mathematics based on respect for truth and a willingness to search for reasons and appreciate their validity [8, p. 9].

Informatics lessons improve such components of the mathematical competence as:

- the ability to understand, use and create mathematical models of objects and processes for solving problems from different subject areas by means of information technology;

– awareness of the role of mathematics as one of the fundamentals of IT [20].

The digital competence is interpreted as the competence that involves confident, critical and responsible using of digital technology for development and communication, the ability to use some tools of information and communication technology safely and ethically in learning and other life situations.

The digital competence includes information and data literacy, communication and cooperation, designing digital content (including programming), security (including digital well-being and competences related to cyber security), the issues of intellectual property, problem-solving and critical thinking [15].

The digital competence manifests itself in:

– understanding how digital technology can support communication, creativity and innovation; awareness of the possibilities, limitations, impacts and risks of digital technology; understanding the general principles, mechanisms and logic of digital development and the knowledge of the basic functions and using various devices, software and networks; critical awareness of the validity, reliability and significance of information and data provided through digital devices; the knowledge of legal and ethical principles related to using digital technologies;
– the ability to use digital technology to support active civic and social integration, cooperation with others and creativity to achieve personal, social or commercial goals; the ability to use, access, filter, evaluate, create, program and distribute digital content; the ability to manage and protect information, content, data (including personal) and to recognize and interact effectively with software, devices, artificial intelligence or robots;
– interaction with digital technologies and content, provides a reflective and critical, even curious, open and forward-looking attitude towards their evolution, as well as a moral, safe and responsible approach to using these tools [8, pp. 9–10].

It is obvious that informatics, as a school subject, plays a decisive role in forming and developing the components of digital competence primarily. However, the efficiency of the development of the components of digital competence depends on the level of formation of separate components of multilingual and mathematical competence. The formation of multilingual competence is manifested in the absence of language barriers when working with software with the English-speaking interface. The formation of mathematical competence is indispensable at different stages of computer modeling – from setting a problem, through constructing a mathematical model, to the computational experiment and conclusions. At the same time, the system of reasonably selected subject (informative) English-speaking tasks with mathematical content is a certain potential for integrated improvement of separate components of multilingual and mathematical competences.

The integration of learning content triples the educational purpose of the lesson and intensifies the process of the lesson. The effectiveness of such lessons cannot be considered satisfactory in terms of quality and pace of improvement of neither key nor subject competences without attracting additional tools. The distance technology tools will help to compensate for the lack of lesson time (on a thorough actualization of basic knowledge the special thematic English vocabulary and/or mathematical foundations, writing integrated mini-complexes, solving a sufficient number of learning problems, personalized summarizing the lesson).

2 Basic approaches as for implementing distant support into the information-mathematical cycle in general and higher education schools

Taking into account the national experience in providing distant support into general education and, in particular, the cycle of information-mathematical subjects, which are taught in general secondary and higher education institutions [3; 23; 33; 34], three main approaches can be noted:

- the first approach is based on displaying the educational resources (and methodical materials) on the official website pages of an educational institution (or its structural subdivisions) or the teachers' personal websites. The educational resources placement is in the distant cloud storages, Google Drive mostly (if there is an opportunity to use advantages of the Google corporate account because of its unlimited cloud storage [11]);
- the second approach is based on the presentation of educational resources as e-courses created and implemented in the educational process with the help of systems or services of learning management, the most common of which today is recognized as Google Classroom and Moodle [1; 14; 22; 32];
- the third approach (only distributed) is based on the specialized tools and services using for educational and scientific purposes, in particular informatics and mathematics, such as CoCalc (formerly SageMathCloud) and Jupyter Notebook [12; 13; 25; 26; 30; 31].

The most popular approach today for the implementation of distant support education, in particular, informatics, into general secondary education institutions is the Google Classroom, and in the higher education institutions is the Moodle.

Among the main common features of Moodle and Google Classroom for teachers should be noted:

- the placement and fast modification of basic and auxiliary teaching resources as files in various multimedia formats or URLs;
- the placement and fast modification of elements of learning activity (both individual and group) – primarily tasks (for practical and laboratory lessons, for individual and group work) and tests (forms). Various multimedia fragments can be added to the content of the tasks and tests (and answer options on them);
- automated control over the timeliness of the students' assignments and archiving of the results provided;
- automated checking of test results (except the "Essay" type questions for Moodle);
- automated recording of learning results in the course log;
- tools for real time remote consultation – chat, etc.;

- automated management by the course users (co-developer (assistants) and students).

Among the main common features of Moodle and the Google Classroom for the course participants (students) should be noted:

- mobile ("always and everywhere") access to all elements of the course – basic and auxiliary training resources of the lesson (class), tasks for practical performance, tasks of home (independent) work, training tests, etc.;
- the calendar of events and a reminder of deadlines for completing tasks;
- tools for communication with the teacher and other course participants;
- constant access to view the achievements of your own.

Obviously, neither the Moodle nor the Google Classroom is a specialized tool for learning informatics in general and programming in particular. However, the openness and extensibility of the Moodle system through new solutions (modules, plug-ins or filters), the above features and benefits for teachers and students have become decisive in the selection of a tool to implement remote support for teaching teachers or students (and teachers-to-be) the basics of Python programming using an integrated approach to the development of key competences.

3 The content and educational tools for teaching programming basics at school informatics lessons

According to the informatics curriculum for 5th-9th grades, the students which did not study informatics in the primary school (2nd-4th grades) will learn the programming basics starts in the 8th grade and continue in the 9th [21]. The teacher has the right to choose the programming language and IDE.

The analysis of the IT textbooks recommended by Ministry of Education and Science of Ukraine for the 8th and 9th grades has shown that in the majority of informatics textbooks (the authors' teams are headed by Yosyp Ya. Ryvkind [27; 28], Olena O. Bondarenko [6; 7], Andrii M. Hurzhii [9]) the subject of study is the compiled programming language Pascal in IDE Lazarus. And only in the textbooks [18; 19], whose author's team is headed by Nataliia V. Morze, the study subject is not the compiled programming language Pascal in IDE Lazarus only, but also it is the interpreted programming language Python in IDE PyCharm. The authors of the textbook propose various options for organizing the process of programming education in their methodical recommendations:

- to study one language from the proposed ones (the teacher's choice);
- to study both languages by parallel (if the students are ready).

There are studying the compiled language C++ and the interpreted language Python in the Polish informatics textbook for 8th grade [10].

For the students, who studied informatics in primary school [20], the studying the text programming language basics begins from the 7th grade (first time in the 2018-2019 academic year).

The available informatics textbooks for 7th grade (2015 edition) does not contain any educational materials on the programming – the teachers are given full freedom to use the educational materials for program implementation. At the same time, the informatics textbooks for 5th and 6th grades (the team of authors, headed by Olena O. Bondarenko [4; 5], instead of the recommended Scratch propose to study the programming basics in Python. Moreover, the programming language Python is also a subject of study according to the informatics textbooks for the 10th-11th grades recommended by the Ministry of Education and Science of Ukraine.

Thus, the analysis of textbooks has shown that Python becomes the main educational programming language rather than an alternative one at the secondary level. The problem of insufficient didactic support for study Python, primarily in the 7th grade, is solved by attracting the resources of national e-learning platforms [24] and author's developments [23]. The above mentioned confirms the relevance of the author's development – the distance Moodle course "Programming Basics (Integrated Approach)" [2].

4 Results

The course "Programming Basics (Integrated Approach)" is corresponded the curriculum (the programming basics on the non-visual programming language) and has a modular-thematic structure (see Table 1).

Table 1. Programming Basics (Integrated Approach) Curriculum

No	Topics	Training hours
1	Introduction to programming	1
2	The linear algorithms: design and implementing	3
3	The conditional algorithms: design and implementing	3
4	The cyclic algorithms – cycles with a precondition: design and implementing	3
5	The cyclic algorithms – cycles with a counter: design and implementing	3
6	The combined algorithms: design and implementing	2
	Summary	15

Each thematic module of the course has the main elements:

1. for forming and developing the programming competence:
   - Moodle pages with new theoretical information;
   - Moodle tasks for practical implementation;
2. for developing the mathematical competence:
   - Moodle glossaries with mathematical references;
   - Moodle tests of mathematical content for training;
3. for developing the multilingual competence:

- URL links to English-Ukrainian dictionaries (Google Sheets) with the topic vocabulary;
- Moodle tests for training proper spelling of the topic vocabulary words;

4. for complex testing of training results:

- control complex Moodle tests on programming, mathematics and English fundamentals.

In addition to the integration of content, defining features of the author's course is the implementation of interactive and action-oriented and differentiated approaches to learning.

The interactive-functioning approach at the stage of familiarizing with new theoretical information is implemented through the possibility of executing the source program code using Python directly on the Moodle page with new theoretical information (see Fig. 1).

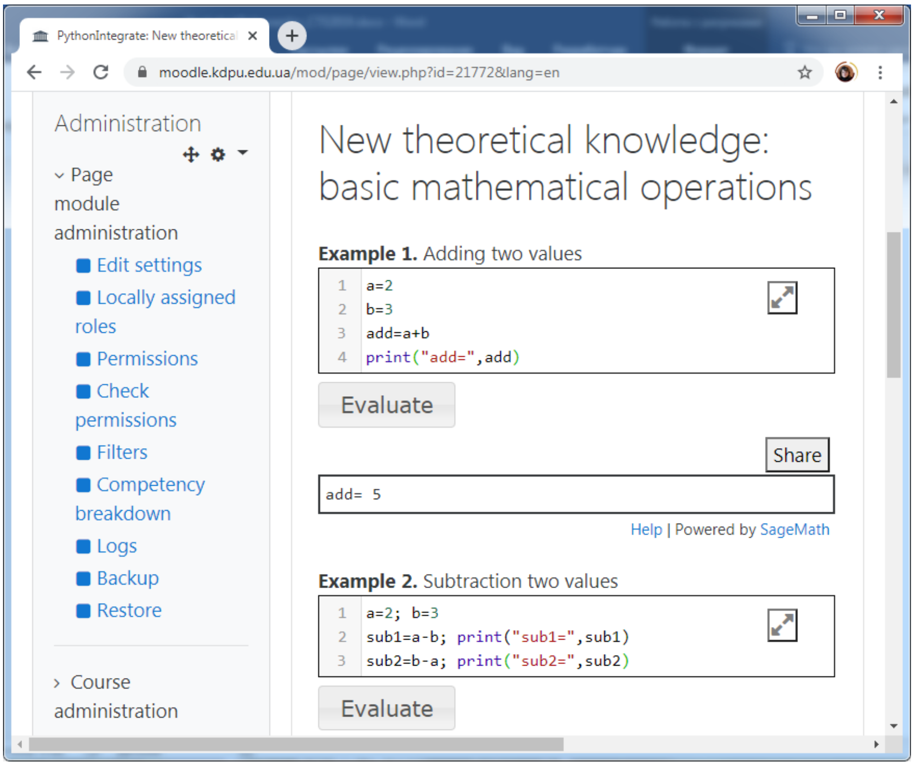

Fig. 1. Moodle page fragment with new theoretical information

Under such conditions, the students taking the course do not need to use local tools (installed integrated programming environments) or other Internet services (browser systems or programming environments). They can check the execution of the proposed program code, make changes to it if necessary and execute it again, and monitor the results of updates on the course page directly.

The ability to execute a program code using Python directly on the Moodle page is implemented by adding a script (see Fig. 2) of a command cell of the network system of computer mathematics SageMath [29].

```
<script src="https://sagecell.sagemath.org/static/embedded_sagecell.js"></script>
<script>
    $(function() {
        // Make *any* div with class 'compute' a Sage cell
        sagecell.makeSagecell({
            inputLocation: 'div.compute',
            languages: ["python"],
            evalButtonText: 'Evaluate'
        });
    });
</script><b>

<div class="compute">
    <script type="text/x-python">
        import random x=random.randint(0,10) print("x=",x)
    </script>
</div>
```

Fig. 2. Moodle page fragment (parameter editing mode) with Web-SCM SageMath command line script

At the stage of practical application of the acquired theoretical knowledge and development of competences in programming (when doing practical tasks) the interactive and action-oriented approach is implemented is implemented with the help of e-workbooks, which are external (relatively Moodle) digital educational resources – the collection of sheets in Jupyter Notebook (see Fig. 3).

Our students are offered workbooks as a task of CoCalc course [26, pp. 54–61], as well as their backups (ipynb files) for working in an offline mode.

At the stage of testing the results of training the interactive approach has been realized by developing a system of tests, where some test questions such as *CodeRunner* and questions such as *Wiris Quizzes* are included (in addition to the traditional test questions – questions such as “multiple choice”, “match”, “short answer”).

The test questions like *CodeRunner* (see Fig. 4) are traditional questions of programming courses, where students are asked to write a programming code for some specification, and then this code is evaluated by the results of taking/passing a series of tests.

Regardless of the behaviour chosen for a quiz, CodeRunner questions always run in an adaptive mode, in which students can click a Check button to see if their code passes the tests defined in the question. If not, students can resubmit, typically for a small penalty. In the typical ‘all-or-nothing’ mode, all test cases must pass if the submission is to be awarded any marks. The mark for a set of questions in a quiz is then determined primarily by which questions the student is able to solve successfully and then secondarily by how many submissions the student makes on each question. However, it is also possible to configure CodeRunner questions so that the mark is determined by how many of the tests the code successfully passes.

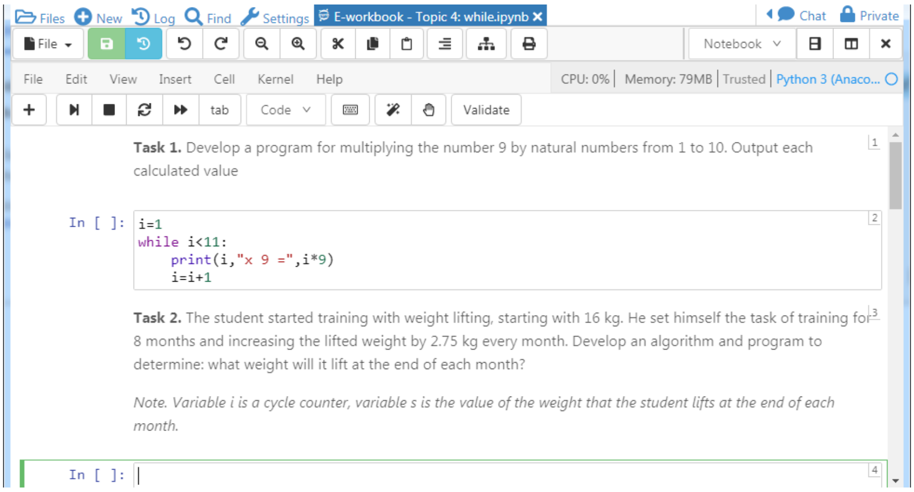

Fig. 3. The workbook page fragment with programming basics in the Python language

CodeRunner has been in use at the University of Canterbury for over seven years, running millions of student quiz question submissions in Python, C, JavaScript, PHP, Octave and Matlab. Laboratory work, assignment work and mid-semester tests in the introductory first year Python programming course (COSC121), which has around 650 students in the first semester and 350 in the second, are all assessed using CodeRunner questions [16].

In test questions of Wiris Quizzes type (Fig. 5) the answer of mathematical content (a fraction, a root, an analytical function, etc.) is automatically processed, entered without keyboard, by means of the touchscreen of a mobile device or simply drawn with a mouse only [17].

The differentiated approach in mastering the basics of programming is implemented by selecting tasks for practical execution and tests taking into account the level of mathematical knowledge of students in different grades (from 7^{th} to 10^{th}). The students are not limited in a choice of tasks for the practical decision – a student of 10^{th} grade has an opportunity to revise mathematics for 7^{th}-9^{th} grades and a junior high school student can try his hand at solving problems with new (that has not been taught yet at algebra and geometry lessons) mathematical content.

The first experimental version of the course “Programming Basics (Integrated Approach)” has been implemented in the educational process of Kryvyi Rih State Pedagogical University:

- within the framework of provision of non-formal and informal education for the students of 9th-10th grades;
- in the process of training informatics teacher-to-be.

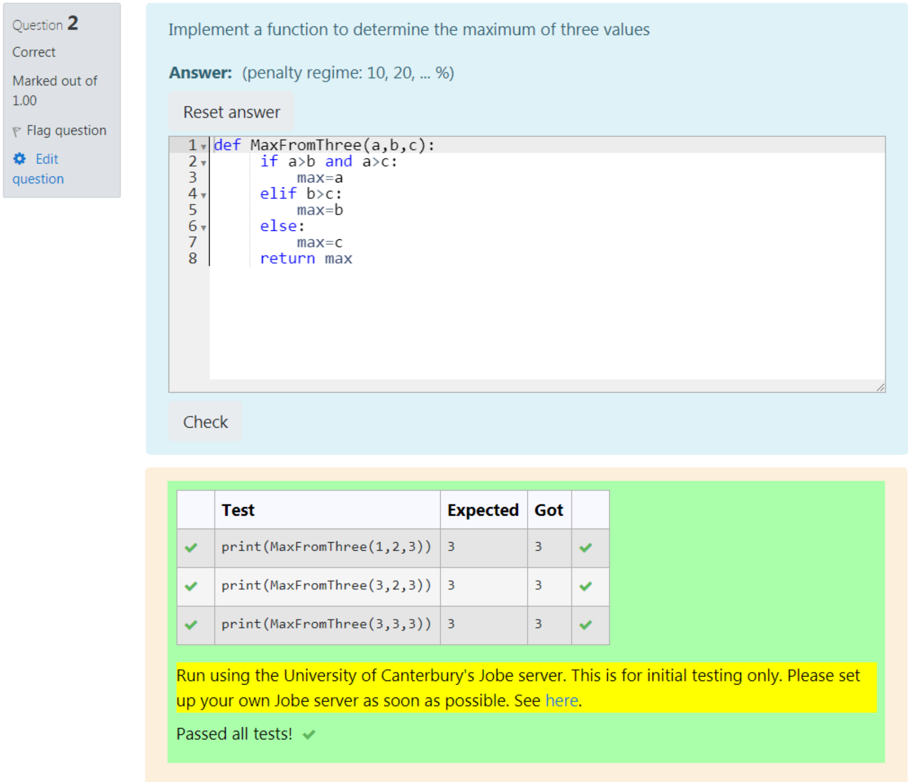

Fig. 4. Illustration of the test questions like *CodeRunner*

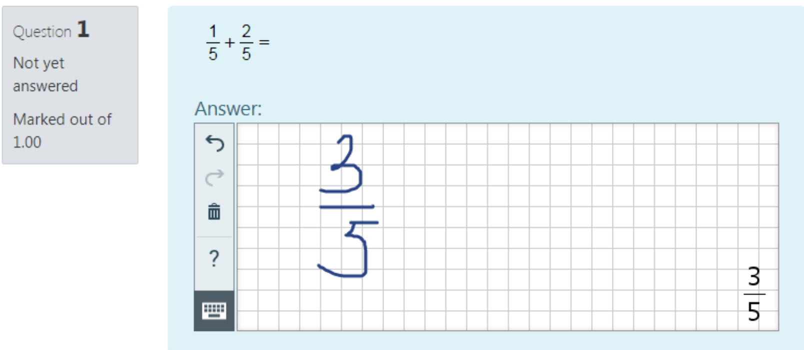

Fig. 5. Illustration of the test questions like *Wiris Quizzes*

An experimental group of 8 students from the 9th and 10th grades are successfully finishing to study the course. The students are self-motivated. The introduction is carried out in their free time when they aren't at school: after lessons or on the weekends. The combination of classroom and distant forms of work ensures continuity and expected effectiveness during the educational process.

The future informatics teachers – 39 1st year master's students specialized in informatics, acquire the content of the experimental version of the course within the framework of the variable component of the discipline "Modern Informatics Lesson".

The results of educational tests and periodic surveys (on the presence of errors and discrepancies, comprehensibility of the content and convenience of software and services, etc.) of both students and future informatics teachers will be taken into account in designing a next version of the course "Programming Basics (Integrated approach)". In the very near future, along with the methodical recommendations for the course, its large-scale implementation will be started.

5 Conclusions

1. The school subject "Informatics" plays an important role in forming a digital competence as subject and key competences. The way of joint improvement of multilingual and mathematical competences at informatics lessons is a construction of system of tasks in English with mathematical content.
2. The lack of lesson time for successful implementation of the triple educational objectives of the lesson – effective mastering new information knowledge and acquiring relevant competences, the special English thematic vocabulary and basic foundations of school mathematics – can be compensated by educational process with the involvement of distant technologies.
3. In support of a thorough study of the basics of text language programming, taking the importance of the content line "Algorithmization and Programming Basics" for the school informatics course into consideration, a distant e-learning Moodle course "Programming Basics (Integrated Approach)" was designed and implemented in the educational process.
4. The success of the experimental training of students and future teachers in the process of studying the integrated course was facilitated by forming an interactive and action-oriented approach, namely:

   - interactive acquiring new theoretical information on programming (doing the source codes directly on the Moodle page);
   - interactive improvement of the special thematic English vocabulary and the fundamentals of school mathematics (working with test tasks in a training mode with no limits in the number of attempts);
   - interactive acquisition of practical skills in programming (performing a system of training exercises on the pages of an e-workbook).

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