Developing digital learning aids for pre-service IT specialists using the functional approach in holistic vocational training

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Abstract

This paper explores the practical aspects and benefits of applying the functional approach to the development of digital learning aids for pre-service IT specialists in the context of their project-based and holistic vocational training. The paper draws on the theoretical framework of holistic education and the functional principles of digital didactic aids design. The paper presents two specific examples of students' project work on creating digital learning aids using the functional approach: (1) a multimedia tutorial for teaching English to schoolchildren and (2) an e-guide on the basics of cryptography for university students. The paper analyzes the outcomes and advantages of such project work from the perspective of holistic and functional approaches. The paper also outlines the directions for future research in this area.

Keywords

digital learning aids, functional approach, holistic vocational training, pre-service IT specialists, project-based activity

1. Introduction

The motivation for this research stems from two interrelated factors. First, the increasing demand for digital learning aids that can support the emerging modes of blended and distant learning in contemporary education at all levels [1, 2]. The design of such digital aids requires the adoption of progressive approaches that are aligned with the prospective educational paradigms. Second, the challenge of preparing pre-service specialists for life and successful work in the volatile world of today, which calls for the modernization of the vocational training process in various domains [3, 4]. The current situation with the vocational training is exacerbated by the unexpected circumstances caused by the global pandemic and the urgency of developing new forms of teaching and learning. Therefore, it is important to build a renewed model of vocational training based on new paradigms.

One of such paradigms is the holistic educational approach, which is emphasized in a number

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of normative documents, such as the Concept of the New Ukrainian School [5, 6], the National Strategy for the Development of Education in Ukraine for 2012–2021, the Law of Ukraine "On Higher Education", the Law of Ukraine "On the Concept of National Education information programs'', Education for Sustainable Development Goals: Learning Objectives and others. According to recent research papers on the theory of holistic education, it is considered as a paradigm that provides educators with a system of principles that can be applied in various ways [7, 8, 9]. The central idea of holistic education is the cohesive development of the whole personality of a learner at both the intellectual and emotional levels [10]. It is also emphasized that such a cohesive development should be supported by strong links between personal experience and real-life problems. However, the evidence from real educational practice shows that the productive and important ideas of holistic paradigm are often implemented in a limited way without fully exploiting its potential for providing integrity at the levels of the content, means and forms of education.

In this research, we aim to implement holistic approach in a comprehensive way, covering various aspects of vocational training, such as: (1) designing the educational content based on the integrative approach to structuring the curriculum disciplines; (2) providing multi-code representation of the educational content to stimulate cognitive processes; (3) integrating students' educational practices with innovative ICT applications to real-life challenges through project-based learning. We argue that these aspects are both driven by and complementary to each other, and thus they enable a more holistic understanding and practice of education.

We also contend that the realization of the main principles of holistic theory requires an appropriate system of learning aids that can facilitate the cohesive development of learners' personality. This leads us to develop digital aids based on the functional approach, which is regarded as the most advanced approach to their design.

In this context, it is essential to prepare IT specialists of various directions (including potential IT teachers) for designing and implementing effective didactic aids that are based on the analysis of their functions and that can support holistic learning of different subjects at different levels of education [11, 12, 13]. Therefore, one of the important components of the renewed model of IT specialists' vocational training based on the holistic approach is the students' project-oriented activity on creating digital learning aids.

The aim of this paper is to present the practical aspects and outcomes of applying the functional approach to the development of contemporary digital learning aids in the process of project-based activity of pre-service IT specialists within their holistic vocational training.

2. Theoretical framework

To conduct this research, we employed a combination of theoretical, empirical, and modelling methods. In the proposed model of pre-service IT specialists' training based on the holistic approach, their preparation for designing innovative didactic aids is realized comprehensively through the integration of common and vocational curriculum disciplines and project-oriented activity.

The theoretical background of the research in the field of digital learning tools development consists of two main components: the holistic educational approach (briefly discussed above)

and the functional principles of digital didactic aids design.

The issues of defining didactic functions of learning aids and applying functional approach to their design have recently attracted the attention of researchers and practitioners (e.g., Grinshkun et al. [14], Grinshkun and Usova [15], Gryzun [16, 17], Kraevskii [18, 19, 20], Lerner [21], Kuts and Lavrentieva [22], Lerner [23], Robert et al. [24, 25] and others). This approach is based on a thorough analysis of the didactic functions of the learning aids and the means of their realization. Functional approach to creating learning aids enables to determine the functional load of its structural elements and the connection between the performance of their required functions [16, 17, 21, 26, 27, 28, 29]. These ideas become increasingly relevant nowadays in the context of designing digital multimedia tutorials [30], as they play a vital role in education.

The problem of didactic functions analysis has always been complex and ambiguous. There are various views on their nature and classification. Based on the review of a number of sources that represent a wide range of functions, we could identify certain groups of them that seem to be pertinent for digital aids. Specifically, *the first group* includes functions that enhance learning motivation; *the second group* contains pure didactic functions that provide effective representation of the learning content and its successful assimilation; *the third group* includes functions of optimization of educational process in terms of adaptation to the learners' needs; *the fourth group* consists of meta-functions that foster learners' progress and increase their general educational potential, which creates a basis for further successful learning beyond the knowledge domain covered by this specific digital aid. It is important to note that these groups of functions are general in nature. Depending on the target audience of the digital aid (schoolchildren or students), the type of academic discipline for which the aid is developed, and some other factors, the emphasis and priorities of these groups of functions may vary.

Nevertheless, the functional analysis for a specific digital learning aid provides practical guidelines for developing the structure of e-tutorials that can be used as a theoretical foundation for their design. The design process involves determining the structure of the tutorial that specifies the interrelations of its components, establishes the mechanism of implementation of these links, etc. As mentioned above, the process of contemporary tutorials development must rely on their deep understanding as an object of design. Thus, it is relevant to acknowledge that a digital learning aid in its state-of-the-art sense has been transformed into an integrated learning environment that incorporates functions of a whole set of learning aids. This has happened due to the use of advanced multimedia and cloud-based technologies in its design.

In addition to determining the structure of a digital aid and clarifying the functional load of each of its structural components, the functional approach also helps to formulate specific requirements for the aid and its design features. This makes the process of the aid development more practically oriented, which is very beneficial for the students' project-based activity, as it gives them a clear understanding of the objectives and significance of their work, enhances their motivation to design high-quality aids that meet the requirements derived from the functional analysis.

The above-mentioned theoretical background provided a basis for applying the functional approach to the development of contemporary digital learning aids in the process of project-based activity of pre-service IT specialists within their holistic vocational training.

3. Results and discussion

The practical aspects and experience of this kind of activity are covered below on the examples of the development of different digital learning aids provided by the students of different specialities within their project-oriented activity in the process of their holistic training.

In particular, we would like to represent multimedia tutorial for English learning support which was designed by the pre-service teachers of Computer Science and English in the process of their project-oriented activity, rested on the previous learning of such curriculum subjects as Programming, Computer Graphics, Pedagogy, English (common academic subjects) and Computer-oriented systems of learning, Basics of E-pedagogy, Design of didactic aids (professionally-oriented subjects).

On the initial stage of the project the didactic functions and structure of the multimedia tutorial were specified due to needs and problems of foreign languages mastering at school.

In particular, pre-service teachers revealed basic demands to the tutorial, determined its functional facilities and defined its structure. In such a way, there was concluded that in order to provide the fulfilment of the leading didactic functions, the English multimedia tutorial for 6th grade pupils has to realize the set of facilities that are given below with the reference to the groups of functions (see "Theoretical framework" section).

First of all, it must provide high-quality visualization of educational content and interactive dialogue with a trainee. It will help to realize in proper way informational, transformational, developing didactic functions (the second group of functions), as well as functions of feedback, friendly correction (the first group of functions) and control (the third group). It should also ensure that the acquisition of linguistic competence is enhanced by the complex involvement of many information perception organs, which will provide the implementation of transformational and developing functions.

The tutorial also has to enable working out of various skills of speech training and in such a way to realize systematic and consolidation functions (the second group of functions). It should guarantee the cognitive activity management including game activity for ensuring realization of didactic functions of developing and self-learning (the fourth group). In addition, the tutorial must provide a strong feedback with a teacher and other trainees to obtain consultations, help, assessment etc (the second group of functions).

Finally, the tutorial has to be easily integrated with other e-resources which will guarantee it integrative and coordinative didactic functions (the third group of functions).

Based on the above functions and relying on research [21, 28, 31, 32], it became possible to design the structure of the multimedia tutorial, since it is conditioned by the need to implement its didactic functions. Thus, students concluded that the tutorial should be the complex of interconnected components characterized below.

For high-quality information visualization, the tutorial should include a multimedia illustration library that offers text, graphics, video, and audio materials [33].

To build language competence via the comprehensive involvement of many sense organs, the tutorial contains an interactive video library with didactic support.

To develop a variety of skills, the manual has a bank of interactive exercises with an immediate output of the results of their implementation.

For learning activity management, the tool has a learning activity management component with repetition of the material and involvement of game elements.

To automate the processes of information retrieval and integration with other electronic sources, the manual has a technological component that will provide its online uploading and the ability to be integrated with other resources. To communicate with the teacher and other students, the tutorial has an appropriate component.

Defined and specified didactic functions and structure of the multimedia tutorial became the basis of its design for the students.

Thus, on the subsequent phases of the project the multimedia English tutorial for 6th grade schoolchildren has been developed with the help of the tools of Ourboox environment, whose capabilities were enhanced by the students' programmed elements. It's worth noting that it does not need to be installed or downloaded due to the fact that it is a cloud-based multimedia book called MultiEnglish. It covers the main topic taught in the 6th grade during English lessons: My family, My friends, Shopping, Food, Sport, Traveling, Ukraine, Great Britain, School life (figure 1).

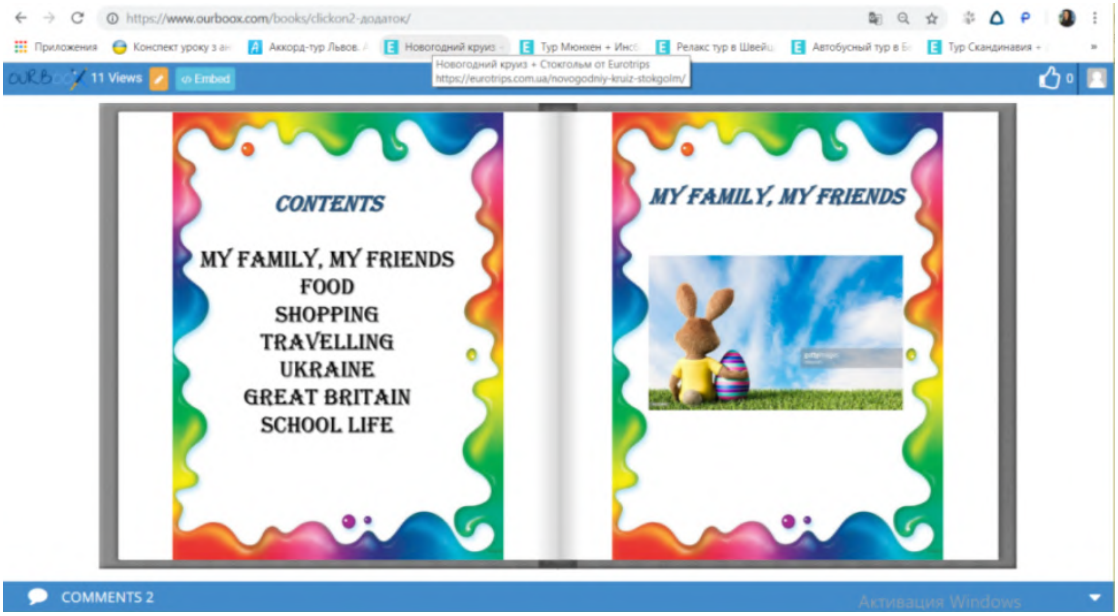

Figure 1: Content of the multimedia tutorial MultiEnglish.

Each topic is represented in four headings (Let's focus on...) that target formation and development of four basic language skills: Let's focus on Vocabulary, Let's focus on Reading, Let's focus on Grammar, Let's focus on Listening and Speaking, Let's focus on Writing (figure 2). The sections contain relevant teaching materials, questions, tasks and various exercises. The demo version of the tutorial is available via the link https://www.ourboox.com/books/multimediaenglish/.

While designing the tutorial, according to its didactic functions and structure, standard features of the Ourboox environment have been significantly extended by HTML markup programming.

Figure 2: Selected categories of the multimedia tutorial MultiEnglish.

Adding appropriate language instructions allowed students to supplement the tutorial with interactive elements of other services that are not provided by the Ourboox environment toolkit. In particular, training exercises, interactive videos, interactive posters, games, static and dynamic illustrations, hyperlinks of a number of services (LearningApps, Quizlet, YouTube, Edpuzzle, Vizia, Gettyimages, ThingLink, ESL Game Plus, Jigsaw Planet, Google Forms) were integrated into the tutorial (figure 3).

In addition, due to editing the HTML code of the tutorial pages, the media content was created. For example, the students-developers could combine text, graphics, video elements and the necessary hyperlinks. Using HTML, it was enhanced Ourboox's capability to format text. For example, it was developed code fragments in HTML with CSS elements to align text and to create numbered lists. In addition, students-developers programmed integration with interactive didactic support into the tutorial. This element allows a trainee to watch the video with a pause at the marked places and do interactive tasks to the video story.

On the whole, thanks to the programmed elements that were added, the multimedia tutorial is able to perform all its didactic functions, defined at the first (theoretical) stage of the students' project.

At the final stage of their project, pre-service Informatics teachers do analysis and reflection of the designed tutorial, revealing its didactic features.

Discussing the didactic capabilities of the MultiEnglish multimedia tutorial, designed on the basis of a functional approach by the pre-service Informatics and English teachers at their project activity, we would emphasize its following features.

The tutorial provides high-quality visualization of educational information and interactive dialogue with the student. A vast library of multimedia illustrations of the application visualizes the necessary elements of the educational content and provides instant feedback. The library contains static and dynamic illustrations of various types, including interactive posters. This type of illustrations enables quick boosting and checking a trainee's vocabulary (figure 4).

This tutorial capacity provides high-quality implementation of informational, transformational, developing didactic functions, as well as the functions of feedback, correction and self-control. In addition, the tutorial enhances the effectiveness of language competencies through the comprehensive involvement of multi-senses activities. In particular, the tutorial allows you to organize the learning activities of the student with interactive video stories, for

Figure 3: An example of an interactive element of a multimedia tutorial that is embedded with HTML programming.

which it has been developed appropriate didactic support. Thus, while viewing the pupil is provided with the tasks that develop their audio skills, replenish their vocabulary, encourage the conscious using of grammar (figure 5).

The multimedia tutorial also has the ability to record a student's speech in order to develop their oral speaking and communication skills (figure 6), which provides realization of the transformational and developing functions.

The developed digital aid encourages training of various skills and can be used as a simulator. The Bank of interactive exercises offers the trainee a variety of exercises of different formats:

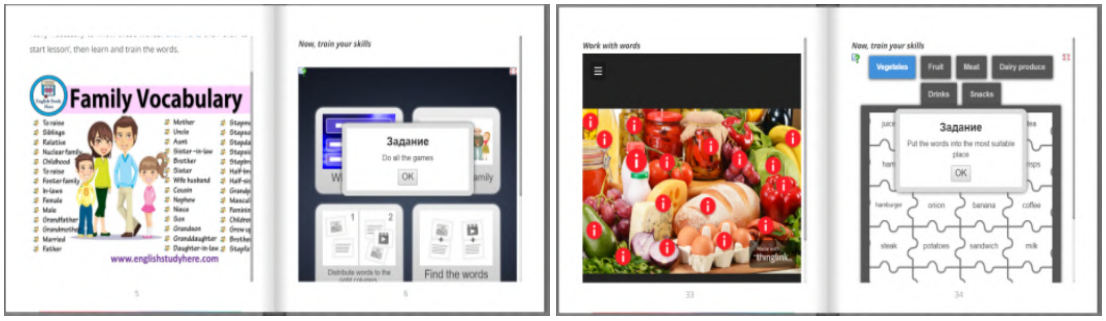

Figure 4: Fragments of work with the multimedia illustration library.

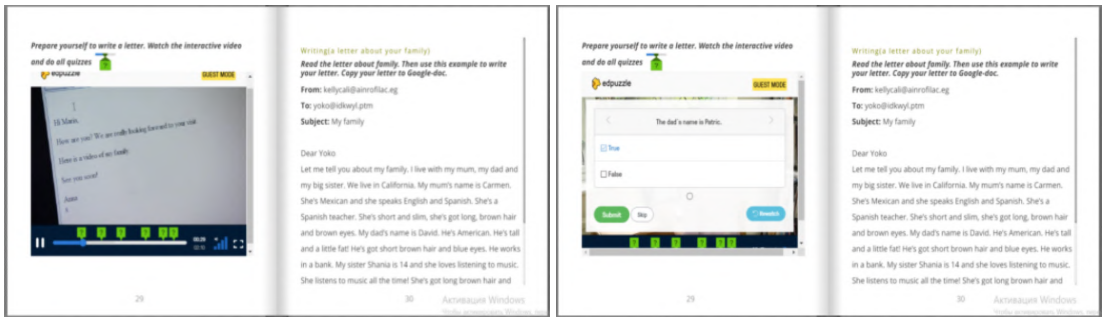

Figure 5: Fragments of the using the interactive video "My Family".

word search, matching, interactive text, puzzle solving, audio and video tasks. In such way, the systematic and anchoring functions are realized. Fragments of different types of training exercises are given in figures 7-9.

The functionality of the developed multimedia tutorial also includes the arrangement of cognitive activities, including game activity. That means that a trainee is able to work at their own pace, both independently and under the guidance of the teacher. In addition, all of the tasks offered to the student can be performed several times to achieve the best results. In order to increase motivation for learning, the tutorial involves pupils into game activities. It offers quizzes, crossword puzzles, cognitive grammar trips, quests etc (figure 10). These kinds of activity provided by the tutorial ensure fulfillment of the developing, systematic and consolidation functions (from the first, second and third groups).

The tutorial expects technological capability of its uploading to other websites and be integrated easily with other electronic sources and environments (figure 11), which facilitates the implementation of integrating and coordinating functions. It is also essential that the tutorial works correctly with all browsers like Google Chrome, Microsoft Edge, Opera, Mozila Firefox.

In addition, the tutorial has the functionality, which helps students to communicate with their teacher. For example, comments element can be used to ask questions, to do the exercise, send a speech to a teacher, or ask for help from other trainees. In such a way, the tutorial implements the didactic feedback function.

Thus, the analysis of the developed multimedia tutorial (provided by the students on the

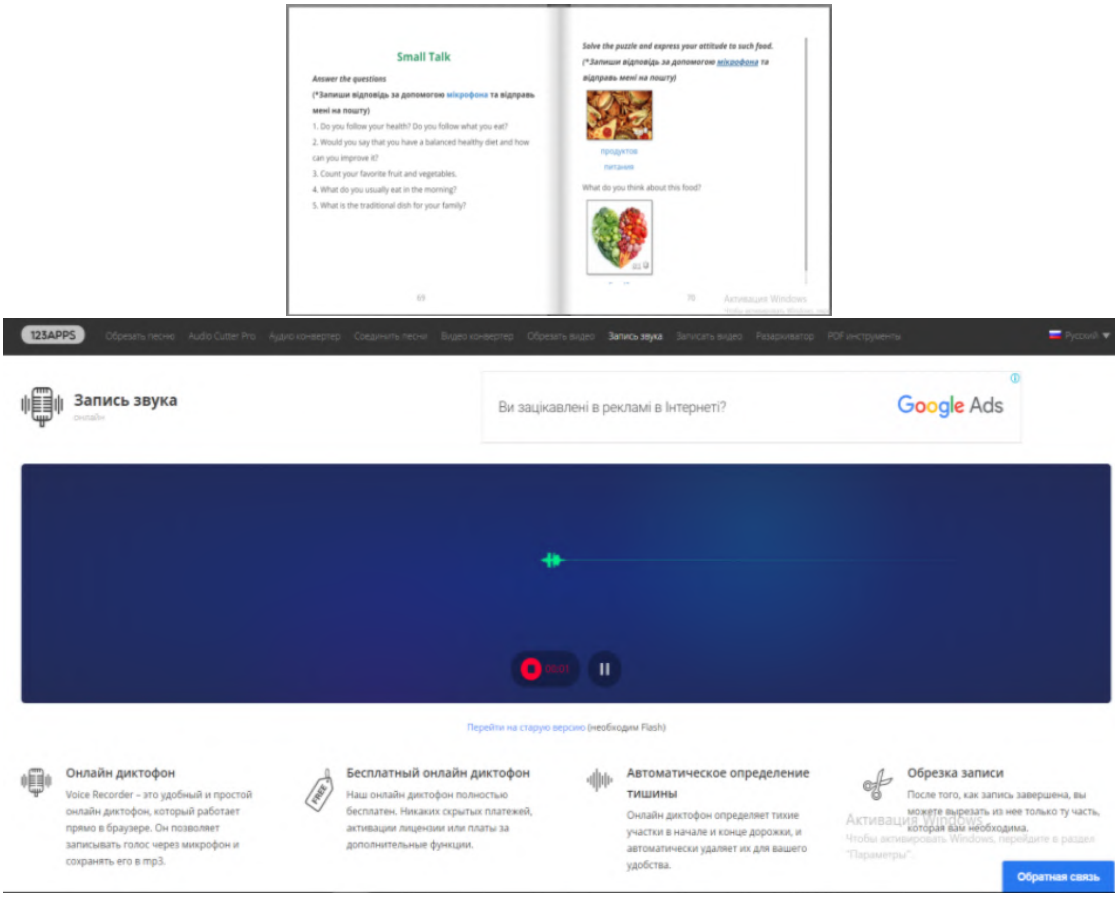

Figure 6: A situation of a student's voice recording while learning the topic "Food".

final stage of the project) testifies that the tutorial designed on the basis of functional approach becomes really innovative, as it creates for a trainee the integral cloud-based cognitive environment oriented on the activity-centred learning. In fact, the tutorial provides pupils with a platform for their independent cognitive activity, for their motivation to learning due to availability of tasks choice and ways of their fulfilling. As a result, it promotes cohesive development of both of students and their potential pupils.

The other example of functional approach applying to the design of innovative digital learning aids is the development of the e-guide on the cryptography fundamentals provided by pre-service IT specialists (unlike the first e-tutorial realized within vocational training of pre-service teachers of Computer Science and English), but also within their project-oriented activity in the process of their holistic training. Including this example, we also aimed to demonstrate main features of the approach realization on the samples of e-guides for completely different target audience (schoolchildren and university students), knowledge domain, forms of potential students' activities etc.

At the first stage of the project activity, the didactic functions and structure of the e-guide

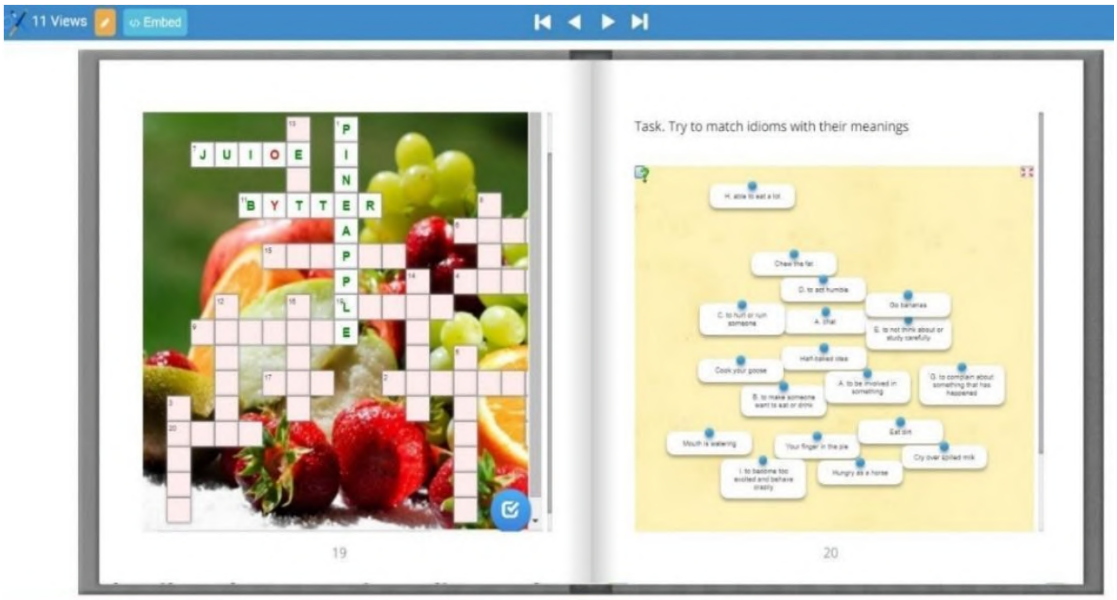

Figure 7: A fragment of matching and interactive crossword puzzles.

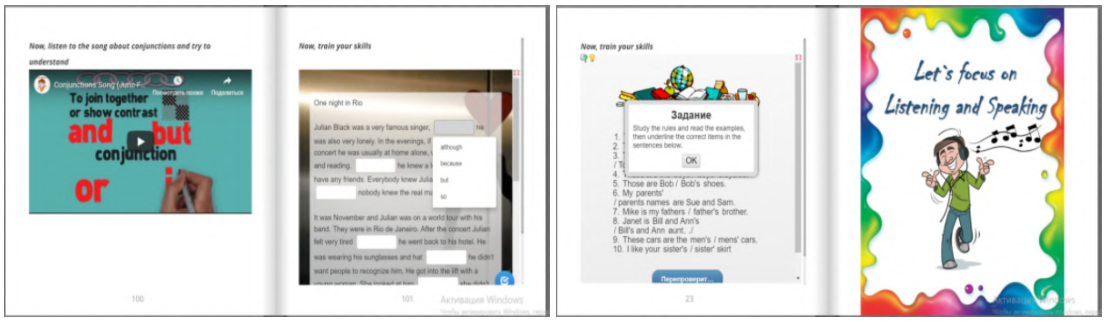

Figure 8: Fragments of work with the interactive text.

were determined due to problems of the course “Information security”, which is a basic one for lots of vocations.

In such a way, resting on the theoretical background on the functional approach (covered above), the students defined proper structural components of the learning aid. In particular, it was determined that the e-guide must contain the textual component organized in hypertext form which presents systematized and didactically processed learning material according to the syllabus of the academic discipline. Here the place of the cryptography fundamentals in the course was determined, and the necessity of coverage in the aid of encryption as one of the means of information protection was established. The learning material was selected and structured on the basis of a number of sources on the basics of cryptography and modern computer encryption systems [34, 35, 36, 37].

It was also determined that the textual component has to provide transition to non-textual

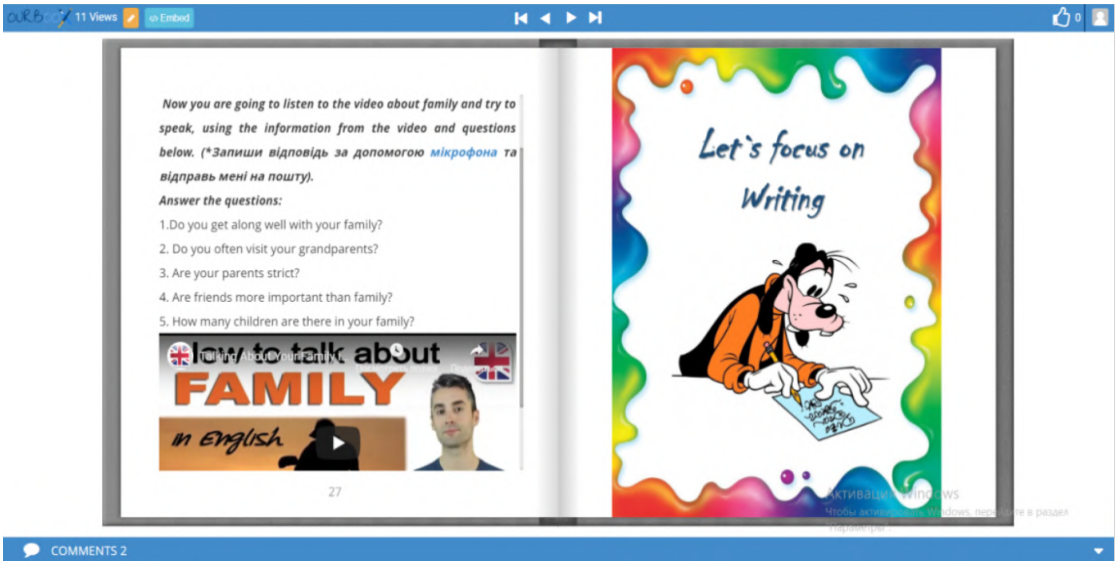

Figure 9: Fragment of work with the video content.

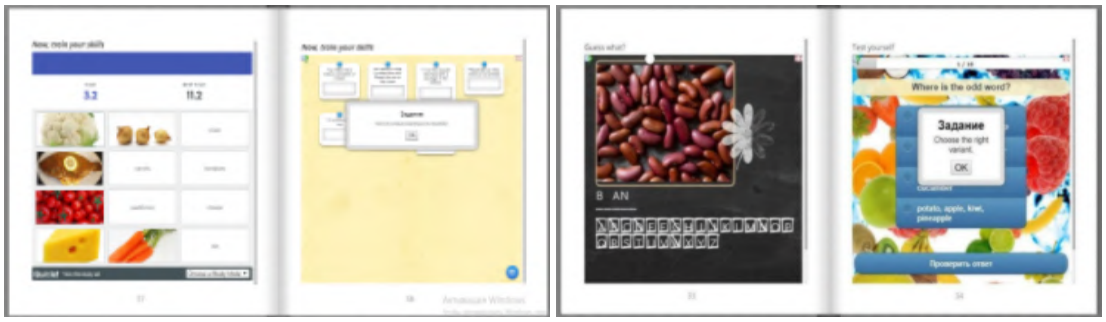

Figure 10: Fragments of the Learning Activity Management component with repeated material and involvement of game elements.

structural components: Illustrative material and Apparatus of the acquisition arrangement.

Illustrative material should contain the static illustrations (technical charts, schemes, photos, pictures etc.) and dynamic ones (animated or video illustrations that demonstrate different methods of information encrypting).

Apparatus of the acquisition arrangement should be represented by a library of learning tasks of different types and a system of self-checking. Among the learning tasks of the e-guide should be distinguished three basic types of the tasks: teaching, training and cognitive-search ones.

At the next stage of the students' project-oriented activity, the e-guide whose functions and structure were specified at the previous stage was developed in the environment of MS Learning Content Development System using its tools and facilities. The developed learning aid covers the following topics on the basics of cryptography: "Basic concepts of information security", "Cryptology as a science", "Classical encryption algorithms", "Computer encryption systems".

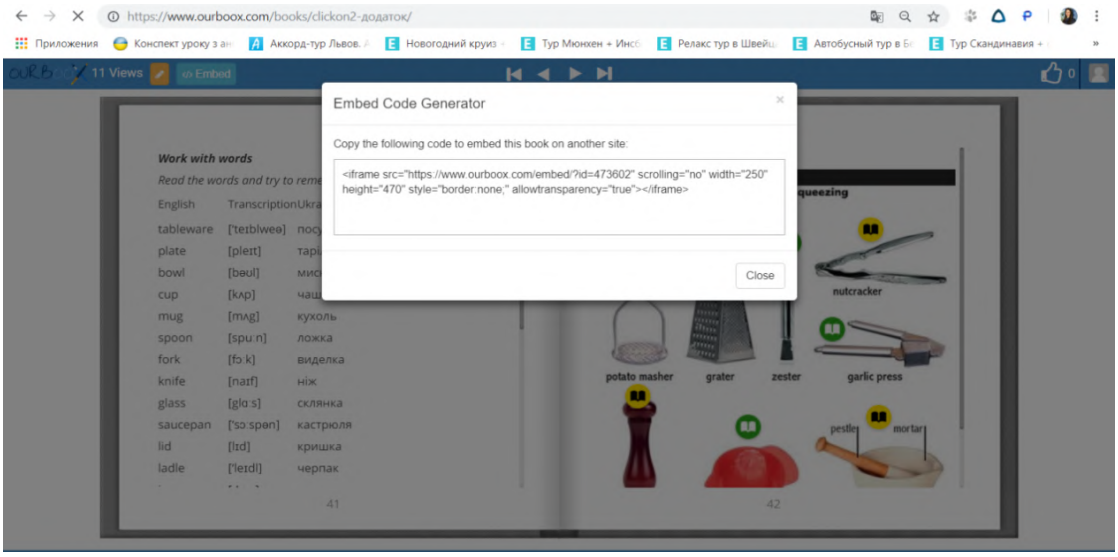

Figure 11: A fragment of the technology component that allows you to embed the author's tutorial on other websites.

As it was planned, the e-guide contains a textual component organized in the form of hypertext, which allows to find quickly necessary learning material on the course, navigate easily the topics and sections, work with illustrations and tasks, refer to external links for other information resources (figure 12).

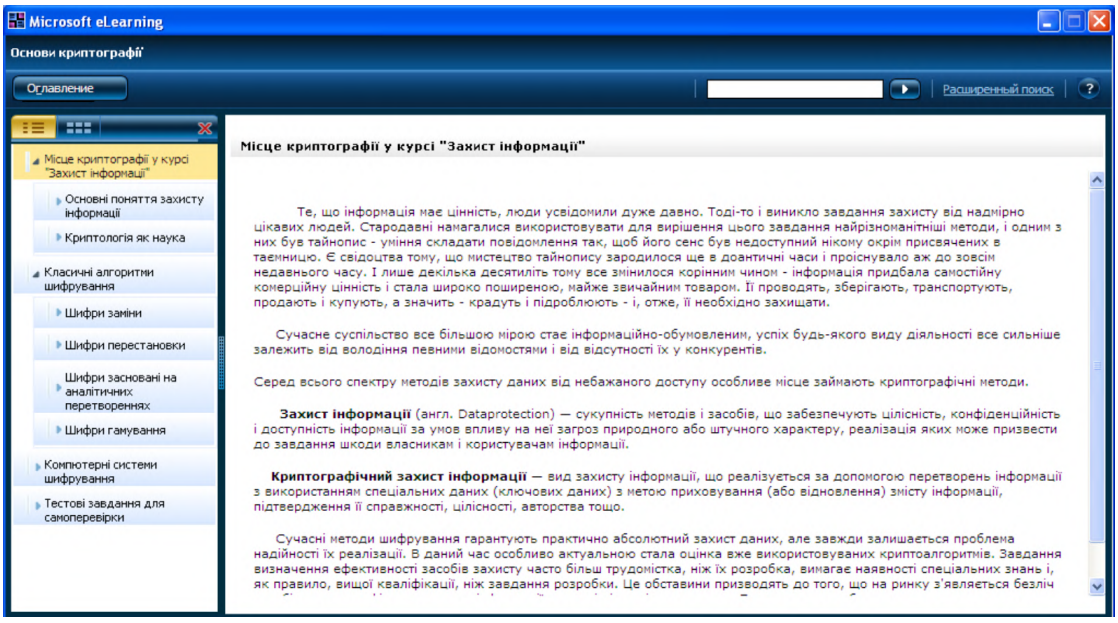

Figure 12: Episodes of work with the hypertextual component of the e-guide.

The textual component is supported by the Illustrative material component which provides a trainee with two types of illustrations. The first type includes static illustrations, such as generalized schemes of computer cryptosystems, the visualization of which facilitates the understanding of educational content (figure 13), contributes to the transformational didactic function and function of visual method use.

The second type of illustrations are dynamic ones which demonstrate the process of data

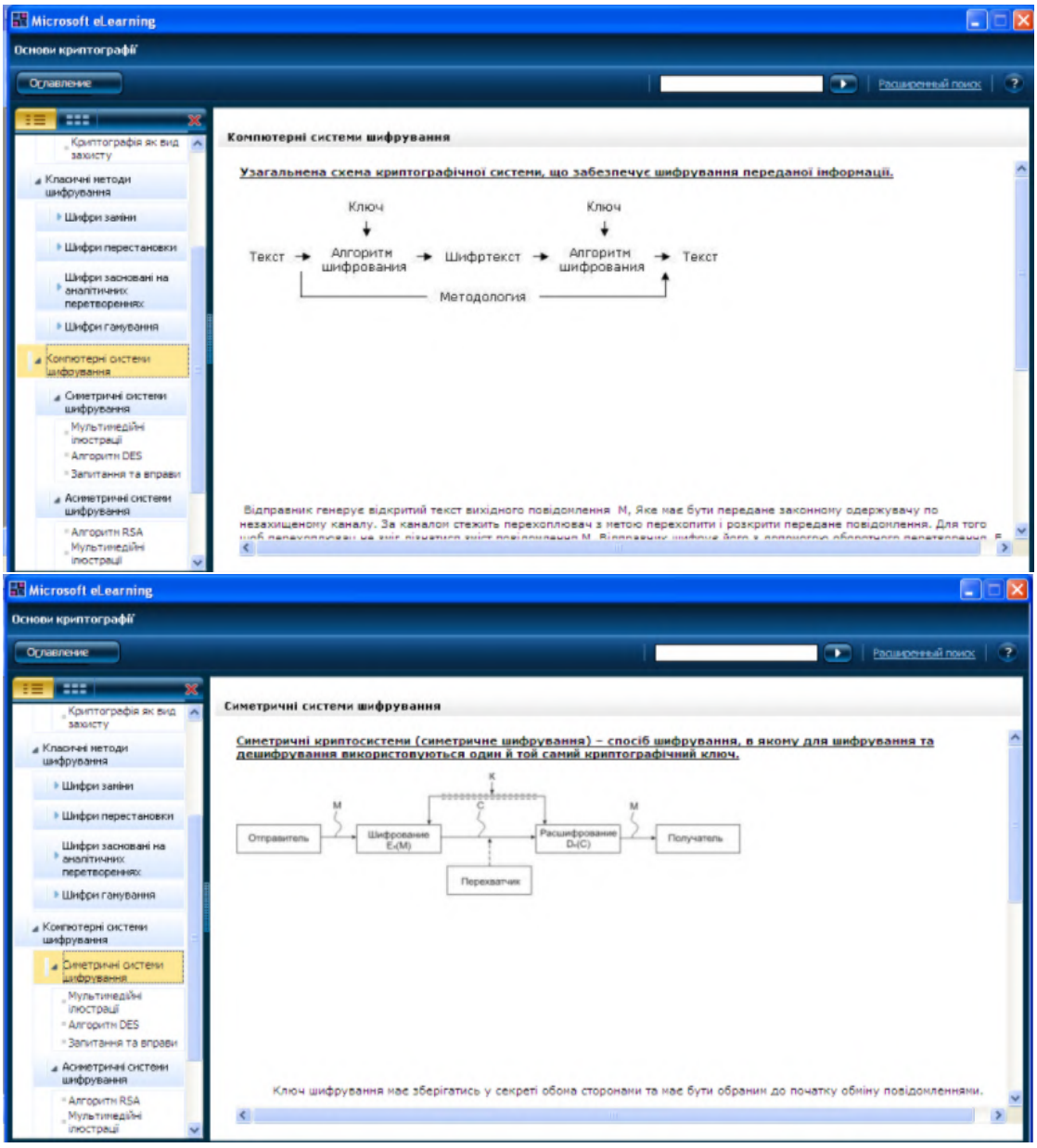

Figure 13: Work with static illustrations on the topics “Computer encryption systems”.

encrypting based on various encryption algorithms; processes that reproduce the sequence of actions in the operation of encryption algorithms, historical information, the essence of some abstract concepts, and so on. This component gives for potentical trainees the opportunity to observe these processes, review them at different speeds and check the assimilation of the content, answering a number of questions to the reviewed dynamic illustrations offered by the e-guide.

Thus, the work provided by the e-guide with its hypertextual component supported by static and dynamic illustrations promotes implementation of informational, transformational and systematizing functions (the second group of functions depicted in the Theoretical framework above).

Apparatus of the acquisition arrangement of the e-guide, as it was planned, is represented by a library of learning tasks of different types that are forcused on the mastering of theoretical content, and a system of self-checking.

The teaching tasks of the developed aid are ready-made programs (realized in different programming environments) that implement a certain encryption algorithm. The e-guide encourages a trainee to work with the program, to find out its purpose and functions, and to analyze the program code. In particular, the teaching tasks allow data encrypting and decrypting based on some classic encryption algorithms. The solution of the teaching task expects trainee's processing, according to a certain scheme proposed by the library of teaching tasks (or by the teacher). Trainees have the opportunity to run them, analyze the operation of algorithms and make conclusions by answering questions. In addition, it is possible to copy fragments of program code and use them to develop trainees'own programs (figures 14-15).

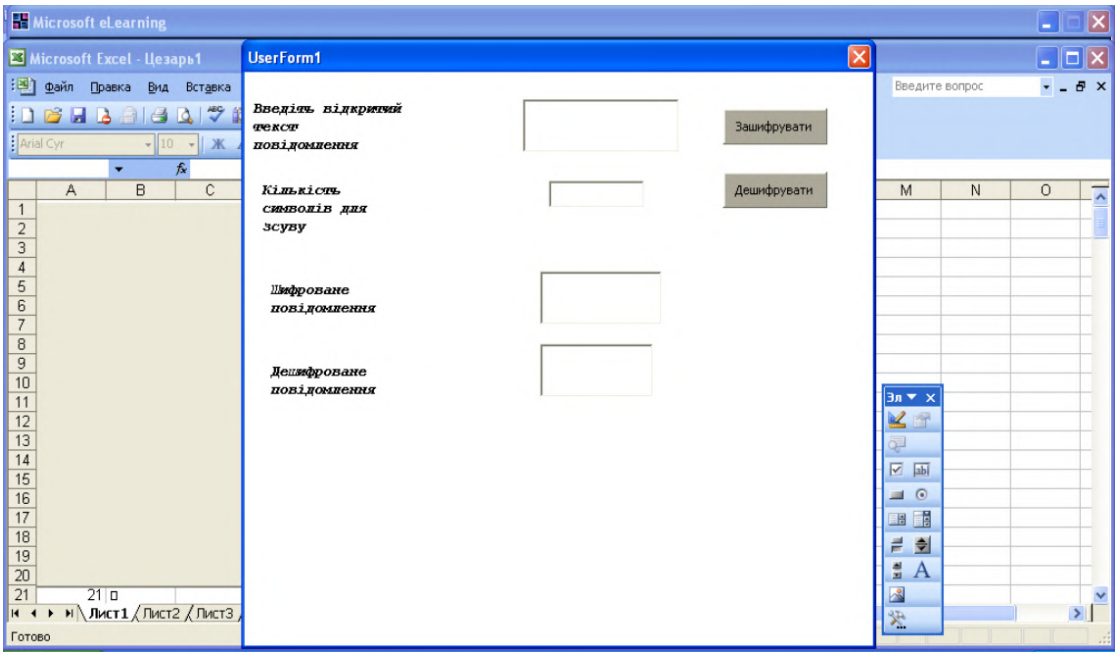

Figure 14: Teaching task for the implementation of the Caesar encryption algorithm.

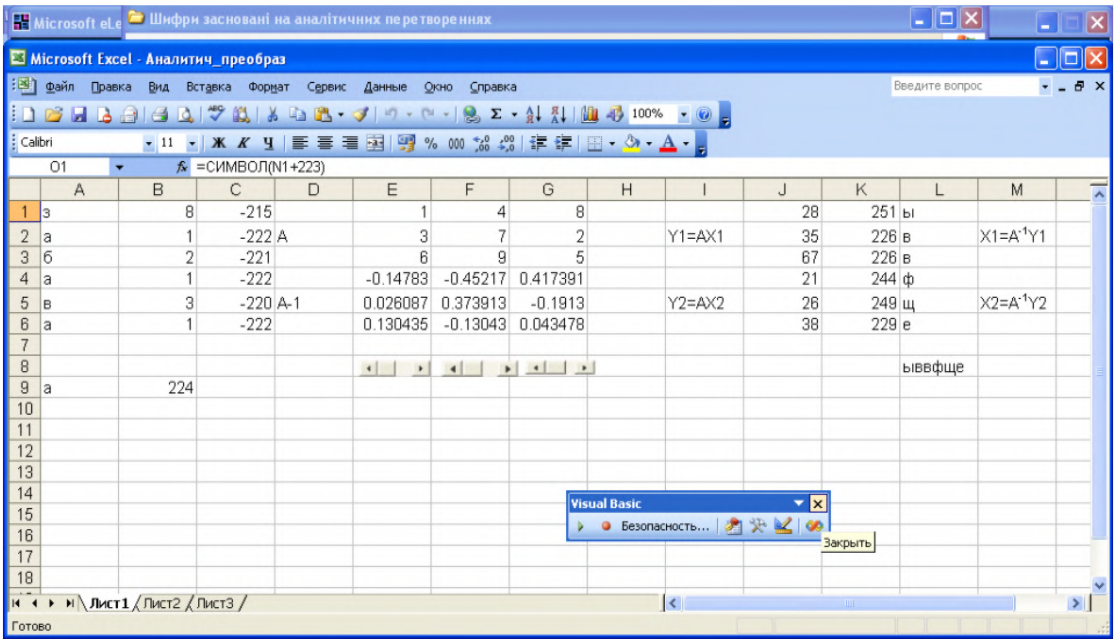

Figure 15: Teaching task for implementation of the encryption algorithm based on analytical transformations.

Training tasks include tasks similar to teaching ones, but students solve them independently, based on theoretical content and program implementation of teaching tasks. For example, working with the code of the learning task, a trainee masters the encryption of a certain algorithm, and then he is offered a training task to implement a decryption program by the same algorithm. Some of the training tasks are focused on working out the skills of using various encryption algorithms via the set of exercises. For example, for the topic "Replacement encryptions" and "Substitution encryptions", the e-guide offers the set of exercises given at the figures 16-17.

Cognitive-search tasks presented by the Apparatus of the acquisition arrangement are aimed at applying knowledge at the creative level. Trainees are offered a number of tasks on each topic: tasks that require significantly transformed knowledge; tasks for independent application of different types of encryption algorithms; research tasks and comparative analysis of different information encryption systems; complex tasks on the composition and those that involve gradual complication etc. Each task has instructions and answer, as well as the references to relevant theoretical material or to the teaching tasks of the manual.

Thus, the developed and filled library of the learning tasks allows to realize at a higher level the functions of consolidation (the second group of functions) and development (the fourth group of functions).

The self-checking system presented in the e-guide is realized with the help of Google Forms (figure 18). The system includes a set of generalized test tasks to check the level of mastery of educational material. The form is connected to the Google spreadsheet and the answers of the respondents are automatically stored in it, which in turn allows the teacher to analyze

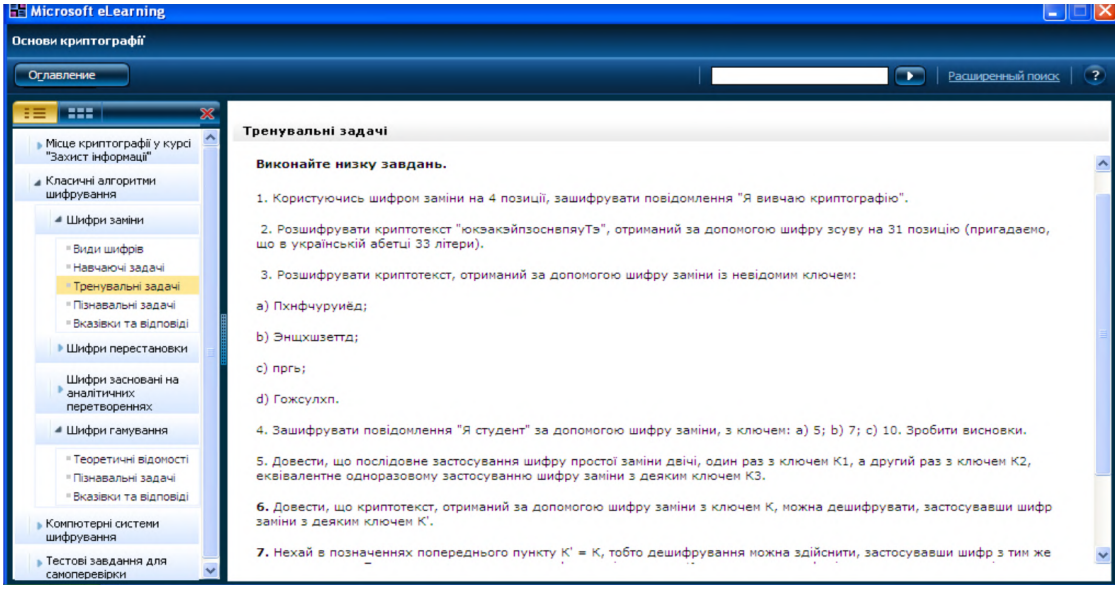

Figure 16: Fragment of work with training tasks on the topic “Replacement encryption”.

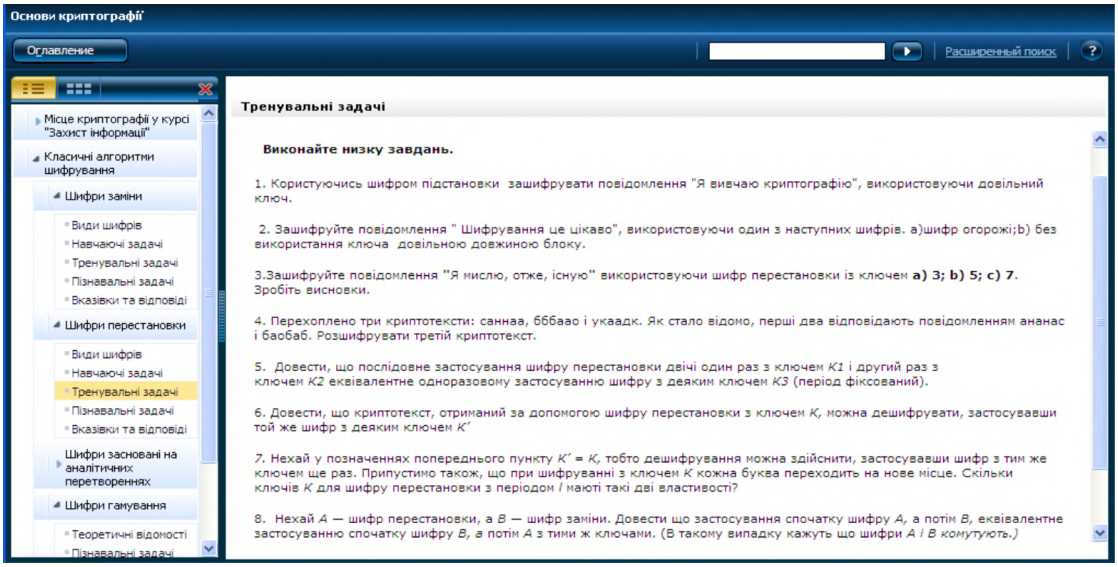

Figure 17: Fragment of work with training tasks on the topic “Substitution encryptions”.

the trainees’achievements. Thus, the implemented system of self-checking contributes to the implementation of such didactic functions as the functions of correction and control (the third group of functions), consolidation (the second group), and developing and educational function (the fourth group).

Thus, the digital learning aid, designed by the students based on the functional approach, makes a whole learning environment suitable for use in the educational process of IT specialists

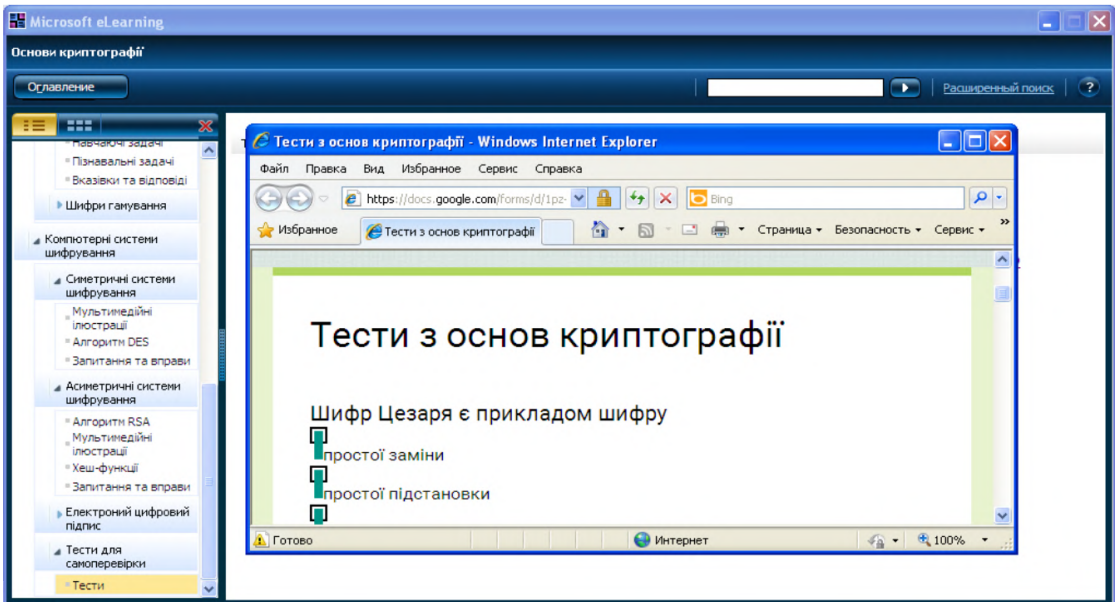

Figure 18: The fragment of work in self-checking system of the e-guide on the fundamentals of cryptography.

training within the course “Information Security” providing its holistic learning.

At the final stage of the students’ project-oriented activity the developed e-guide was tested and elaborated. In addition, there were offered some methodical recommendations as for its using at the educational process of the university in its different forms.

Summing up the depicted experience and specific examples, we would emphasize the following. The functional approach which was applied by the students to the design of the digital learning aids demonstrated its great benefits as for the quality of the aids as the results of the students’project-oriented activity. In particular, the functional approach enabled the students (1) to specify the goals of development; (2) to determine the aid’s structure components, their purposes, and their mutual connections; (3) to clarify the choice of the fulcrums for the purposes achievement; to control the process of the aid development; (4) to provide objective estimation of the results; (5) to promote the demand and practical application of the created digital learning aid. Here, it is important to point out that the result of the academic project-oriented activity had not only learning value, but also obtained essential practical application. Th elaborated digital learning aids were approved in the real educational processes at school and at university during various kinds of practices. The results of the work were also presented during the students conferences and workshops.

It is also worth underlying, that on condition of such an interdisciplinary preparation and project activity, pre-service IT specialists obtain meta-skills on the design of innovative digital learning aids. In the process of this kind of training, potential pre-service IT specialists obtain full understanding and capability for practical embodiment of core ideas of holistic educational approach via their personal experience of development of the learning aids. In addition, the application of the fuctional approach made students’ project activity more practically driven

and motivational.

It seems to be reasonable to predict positive influence of this kind of training on the forming of the students' holistic system of professional knowledge and skills. Elaboration of proper methodology of its diagnosing and estimation is a prospect of our further research.

4. Conclusions

This paper presents the practical aspects and outcomes of applying the functional approach to the development of contemporary digital learning aids in the process of project-based activity of pre-service IT specialists within their holistic vocational training. The paper draws on the theoretical framework of holistic education and the functional principles of digital didactic aids design. The paper illustrates two specific examples of students' project work on creating digital learning aids using the functional approach: (1) a multimedia tutorial for teaching English to schoolchildren (done by pre-service teachers of Computer Science and English) and (2) an e-guide on the basics of cryptography for university students (done by pre-service IT specialists). The paper analyzes the benefits and advantages of such project work from the perspective of holistic and functional approaches. The paper also suggests some directions for future research in this area.

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