The Adaptive Course of Physics at a Technical University

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Abstract. An important component of the professional development of a modern engineer at a technical university is knowledge of fundamental disciplines, physics in particular. However, first-year students lack basic knowledge and skills in physics, especially in solving physical problems and tasks. Some students realize it and try to eliminate the defects of the previous stage of their education by their own.

With the aim to help students in eliminating the gaps in their knowledge in physics we developed teaching materials for the adaptive course under the flipped classroom model of the blended learning.

The developed materials include brief theoretical information, methodological guidelines for solving problems and examples of solutions, as well as thematic tests to monitor students' knowledge level. The materials are hosted in the LMS Moodle.

The use of the developed materials showed an increase in student activity in the classroom in solving the problems. The results of the final control revealed that most students eliminated knowledge gaps.

Keywords: Physics, Students' knowledge problems, Adaptive course, Blended learning, Flipped classroom model.

1 Introduction

The qualitative higher technical education has in its basis the knowledge that students acquire while studying such fundamental disciplines as physics and mathematics. In any technical university mastering these sciences needs the knowledge and skills that students had to learn during their school years. But according to our observations and numerous facts of confirmation in the publications, we can state that a lot of students lack the basic knowledge in these fields. And thus, those students have problems in mastering physics of the technical university syllabus at the corresponding level. Such gap of knowledge is then followed by the low level of the professional preparation as this knowledge has a vital influence on the formation of engineering thinking and unique methodological knowledge. These two factors are the background for the further self-development, self-improvement, long-life learning and allow any person to master some knew knowledge and competences, as well as find solutions for new professional problems and tasks.

It is possible to lessen the gap between the actual levels of students' knowledge and the knowledge needed to study physics at the university level by means of the adaptive course. Such course, by now, is not included in the syllabi and curriculums and its organization must be supported mostly by the independent students' works with the educating materials. Having organized this kind of work using telecommunication technologies, periodic communication with the teacher in the classroom gives the lecturer possibility to involve more students to the work (those students who need overcoming the lack of knowledge and skills) with the minimum usage of the classroom hours. In fact, such work in its form is the implementation of blended learning.

The purpose of our paper is to present the methodology of organizing the work aimed at the diminishing gaps of knowledge in physics of the first-year students at a technical university with the help of blended learning techniques.

2 State of the Problem

The effective mastering of knowledge and ways of activities take place only when these knowledge and skills are in the nearest sphere of the personality development. As learning the course of General Physics at most faculties of a technical university starts at the first year, then the zone of the nearest development of students are determined by their basic knowledge and skills received at school and then showed at the External Assessment Testing (EAT). These knowledge and skills have to build the background for the future mastering of knowledge of the higher level. Nevertheless, a great number of scientists state that for the recent years the physics knowledges of students decreased and not only in Ukraine. For Ukraine, it is proved by the results of EAT.

We think that the most reliable information about the knowledge of physics among the school-leavers present EAT results before their statistic processing (the so-called 'raw' results). Using the results of the "Official reports on the delivering of the "External assessment testing of the knowledge acquired on the basis of the complete secondary education" during the period 2015-2019 [12], [13], [14], [15], [16] we calculated the ratio of the average mark of the test to the possible maximum mark. Some increase of this ratio can be explained by the improvement of the school-leaver's preparation as well as the simpler tasks at the testing.

Performing the EAT task on physics during the period from 2015 to 2019 is on average at the level 32 % of the maximum possible as it can be seen on Fig.1. This clearly demonstrates the fact that potential students have considerable gaps in their knowledge; for all this, the function maximum of the distribution of tests raw grades of different years lie at 13-22. Most concern is caused by the fact that the open tasks, that actually are not difficult ones, are solved by not more than 15 % - 17 % of the school-leavers [12], [13], [14], [15], [16].

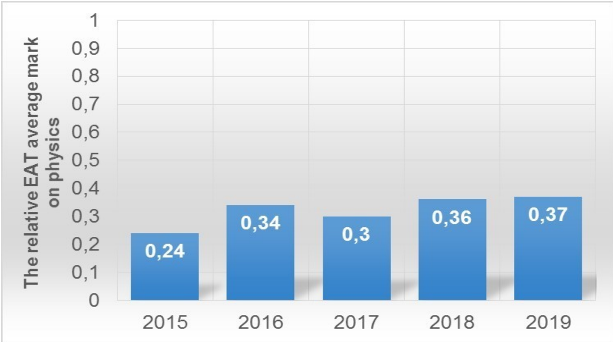

Fig. 1. Annual distribution of the average mark ratio of the test to the maximum possible mark.

We can also prove the weak basic knowledge in physics with the results of The Ukrainian Olympiad on Physics for School-leavers that took place in Igor Sikorsky Kyiv Polytechnic Institute in 2018-2019. As it was found out many participants were not able to give correct answers to simple enough questions that were formulated in the way that was different from the school one. It can prove the fact that at school and at the preparatory courses the pupils 'are coached' for the solving of some particular types of problems and they are not taught to have and develop their critical thinking, and the ability to analyze the situation and make conclusions [6].

The low level of the basic knowledge causes the appearance of substantial problems while studying physics, and thus makes lower the level of knowledge which then becomes evident as most educating material has to be learned independently. That is why detecting the gaps in the students' background knowledge and creation of the corresponding conditions to overcome them are of great importance.

To detect the gaps of knowledge among the first-year students we developed the diagnostic technique (see Fig.2) that presupposes the following:

- EAT reports analysis;
- the entry survey and entry test among the students at the beginning of the semester;
- a questionnaire and survey in the middle of the semester among university physics lecturers;
- residual knowledge control at the end of the semester.

The results of the survey delivered among the physics teachers allowed us to distinguish the reasons that cause the problems for students in studying physics at a technical university:

- **subject reasons,** that are due to the low level of subject competence in physics among the general secondary-school leavers, are as follows:

- problems in mastering the theoretical part of the course;
- the absence of skills how to apply the knowledge in physics and mathematics while solving the problems;

- inability to cope with algebraic expressions and receive the results of the solution of a physical problem or to prove a theory statement in general;
- unskillfulness in dealing with the graphic information;
- unskillfulness in applying the knowledge of one part of physics for the usage of them in other ones;
- inability to work with the units of physical quantities;
- lack of skills and experience in delivering an educational physical experiment;
- the deficiency in mathematical preparation (it is worth mentioning that according to the survey about 30 % of the students are the graduates of the humanities profile schools where physics and mathematics are of the second importance);

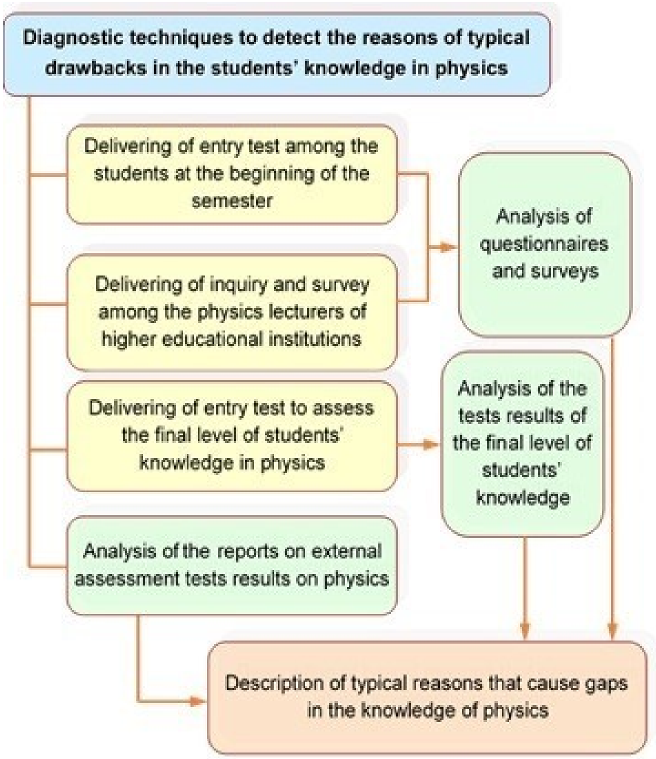

Fig. 2. The block diagram of the diagnostic technique to detect the reasons of low level knowledge on physics among the students.

— **general education reasons** caused by:

- inadequate level of information competence that presupposes the skill in organizing educational information search;
- absence of skills of independent work as well as the work with the manuals, hand-books, and reference books on physics.

— **general cultural** caused by:

- low terminology basis;
- inability to express their ideas clearly and logically;
- inability to listen to the interlocutor and make the corresponding conclusions

The task of the entry test is to detect the actual knowledge of the higher educational institution students [18]. For the lecturers the results of this control give the information on the structure of each student's knowledge and enable the teacher to plan the work on overcoming the detected gaps. On the other hand, this test is also important for the students, as it gives the possibility for them to compare their actual knowledge and skills with that needed to study physics in the technical university, so make the conclusion about the necessity of correction his/her level of knowledge.

We assessed the actual first-year students' level of knowledge in physics by the entry test delivered by on-line testing.

The entry control consisted of the items given to the school graduates at EAT during the period of 2009-2019. It had 16 close tasks and 5 open tasks. The distribution of the marks in percent for 530 students of different faculties of Igor Sikorsky Kyiv Polytechnic Institute is presented in Fig.3. The overall average mark for the test equals 41,4 % of the maximum possible value.

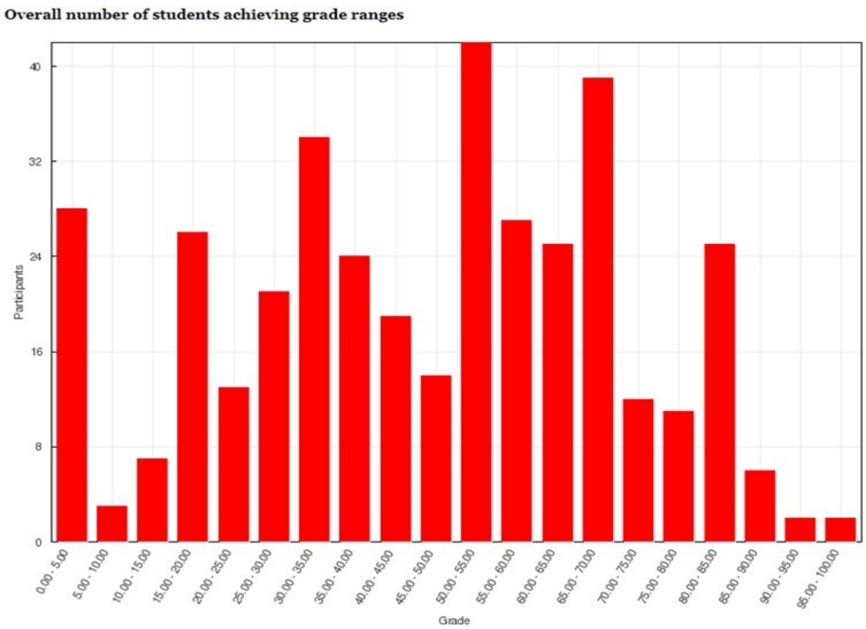

Fig. 3. Distribution of the results of entry test on physics

The general statistics of the entry test is slightly better than that of the EAT. However, most results gained by the students are not satisfactory according to the ESTC at a higher educational institution because most of students cannot get the minimal positive mark E lying in the range of 60%. As for the results of the open tasks, there is almost no difference between the EAT results and the entry tests results as only 15 - 20% of students give the correct answers. Inability of future engineers to use theoretical knowledge in practice is a great problem as the engineer's work suggests such activity. That is why it is underlined in the syllabus of "General Physics" of any technical university that one of the most important goals of education is the formation of students' skills to solve the practical physical problems and tasks from different areas which will help them in future to solve engineering problems [18].

So, if we eliminate the gaps in the students' knowledge and improve their basic preparation in physics, this will favour the qualitative mastering of the material of the course of general physics at a technical university.

3 Main Part

To diminish the drawbacks of the basic preparation in physics among the first-year students we developed the didactic materials of the adaptive course that can be implemented in the form of blended learning. According to D. R. Garrison, and H Kanuka, blended learning is a thoughtful combination of the experience of classroom and online education [8]. Following from the fact that the syllabi do not have planned hours aiming at the overcoming the gaps in students' basic knowledge in physics the most suitable form for such kind of work is the flipped-classroom model of blended learning. The advisability of using this model is proved by our experience in organizing the students' work while preparing them to the physics labs [2], [11]. As the analysis of the available research shows [1], [5], [7], [8], [10], [17], [20], [23] the usage of the blended learning technique does not need the dramatic changes in the classic model that forms significant social and cultural traits. Moreover, the usage of this technique motivates the students' cognitive activities and forms the qualities that are of great need for the life and actions under the conditions of information society.

Using the flipped-classroom model in the system of blended learning changes the character of the information interconnection between the participants of the educational process, the ways of presenting the information and content of the educational and methodological support of the educational process [19]. In such a way, a new methodological system of education is formed and the corresponding related to its information educational environment must be formed. Such environment S.U. Goncharenko characterizes as the combination of conditions that predetermines the appearance and development of the processes of information-educational interrelation between those who study, the teacher and the means of new technologies, as well as the formation of the cognitive activity under the condition that all the components of this environment have the subject content of each particular educational course [9, p. 149].

The most expedient form organizing the students work to overcome the gaps in their basic preparation is the flipped classroom model of blended learning. In this model [20], students rotate on a fixed scheduled time (consultations/tutorials) and independent work with the instructions and materials in the format of the remote access during their out-of-classroom- time. Besides, students can choose time, place, path, and/or pace and the rhythm of their work with the Internet resources. The generalized scheme (developed by us) of this model of students and teachers work is presented in Fig.4.

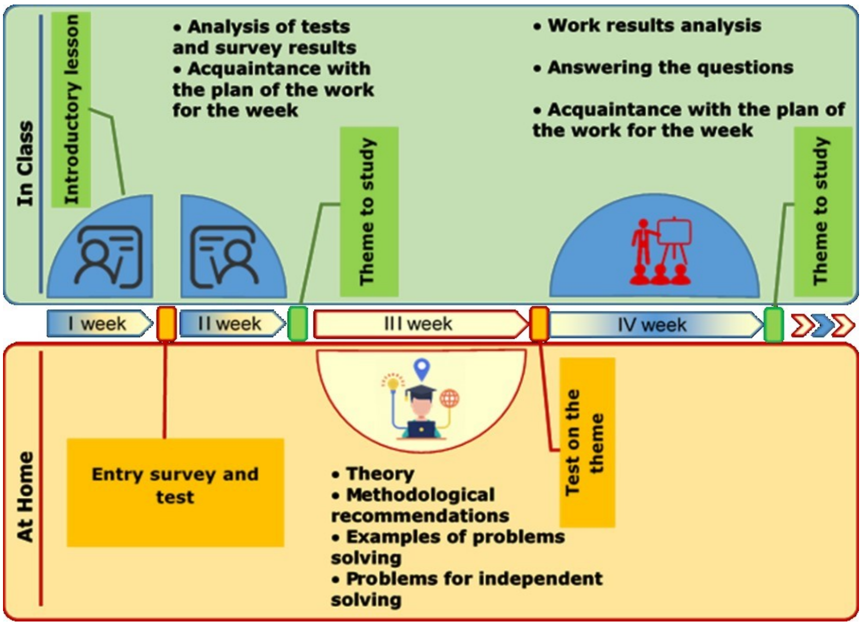

Fig. 4. The scheme of organizing the work of students and teachers in the flipped-classroom model of blended learning.

During the first week of semester at the technical university the lecturer informs the students about the peculiarities of the subject, its demands and asks the students to complete the on-line questionnaire and entry test on the subject. The entry test includes the items on physics from the previous years' EAT. The students do these tasks at home. The gaps detected by the entry test make it possible to plan the individual trajectories of correction for the students, these trajectories have the stages to correct theoretical knowledge and skills to solve the problems. Schematically the work succession while developing individual trajectories is presented in Fig.5.

During the second week the lecturer sums up the results of students' work at home, and according to the testing results defines the typical problems in his/her physics knowledge due to the secondary school program. If necessary, the lecturer offers the students to have the adaptive course to overcome the problems at their wish. The goal of the course for the students is to repeat or study theoretical material and to acquire practical skills to apply their knowledge in physics and mathematics for solving problems under the EAT program on physics [21] in accordance with the developed thematic plan. During the following period, the teacher gives students new tasks for the next weeks at the tutorials. The students, having the theme for independent study, repeat/learn theory, get acquainted with the methodological recommendations on problems solving and with the examples of using these recommendations while solving physical problems. While solving test tasks and problems for the independent work the students consolidate their theoretical knowledge. The final control of the weekly work is the test on the same subject. The control tests are located in Moodle environment where students' works results are registered automatically. Due to these results, the lecturer can make necessary changes in the thematic plan or develop an individual trajectory of the work of the particular student. During face-to-face consultation, the students can have any explanation of the not-understood questions.

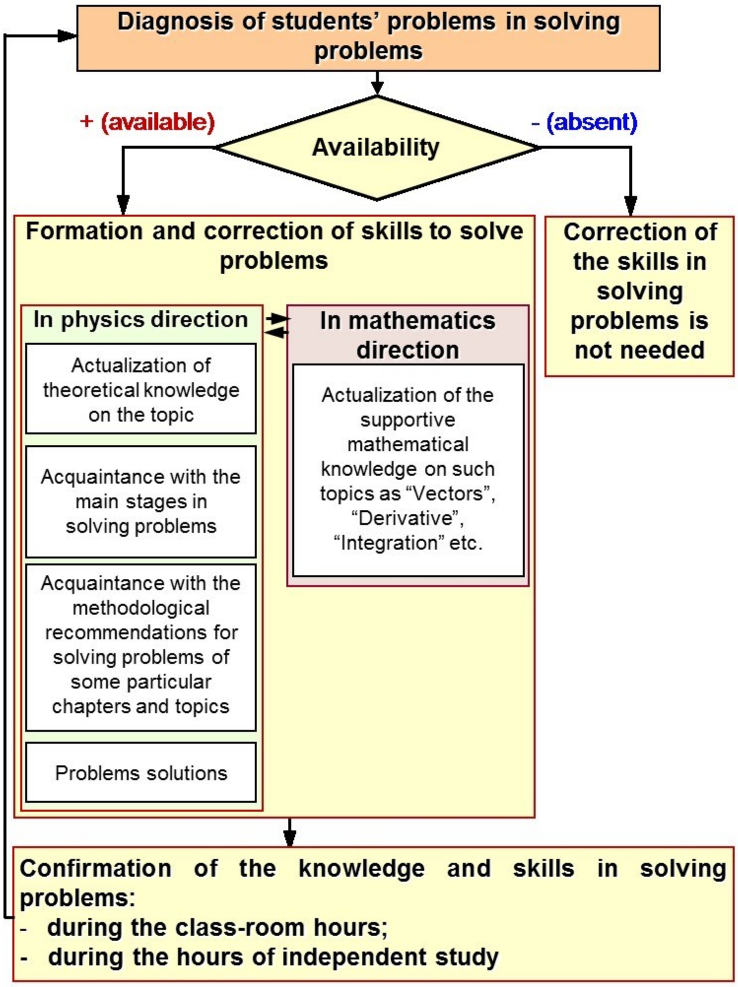

Fig. 5. Methodological approach to the correction of the theoretical knowledge and skills in solving physical problems

To involve the students with the gaps in basic knowledge into such a control system and to motivate their diligent work, there are bonus marks in the ECTS of the adapted course program.

The students can find theoretical material of the secondary school program in manuals of different authors or their e-variant in the Internet. As for the problems solution, we think it is worth having your own set of materials that will correspond to the stated goals. Also, as solution of a physical problem gets very often complicated because of the weak mathematical preparation of the students, then mathematical direction related to the physical problems is implemented simultaneously with the physical one. Moreover, for the control and self-control of the students' results it is important to have a set of testing tasks.

To realize the proposed methodological approach of building up and correcting students' knowledge and skills while solving physical problems, we developed the e-complex (Fig.6), that includes the thematic plan, the manual and the system of testing tasks. These materials are located in the LMS Moodle on the special site of the Department of General Physics and Solid State Physics, Igor Sikorsky Kyiv Polytechnic Institute, Faculty of Physics and Mathematics.

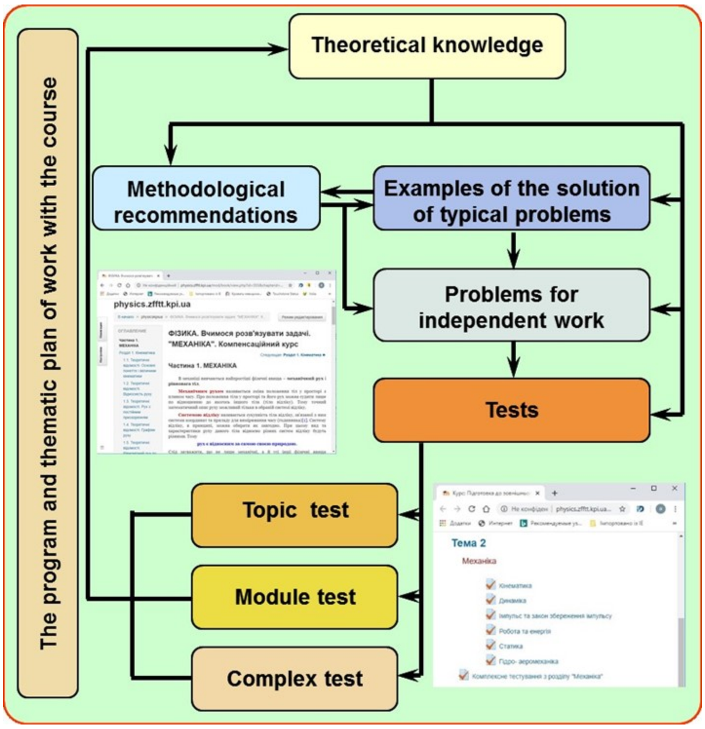

Fig. 6. The structure of e-manual on the solution of physical problems for pupils and students.

While creating the e-manual [4] we kept in mind that it must meet the demands of the following principles: quantization, completeness, visibility, branching, regulation, adaptation [22].

The content of the manual depicts the traditional logics of studying physics at school. That is why it consists of 6 parts:

1. Mechanics.
2. Molecular physics and thermodynamics.
3. Electrodynamics.
4. Vibration and waves.

5. Optics.
6. Modern physics.

Each chapter is divided into the content units:

- brief theoretical material needed for the solution of the problems of this content unit;
- methodological recommendations for the problems solution;
- examples of problems solution;
- tasks (problems) for independent work;
- additional information block.

Theoretical material and examples of the solved problems for each chapter according to the principle of visibility have the illustrations that characterize physical processes and laws.

To our mind, thematic plan (Fig.7) has the optimal program division corresponding to each educational week. Such division, from one hand, guarantees deep enough work on the educational material and, on the other hand - quick revision. There are corresponding to each topic (column 1) indicated chapters (column 2), where students can find the related theoretical material [3].

THE THEMATIC PLAN ON WORK PLAN ON PHYSICS. PART 'MECHANICS'

№ п/п	THEME	Chapters of the book	Problems		
			Typical and basic	For revising	Additional
	1	2	3	4	5
1	**The basic notions, definitions and units in kinematics.**				
1.1	Trajectory, route, displacement	*b4*	1.2, 1.11		1.26
1.2	The average (route) speed	*b5.1*	1.13, 1.14	1.74	
	The average velocity of displacement, instantaneous velocity	*b5.2*		1.15	
1.3	Movement relativity, velocity of relative movement	*b5.3*	1.121, 1.122	1.16, 1.32	П.1.3.
	Velocities adding law	*b5.3*	1.21	1.19, 1.17	П.1.4.
1.4	Uniform straight motion	*b8*	1.118, 1.69	1.28	1.137,

Fig. 7. A fragment of the thematic plan

All the problems were grouped according to the level of difficulty with the aim to differentiate the tasks. Level A problems require knowing formulas, definitions, laws and are dedicated to be remembered. Group B consists of typical and standard problems, whose solving requires the analysis of a physical situation, knowledge to apply laws and formulas of physics and without a single mistake make mathematical transformations. Group C involves the most complicated and interesting problems, which require good knowledge of the theory, skills to combine knowledge from different parts of physics and flexible thinking as well. Also, we included the simplified variants of tasks from the course of general physics. Solving such problems requires using elements of higher mathematics. This allowed us to create favourable conditions to master the course "General Physics" at a technical university.

Using the thematic plan and the manual helped us to involve students into the educational process of acquiring important skills for the future engineers to solve problems; and we got the possibility to predict and take into account their work results. Such planning enabled us to dose up the material and organize it in the chronological order. Due to the planning, we reached the correct organization of the educational process and it became possible to use the handbook in the most rational way. Some of the methodological recommendations given in the manual can be used for the solution of problems in the course of General Physics for the bachelor's degree in engineering.

Knowledge monitoring is a key component of the educational and cognitive process. The monitoring goal is not only to detect and evaluate the level of knowledge acquired by students, but also to stimulate and motivate their educational and cognitive activity and self-education.

Control is one of the important pedagogical conditions to ensure the feedback. Structurally the control of educational achievements has the following (fig. 8):

1. diagnostic block of determination the entry level of students' knowledge and delivery of the students' questionnaire in the on-line regime;
2. the block of control of students' educational activity results during the period of work on the material stated in the thematic plan of the adaptive course.

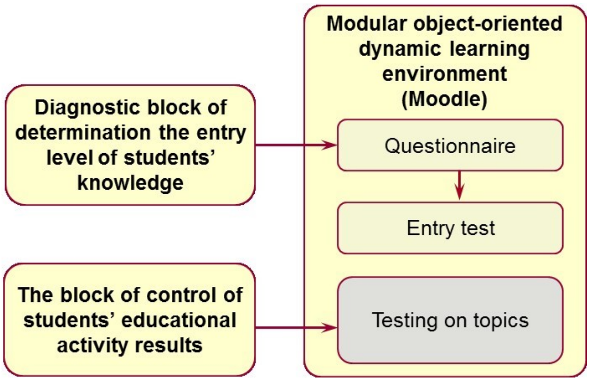

Fig. 8. The organizing scheme of students' knowledge.

The system of tests to monitor the educational activity of students during the adapted course is composed of the same parts as a handbook. Each part is divided into units. For example, part "Mechanics" consists of such units as "Kinematics", "Dynamics", "Momentum and the law of its conservation", "Work and energy", "Statics" and "Hydromechanics" etc. "Kinematics" consists of "Fundamentals of Kinematics. Linear uniform motion", "Rectilinear motion with constant acceleration. Graphics of kinematics values", "Projectile motion", "Uniform circular motion". For each unit we formulated our own items and we used items from EAT tests 2008 – 2019 years. All the test items were classified into complexity levels: A (basic), B (intermediate), C (high) that are marked 1, 2 and 3 correspondingly. In our opinion at the basic level students have to know definitions, notions, laws, formulas and if necessary, have to know how to calculate with the help of one particular formula one unknown quantity with the known ones. At the intermediate level students have to produce basic mental operations (analysis, comparison, juxtaposition) and on this basis they have to find those laws that explain physical situation and fulfil the necessary calculations. At the high level, students have to know how to explain more complicated physical phenomena applying their knowledge of more than one part of physics.

Students took on-line testing in the appropriate time and place (at home, in the library, etc.). Such approach gave the possibility for the students to check their level of mastering the material from the thematic plan to be learned. Our experience proved that such form of delivering testing made it possible to motivate and activate students' educational and cognitive work. While performing the tests students can use literature that help give answers to the given questions and tasks. Under the conditions of hard mental activity, the found information was remembered much better and this followed by memory and thinking development, ordering of knowledge, its deepening and clarifying them. Besides, while carrying out the search for the correct answer the student was mastering the skills of working independently with different sources which will enable him to independently process the information on his qualification in the future.

The regular testing control of knowledge of physics stimulated the independent work of students and gave the possibility for the teachers to monitor the dynamics of overcoming the detected problems in the competence under the secondary school program.

4 Results

To understand and clarify the role of the adaptive course while mastering the basic skills in physics we delivered the survey among the students of the Faculty of Heat and Power Engineering of the Igor Sikorsky Kyiv Polytechnic Institute at the end of the course of physics. 133 students took part in the survey. The research showed that the proposed form of the students work organization with the materials of the adaptive course in physics made it possible to revise theory, acquire the skills to solve physical problems, and the consultations with the teacher assisted in eliminating most difficulties, that appeared while learning the material. The analysis of the students questionnaire results after finishing their work with the adaptive course showed that 51% of them consider the course to be helpful in better understanding theoretical material on physics under the frame of the syllabus of a technical university and help them to pass final exams.

To define the role of the progressive testing in the process of eliminating gaps in basic knowledge we also conducted a survey among the students. Having processed statistically the received results, it was found out that 49% of students did the tests after thorough preparation using the manuals and our adaptive course, and 40% - after work with the manuals, hand-books and consultations with the teachers. As this kind of testing was delivered in the form of the remote access, so 60% of students used the material of our e-handbook to find the answers to the test tasks. 80% of the students stated that work with the materials of the adaptive course and progressive tests helped them to consolidate theoretical knowledge which created prerequisites for the better comprehension and understanding of the university course on physics.

It was chosen three criteria to check the effectiveness and the influence of the methodological approaches and teaching materials under the frame of the adaptive course developed for the technology of the blended learning on the students advancement: 1) cognitive, that evaluate the students' ability to form the associative-reflective interrelation between the theoretical material on physics and mathematics; 2) activity, that evaluate students' skills in applying theoretical knowledge in the practical work and independent mastering the material on physics; 3) results, that checked the ability of students to assess their own results while mastering the material on physics.

We developed low, intermediate, sufficient, and high level of the evaluation of the effectiveness of the methodical system for the proposed criteria system. The statistical hypothesis significance of the differences between the student control groups and student experimental groups for the chosen criteria was delivered with the help of the Pearson Criterion χ^2. Having compared the critical (χ^2_{cr}) and empirical (χ^2_{emp}) values, we found out that it was twice bigger than the critical meaning for all the criteria. That is why, we made the conclusions about the significance of the changes of the figures of the respondents in control and experimental groups after delivering the pedagogical experiment. So, we can state that the results of the research-experimental work proved the unbiassed nature of the chosen approach to improve the effectiveness in teaching physics for the students and eliminating the gaps in their previous learning of physics.

5 Conclusions

In this paper we present our scheme of organization of students and lecturers work in the flipped-classroom model, and the cooperation between the students and lecturer in the process of eliminating gaps in the basic knowledge in physics in the frame of the developed adaptive course.

To construct such a course methodological approaches and an e-set of teaching materials were developed with the aim to identify the main shortcomings of the first-year students' knowledge of a technical university. The e-set of teaching materials includes the thematic plan of the work, e-handbook and the system of testing tasks.

The methodological approach in our research made it possible to focus on the independent work of students. The regular fulfilment of the testing tasks assisted in formation students' skills in independent mastering of knowledge. On-line testing tasks results processing is the key factor in the intensification of the cognitive activity. The impact of the developed by us adaptive course on the students' achievements was checked by our experimental method. To do this we divided the students in control and experimental groups and compared their learning achievements. The obtained results were then processed by Pearson Criterion χ^2. The statistics analysis of the experimental results demonstrated significant changes in the experimental groups comparing to the achievements of the control groups respondents. The empirical criterion value for all chosen criteria was twice more than the critical one.

The usage of the adaptive course on physics developed for the flipped-classroom model at a technical university made it possible to create the conditions needed for the effective elimination of the gaps in students' knowledge of physics, to acquire skills, to receive the knowledge independently and perform the self-analysis of the educational achievements results on the subject without considerable spending of the class-room hours.

Nevertheless, according to our observation the experimental competence among students is rather low. Thus, we see the further research in developing and including e-simulators of the lab works on physics in the adaptive course with the aim to help students form the basic experimental skills in working with the equipment, processing and presenting the obtained experimental data, and to test such students work in the flipped-class-room model.

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