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SCIENCE-DRIVEN EDUCATION AS A PRECONDITION FOR THE FORMATION OF THE COMPETITIVE UKRAINIAN ECONOMY

Abstract. Today, the growing needs of the labor market in qualified personnel and the strategic objectives of Ukraine to form a competitive economy require radical changes in the education sector by introducing science-intensive education and research-oriented training to develop Competencies 4.0. The comparative analysis confirmed the inconsistency of the structure of training of specialists of Ukraine not only with the similar structure in developed countries but even with the structure of countries with the appropriate level of economic development. To solve mentioned problem on the basis of the study, the article presents: the structure of systemic interaction of the activities of higher education institutions and the structure of their funding with the involvement of institutional and extra-budgetary sources; proposed normative-legal, organizational, financial measures aimed at increasing the quality of education, which would correspond to the level of the world's leading countries. Activities include specific recommendations, such as encouraging students to do research using a sub-project approach with separate terms of reference and budget; non-financial involvement of students in the research projects of leading scientists as a tool to stimulate the acquisition of new skills and knowledge, the rating approach — «the best student — the best researcher», etc. Using the methods of mathematical formalization, a forecast of the deterioration of the quality indicator of mathematical and natural education was formed, which became the justification for the urgency of educational reforms; the existence of correlation of nominal GDP per capita from the indicator of the quality of mathematical and natural education is proved and the values of time intervals necessary for the manifestation of this dependence are established. These research results provide an opportunity for both scientists and management practitioners to use them in their work.

Keywords: science-driven education, science education, STEM, knowledge-intensive education, STEM education, quality of human capital, competitive economy.

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НАУКОМІСТКА ОСВІТА ЯК ПЕРЕДУМОВА ФОРМУВАННЯ КОНКУРЕНТОЗДАТНОЇ ЕКОНОМІКИ УКРАЇНИ

Анотація. Сьогодні зростаючі потреби ринку праці у кваліфікованих кадрах і стратегічні завдання Україні з формування конкурентоздатної економіки вимагають докорінних змін освітньої галузі на основі впровадження наукомісткої освіти та дослідницько-орієнтованого навчання, спрямованого на формування Competencies 4.0. Порівняльний аналіз підтвердив невідповідність структури підготовки фахівців України не тільки аналогічній структурі в розвинених країнах, а навіть структурі країн відповідного рівня розвитку економіки. Для розв'язання цієї проблеми на основі проведеного дослідження наведено: розроблену структуру системної взаємодії напрямів діяльності вищих навчальних закладів і структуру їх фінансування із залученням інституційних і позабюджетних джерел; запропоновано нормативно-правові, організаційні, фінансові заходи, спрямовані на нарощування такої якості освіти, яка б відповідала рівню провідних країн світу. Заходи включають конкретні рекомендації, наприклад, заохочення студентів у науковій діяльності з використанням субпроектного підходу з окремим технічним завданням і бюджетом; позафінансове залучення студентів до участі в наукових проєктах провідних учених як інструменту стимулювання для набуття нових навичок і знань, за рейтингового підходу — «кращий студент — кращому дослідникові» тощо. За використання методів математичної формалізації сформовано прогноз погіршення показника якості математичної та природничої освіти, який став обґрунтуванням нагальності реформ освіти; доведено наявність кореляції номінального ВВП із розрахунку на одну особу населення від показника якості математичної та природничої освіти і встановлено значення часових проміжків, потрібних для проявлення

цієї залежності. Результати проведеного наукового дослідження надають можливість як науковцям, так і практикам-управлінцям використати їх у своїй роботі.

Ключові слова: наукомістка освіта, наукова освіта, STEM, якість людського капіталу, конкурентоздатна економіка.

Формул: 1; рис.: 5; табл.: 2; бібл.: 24.

Introduction. The response to the complex challenges of Industry 4.0 must be based on radical reforms in the education sector. Not even the proper quality of education reforms, but their inadequate pace, will lead to the devaluation of human capital and, consequently, to the growing non-competitiveness of the economy, resulting in the decline of the social sphere, pauperization of the population. Education reform in Ukraine is significantly complicated by economic and political crises, hostilities in the country, social unrest, and so on. The development and implementation of modern technologies require new qualities from the specialist, which are lacking in today's labor market—creativity, initiative, communication, ability to learn. There are already some changes in the field of education: private education has been introduced; the structure and directions of training have been reformed; democratic innovations in management have been carried out; higher education institutions (HEIs) have been given some autonomy. But today, there is a need for more radical changes based on science-intensive education and research-oriented learning to form Competencies 4.0.

Analysis of research and problem statement. Many researchers have studied the problems of reforming science-intensive education for Industry 4.0, Economics 4.0, Competencies 4.0. Verhoefa et al. [1] point out that the digital transformation of business requires specific organizational and educational approaches. Chakravarty et al. [2] explore IT competencies and argue that they need to adapt to education. Coreynen et al. [3] studied the dynamic resources of science-intensive business and pointed to human capital as the primary resource. Mahlow et al. [4], Kholiavko et al. [5], Cotet et al. [6], and Shashkova et al. [7], in their studies, discovered the various aspects of human capital formation for Industry 4.0. Oliveira et al [8] studied the TADEO method (Portuguese: Transformação Digitalna Educação — digital transformation in education) to guide the adaptation of learning to Economics 4.0. Goh et al. [9] prove that teachers should be current scientists and teach students to study new technologies. The work of Himmetoglu et al. [10] indicates that the main components of Education 4.0 are «mental transformation, integration of digital technologies into education, uninterrupted learning environment, lifelong learning, research and multidisciplinary education», which requires special technological and scientific skills, learning skills and personal qualities. Hussin [11] has studied nine trends in Education 4.0., and formulates requirements for students and teachers in this regard. Fotea et al. [12] analyzed the relationship between higher education institutions and the processes of regional economic development of the EU and pointed out the need to involve highly qualified scientific personnel in educational processes. Hladchenko et al. [13] consider structural changes in Ukrainian higher education focusing on their dynamics, in particular, «conversion and drift for the implementation of international educational trends, such as quality assurance and the concept of a research university». Cavas [14] points out that countries need to modernize education to remain competitive in science, technology, and innovation and argues that science education is directly related to Industry 4.0. Gázquez et al. [15] provide a detailed analysis of the lack, needs, and competencies required for Key Enabling Technologies (KETs) Industry 4.0 (I4.0) in both higher education and the EU manufacturing sector and thus proves the need to modernize education in combination with modern technologies. Al Maadeed et al. [16] point to the need to combine new learning systems and involve students in new research programs. Sharma [17] confirms this by researching aspects of the digital revolution in Education 4.0. English [18] proposes the introduction of training through direct participation in engineering, even for such a fault-sensitive industry as aerospace. Yeping Li [19] developed an analytical review of the consequences and prospects of STEM education. De Coito [20] details the use of the STEM approach as a synthesis of disciplines, ensuring the appropriate qualities of future professionals. Steyn [21] noted that without the synchronous activities of all

aspects of the educational process — scientific and business circles, without the participation of the coordinator, success is impossible.

Unsolved aspects of the problem. Despite the significant number of scientific papers, the issue of introducing knowledge-intensive education in Ukraine as a prerequisite for the formation of appropriate qualities of human capital and a competitive economy needs further study.

The purpose of the article. Prove the connection between the quality of education and economic indicators, propose measures for introducing knowledge-intensive education, and the structure of systematic interaction of activities and funding of higher education with the involvement of institutional and extrabudgetary sources. The research methodology includes a set of general and special methods of cognition, methods of analysis and synthesis, induction and deduction, scientific abstraction, logical analysis, mathematical formalization, which are used in research, analysis, evaluation of information, and conclusions formulation.

Research results. The Program for International Student Assessment (PISA) test and the TIMSS (Trends in International Mathematics and Science Studies) study showed that the level of education in Ukraine is lower than in neighboring countries, not only in mathematics but also in science and reading. According to the World Bank, the Quality of Math and Science Education Index for Ukraine is currently higher than the regional average (Eastern Europe and Central Asia). Still, after a period of growth in 2016—2018, there is a tendency to deteriorate the ability to apply knowledge, analyze, argue and communicate effectively in the process of solving and interpreting problems in different situations (*Fig. 1*).

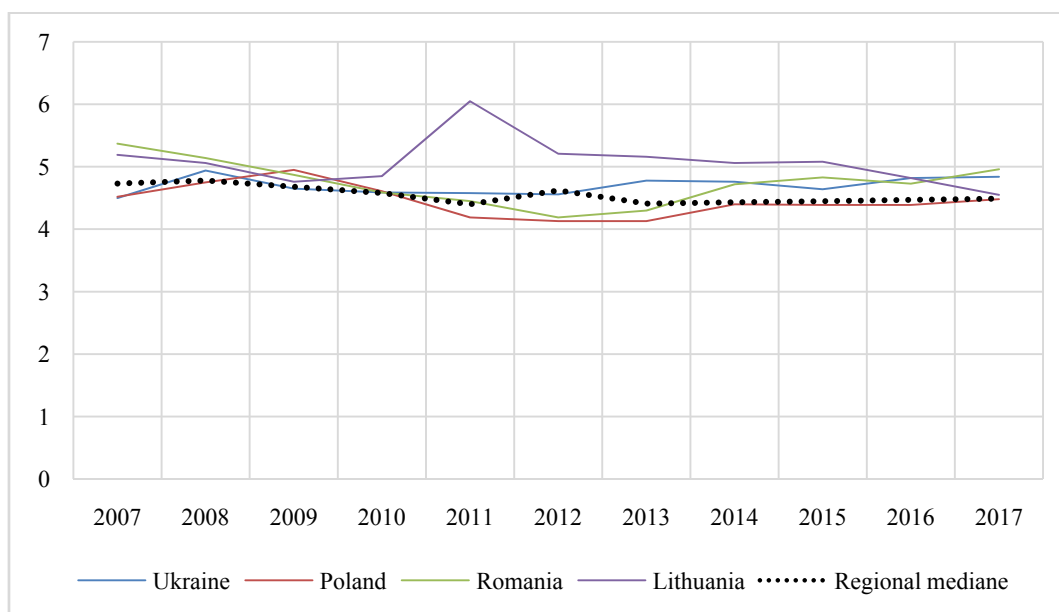


Fig. 1. Comparative analysis of changes in the index of Quality of Math and Science Education

Source: built according to the World Bank.

This happens, firstly, due to the fact that with complex socio-economic transformations, the labor market in Ukraine is late in forming a new structure of demand for highly qualified personnel, which reduces the level of motivation of students to study. Secondly, obtaining quality education requires personal abilities, hard work (from which students are accustomed to the introduction of the institute of paid education), and adequate funding, including using their own and family budgets.

Analysis of the Ukrainian Center for Educational Quality Assessment data on the indicator of the quality of mathematics and science education confirms the data of the World Bank (*Fig. 2*) and, to a greater extent, allows forming a forecast for the coming years.

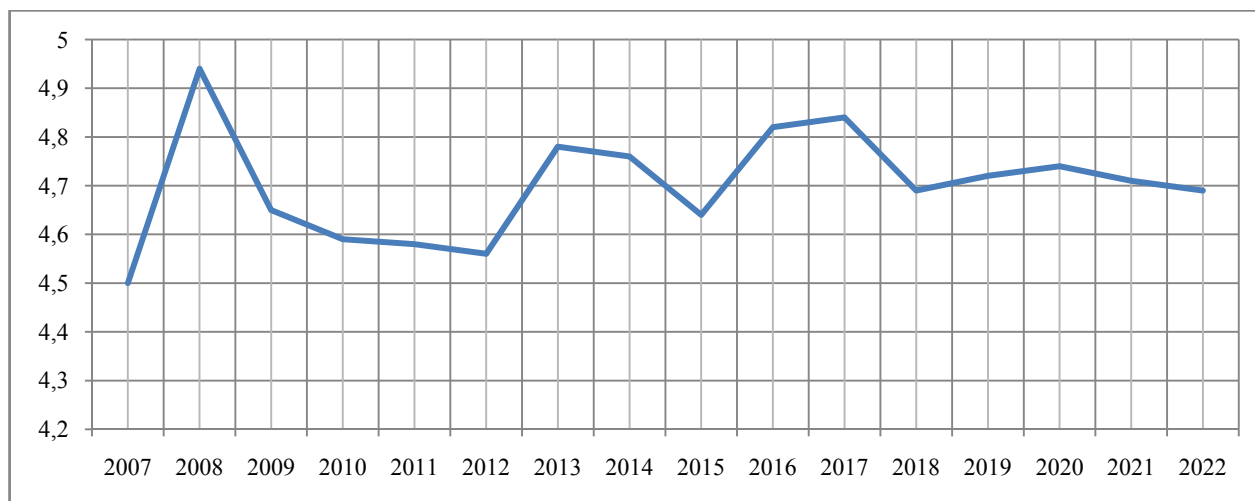


Fig. 2. Dynamics of the indicator of the quality of mathematical and natural education

Source: built according to the Ukrainian Center for Educational Quality Assessment.

Notes: the period 2021—2022 — according to the own calculations.

Using the time series method, a polynomial equation of the dynamics of the quality index of mathematical and natural education is formed:

$$y = 0,0001x^5 - 0,0047x^4 + 0,0653x^3 - 0,4005x^2 + 1,0164x + 3,8839.$$

That is, without the introduction of significant changes in education, the quality of mathematics and science education is expected to decrease below 4.7.

Analysis of the structure of training specialists in the fields of knowledge (Table 1) pointed out, on the one hand, certain differences in different countries (for example, Saudi Arabia). On the other hand, the identity of trends in the respective groups of countries. The comparative analysis showed that the share of specialists trained in Ukraine in the field of «Science» is 1.25 times lower than the average for the countries of the 1st group, for the 3rd group almost twice; in the area of «Health and Welfare», respectively, less than 1.92 and 3.44 times; «Engineering, industrial production, construction», respectively, 78.5% and 58.7% higher than the countries of the 1st and 3rd groups.

Table 1

The structure of graduates in the fields of knowledge

Areas of knowledge	Groups of countries											
	1						2	3				
	Ukraine	Russia	Poland	Czech Republic	Hungary	Brazil	Saudi Arabia	France	Sweden	United Kingdom	USA	Japan
Science	4	6	7	9	6	7	20	11	7	13	8	3
Engineering, industrial production, construction	21	22	9	14	8	6	4	16	17	9	7	18
Education	9	10	16	14	13	23	7	2	16	11	11	7
Humanities and arts	5	3	8	7	12	3	41	11	6	16	13	15
Social sciences, business and law	45	46	44	33	40	38	15	41	24	31	38	27
Agriculture	4	4	2	4	2	2	0	1	1	1	1	2
Health and well-being	5	6	9	9	10	14	9	15	26	17	15	13
Services	6	2	5	5	9	2	0	3	3	1	7	9
Other areas	1	1	0	5	0	5	4	0	0	1	0	6

Source: formed using data [23; 24].

The data proves the need to radically change the training structure of specialists in Ukraine following the strategic planning of education and market needs. The larger share of specialists in developed countries in the fields of «Science» (primarily — state-of-the-art research) and «Education» (including STEM-education) means that the synergy of these two fields of training creates preconditions for the growth of their economies, creating science-intensive education trend.

As Ukraine is in the first stages of implementing the latest approaches in education, it is necessary to consider the experience of leading countries [19—22] to overcome the difficulties of managing STEM learning in a transdisciplinary approach. Ensuring the appropriate level of knowledge-intensive education has several aspects that correspond to STEM education: proper motivation of the parties, sufficient funding, and effective systemic management organization. «Parties» means stratification not only at the level of teacher-student and university-teacher but also at the macro level: business, science, and education. It is the coincidence of interests and goals of business, science, and education and, accordingly, their joint work to ensure adequate funding for research and educational activities, the formation of appropriate motivation of research teachers and students to improve all aspects of education and, consequently, growth quality of human capital.

Our approach is considered in developing the structure of systematic interaction of research, educational and research, and consulting activities of universities (Fig. 3).

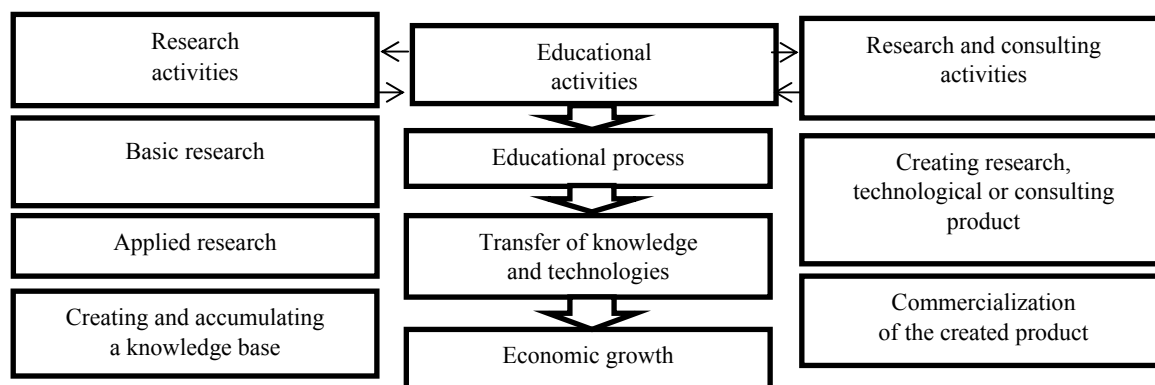


Fig. 3. The structure of the system of interaction of research, educational and research and consulting activities of universities

Source: own development.

This structure will ensure the synergy of these aspects of the activities of research universities. The analysis also allowed to form some requirements for introducing knowledge-intensive education. To do this, it is necessary to: introduce and organizationally ensure the status of a teacher-researcher; to regulate financial instruments to encourage teachers to research; to reduce the classroom load of the teacher; to form the resource potential of the teacher-researcher. To financially encourage students in scientific activities, we have proposed forming a subproject approach (with separate terms of reference and budget). In addition, it is worth offering non-financial involvement of students in the research projects of leading scientists as a tool to stimulate the acquisition of new skills and knowledge (in particular, using a rating approach — «best student — best researcher»).

From the organizational point of view, it is necessary to consider new approaches to the formation of structure of financing of high school with attraction of extra-budgetary means; to promote the formation of research laboratories, groups and teams; creation of scientific schools’ informal associations of scientists. The scientific literature outlines specific approaches to determining the quality of scientific schools and research teams. In particular, it is proposed to introduce «scientific expertise» and «national register of scientific schools». In our opinion, the quality of associations of scientists should be determined by recognizing the world scientific community or using their work by leading business structures of developed countries.

The introduction of knowledge-intensive education today requires significant changes in the Ukrainian labor market. Due to the growing share of modern, in particular, information, communication, military, and other technologies in GDP, the demand for highly qualified personnel is growing. The period of extensive development of Ukrainian higher education and attempts to involve the maximum number of students in education for neglecting the quality of education is over. Their own negative experience of employment of university graduates has proved to them that having a diploma no longer guarantees a qualified job. This situation creates a tendency to reduce

enrollment in universities and encourages educational institutions to take measures to increase the quality of their graduates. Despite some autonomy, universities cannot quickly introduce new specialties needed by the labor market and update training courses' structure and scope.

As state planning of the training structure (see *Table 1*) is ineffective, giving more independence to a limited number of leading universities would be appropriate. We mean a limited number of steps, understanding that a proper level of knowledge-intensive education is a complicated process with a specific duration over time. Such universities should be legally required but also given the right to employ research teachers, financial and non-financial incentives for both teachers and students, and so on. Proper management of this process can result in the growth of human potential and, consequently, the country's economy (see *Fig. 3*).

The study confirmed the relationship between the level of technology development and, accordingly, the country's economy and the specific costs of research in relation to GDP (so-called «science-intensive GDP»). Only when the level of these costs is $\geq 0.9\%$, the basis for developing the national economy is formed. Thus, in the EU countries, the trend of significant growth in research spending has been noticeable since 2008. Compared to the level of 2000, the knowledge intensity of GDP in the EU countries increased by an average of 1.5 times. In Ukraine, the costs of higher education institutions for research also tend to increase, although there are periods (for example, 2018—2019) of slowing down this process (*Fig. 4*).

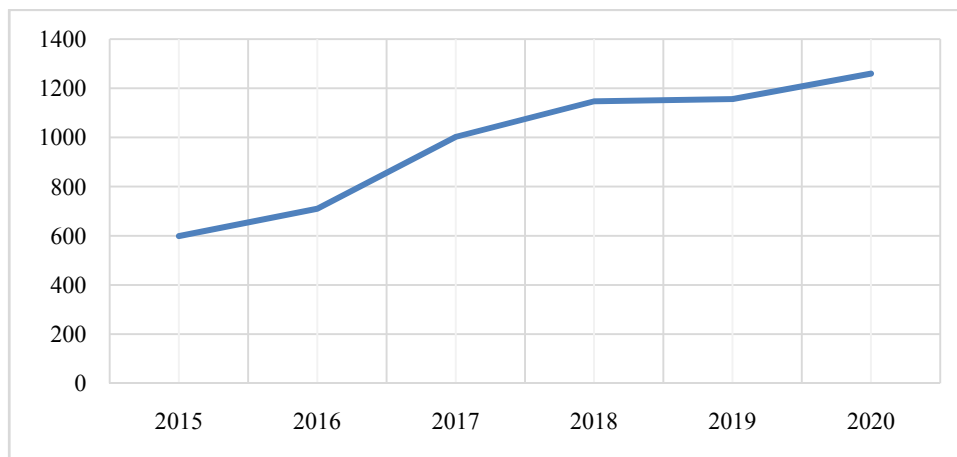


Fig. 4. Expenditures of universities for scientific activities, UAH million
Source: based on data from the State Statistics Service of Ukraine.

This provides additional financial opportunities for universities to stimulate research teachers and form an appropriate scientific environment: research schools, research groups, and laboratories.

That is why it is essential to propose the structure of university funding with the involvement of institutional and extra-budgetary sources of funding (*Fig. 5*), taking into account the synergistic interaction of business, research, and educational processes.

The university will also gain experience and knowledge, and the result will be the quality of education, which will strengthen the university's extra-budgetary funding (see *Fig. 5*).

The study also established a correlation between nominal GDP per capita from the indicator of the quality of mathematics and science education. The results of the calculation are shown in *Table 2*. Use in the analysis of nominal GDP in dollars is conditioned by the need to remove the influence of factors of national currency fluctuations, which can be considered insignificant «noise effect», which only blurs the correlation between the studied indicators. The lack of correlation of nominal GDP per capita from the indicator of the quality of mathematical and natural education in time lags of 4 and 7 years emphasizes the importance of the level of correlation of these indicators in time lags of 5 and 6 years with a correlation coefficient up to 0.5549.

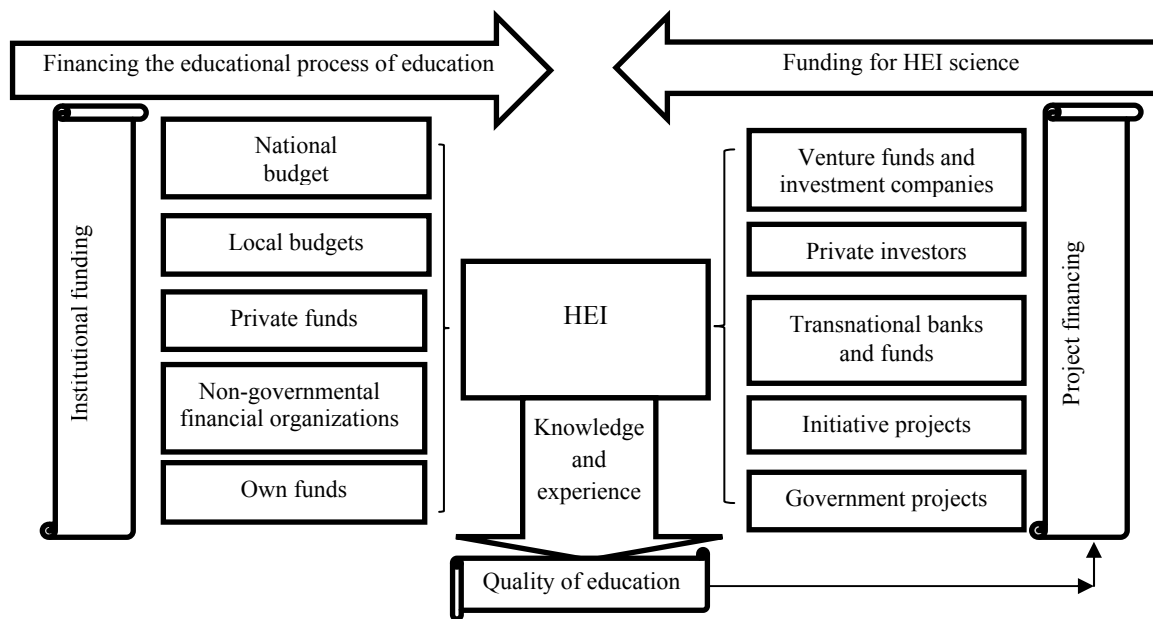


Fig. 5. The structure of university funding with the involvement of institutional and extrabudgetary sources

Source: own development.

Table 2

Dynamics of correlation of nominal GDP (in USD per capita) from the indicator of the quality of mathematics and science education

Parameter	Value			
Time lag, years	4	5	6	7
Correlation coefficient	0,020749	0,540902	0,554929	-0,37408

Source: own calculations.

Establishing the presence of time lag and identifying its length is also a significant result of the study.

The time lag between changes in GDP per capita and the achievement of a certain level of quality of education is necessary to show the effect of dependence.

The carried-out calculations establish the presence of correlation of nominal GDP in dollars. The USD per capita indicator of the quality of math and science education shows a link between them, which only predicted or declared in other studies.

Conclusion. The introduction of knowledge-intensive education, normative and organizational support of the status of teacher-researcher, and enshrining in law the granting of greater rights to universities with adequate scientific potential is an urgent and important task to ensure the quality of human life capital and create a competitive economy. The comparative analysis of the training structure of specialists in Ukraine and other countries confirmed the inconsistency with a similar structure in developed countries and even countries with the appropriate level of economic development.

As a result of the research, it has been defined and described: the structure of system interaction of the directions of university activity; the structure of university funding with the involvement of institutional and extrabudgetary sources; normative and legal regulation of financial instruments to encourage teachers to research; approaches for reducing the classroom load of the teacher-researcher for research work, encouraging students in research using a subproject approach with separate terms of reference and budget, non-financial involvement of students in the research projects of leading scientists as a tool for acquiring skills and knowledge using the rating principle. There were formulated some new approaches to forming the structure of university funding with the involvement of extra-budgetary funds; promoting the formation of research laboratories, groups,

and research teams; developing scientific schools as informal associations of the scientists and revisioning of the scientific school status.

The study confirmed the relationship between the level of technology development and the economy as a whole and the specific costs of research in relation to GDP; analytically formed a forecast of the dynamics of the indicator of the quality of mathematics and science education, as a justification for educational reforms; the existence of correlation of nominal GDP per capita from the indicator of the quality of mathematical and natural education is proved and the values of time intervals necessary for the manifestation of this dependence are established. The presented results of the conducted scientific research give both scientists and practicing managers an opportunity to use them in their work.

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