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ANALYSIS OF ENGINEERS' CHEMICAL EDUCATION SPECIFICS IN THE CONTEXT OF PROVISION OF INTEGRAL EDUCATION IN THE FIELD OF NATURAL SCIENCES IN UKRAINE

In this article, the formation of a competent understanding of the natural science education is considered, because for it to become functionally integral, all its constituent parts must act concertedly within the framework of the future qualification. The quality of education suits the society's and the state's current demands because it is fundamental, and the main task of reforming engineering education is to create the conditions for instilling independent, critical, and creative thinking in graduates and to provide professional growth capabilities. The autor analyses the problems of the fundamentality component of the education in the natural sciences disciplines in technical universities. Specifically, we are talking about the gap between the school graduates' level of proficiency in fundamental disciplines and the requirements thereto in higher educational institutions; also revealed are the problems in the 2016 university admissions process, because of which students with low knowledge of natural sciences entered universities in greater numbers that year. The article demonstrates that it is impossible to ensure further civilisation and technical growth of the society at its current development stage without the fundamental chemical knowledge as an important component of natural sciences.

Keywords: *fundamental disciplines, monitoring quality of studies, modern facilities of motivation of studies, steady development and safety of society.*

Introduction

In line with the Bologna Declaration, the modernisation of higher technical education in Ukraine over the recent years enabled substantial updates in the teaching content and methodology and the introduction of new approaches and technologies into the scientific and educational process. In addition, the requirements were set for the combination of knowledge and skills in a given domain, as well as those for the acquisition by the graduates of the action, problem-solving, and decision-making competencies involved in practical professional activities.

In the times of global economic transformation, all graduates of higher education institutions must have the knowledge, skills, and experience to understand and solve the problems of the modern everyday life, taking into consideration the environmental, social, cultural, and economic consequences, and, ultimately, to take on a global responsibility. These objectives can be accomplished in education only with the integration of the personnel training aspects as related to the sustainable development of society and business.

Franz Rauch, the author of the article (F.Rauch,1), emphasises that education, especially in chemistry, could help focus young people on technological progress based on the principles of sustainable society development: "The idea of education for sustainability offers a justification for focusing the young generation to become responsible citizens and to allow them developing corresponding skills. All learning domains, and thus also chemistry education, are asked to contribute to this goal".

The leading Ukrainian technical universities cooperate with the European education community in the field of engineering education. The emphasis on the priority of engineering trade development can help create the conditions for an innovative breakthrough, economic success, and sustainable development of the country. Without acquiring quality chemical knowledge in university engineer training programmes, it is impossible to efficiently solve the urgent problems and come up with a balanced strategy for the future stable development of the society.

Therefore, engineering higher educational institutions urgently need to improve the quality of students' education in chemistry. In this regard, problems of methodological and organisational nature appear as yet unclear. To which extent an engineer should study chemistry? Is there a difference in the training of a mechanical, a design, and an environmental engineer? Which form of training is preferable: classroom or independent? Is there a need for one-on-one laboratory classes, or thoroughly explained experiments? What are the methods of assessing students' unsupervised work and quality of teaching?

These issues have been left out in the literary battles of Ukrainian teachers thus far, albeit remaining a subject of vigorous debate among the teachers, the scholars, and the authors of textbooks and various chemical courses in many countries of the world.

For instance, Teh Fu Yen – the author of *Chemistry for Engineers* textbook teaching in the University of Southern California – emphasises that chemistry is the centre of all engineering sciences: “Engineering requires applied science, and chemistry is the centre of all science. The more chemistry an engineer understands, the more beneficial it is. In the future, global problems and issues will require an in-depth understanding of chemistry to have a global solution” (Teh Fu Yen, 2).

Mahapura Gandhi, an Indian teacher of chemistry at the Engineering College (Mumbai Area, India), explains the need for chemical knowledge for engineers of any profile as follows: “An aeronautical engineer must have to think about material which is lighter yet stronger so that it can fly easily in space, hence alloys are developed. A civil engineer must know about the nature of the soil, rocks, concrete, steel, etc. for stability. An electronic or electrical engineer has to know about electrons, conduction, magnetic nature. A mechanical engineer has to have an idea about materials and fuels for better efficiency. Even medical science and agriculture is based on chemistry" (Nilam Das, 3).

NTUU “Igor Sikorsky Kyiv Polytechnic Institute” and other leading domestic technical higher educational institutions have joined efforts with the European educational community in the field of engineer training and mutual recognition of engineering education certificates. As a result, our country has got effective programmes to train engineers, programmers, and designers for various industries and economic sectors.

The University prioritises strengthening of the role of fundamental training based on the synthesis of general scientific knowledge and engineering thinking, the application of scientific research results in the field of competitive R&D, and their introduction in manufacturing (F.H. Vashchuk, 4).

The figures voiced during the World Economic Forum (Kyiv 2015) in regard to the state education systems showed that Ukraine was ranked the 40th in the world out of 144 countries by Global Competitiveness Index (GCI). However, when it came to the education system quality assessment, Ukraine was the 72nd (see Table 1). So, this is where Ukraine lags as compared to many other countries.

Table 1.

Ukraine: Higher Education and Vocational Training component on the Global Competitiveness Index.

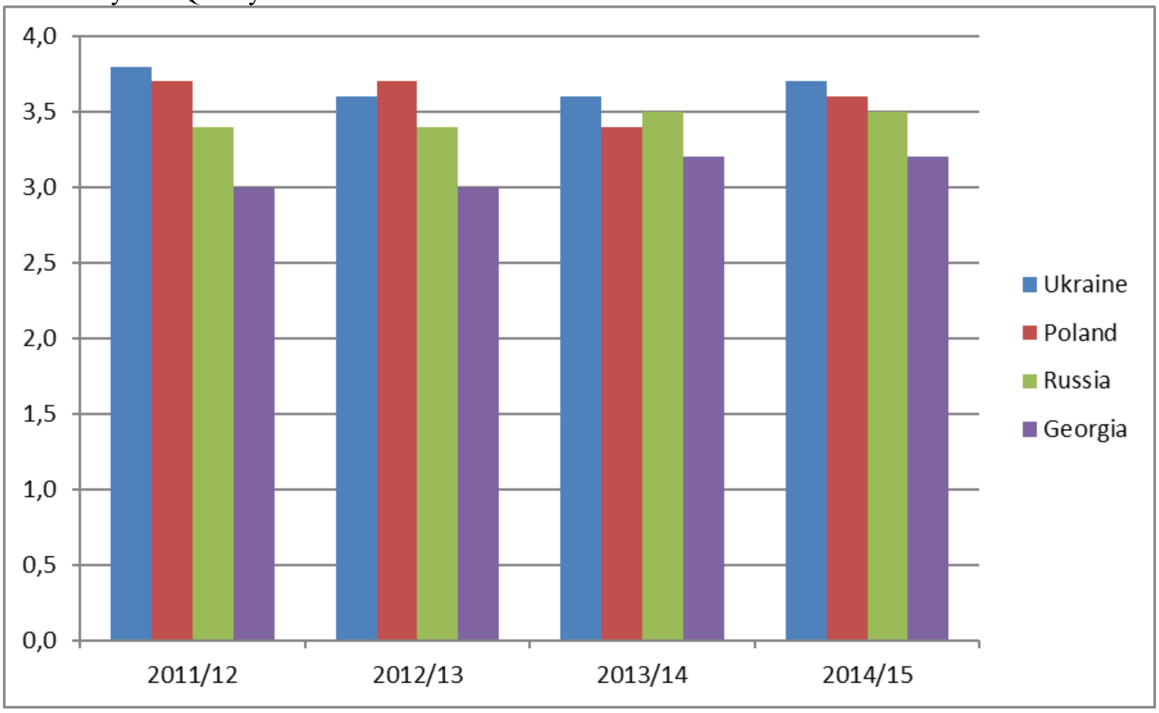
Indicator	**Score***	**Rating (Ukraine)**
Higher education and vocational training	4.9	40
Quantitative indicators in education	6.8	14
Secondary education coverage (%)	97.8	41
Higher education coverage (%)	79.7	13
Education quality	4.2	65
Education system quality	3.7	72
Math and natural sciences teaching quality	4.8	30
Management school quality	3.9	88
Internet access in educational institutions	4.3	67
On-the-job education	3.8	88
Research availability	3.9	84
Personnel development	3.8	92

According to the Global Competitiveness Report 2014/2015

(* score of 1 to 7 in addition to the estimate (% and other) values. For studies on other GIH components, visit www.forumkyiv.org)

The best education quality was seen in the fields of natural science and maths. The assessment put Ukraine the 30th by GCI in terms of natural science and maths teaching quality above Poland, Georgia, and Russia (Fig. 1) and below the Baltic countries, Israel, Slovenia, and South Korea. When it comes to the professional orientation of the domestic higher education and its managerial and economic components, the performance is much worse at the 82nd place for Management Quality and the 92nd for Personnel Development.

(a) Education System Quality



(b) Maths and Natural Sciences Teaching Quality

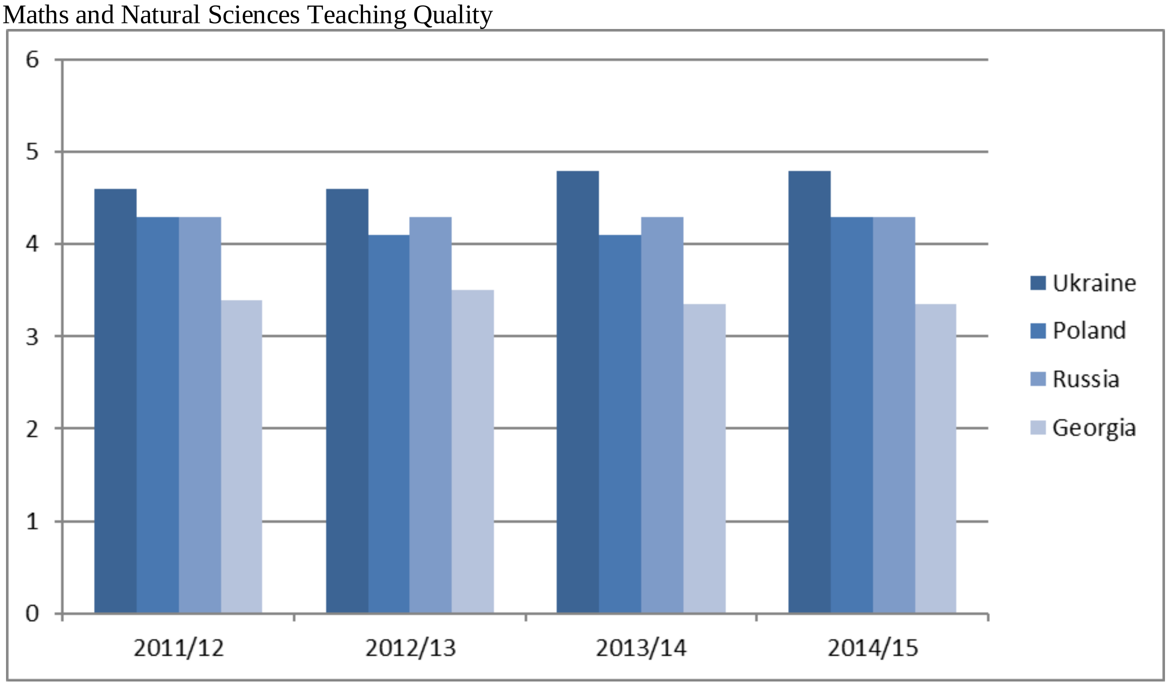


Fig. 1. Competitiveness of the Ukrainian education system in comparison with neighbouring countries according to the Global Competitiveness Report 2014/15:
a) Education System Quality; b) Maths and Natural Sciences Teaching Quality
(1—the minimum score, 7—the maximum score).

One of the leaders of in Ukrainian higher education, NTUU "Igor Sikorsky Kyiv Polytechnic Institute" provides training in the main areas of modern science and technology for engineers geared toward innovative economies.

Versatile and thorough study of natural sciences is key to successful training of engineers who can do advanced technology and design development, successfully work in various fields from science to production, and remain professionally mobile for a long time. However, quality engineer training within the framework of the technical training programs is greatly complicated by the growing gap between the level of school graduates' education and the requirements higher education institutions present.

Aim and tasks

The subject of this article is the analysis of the aspects related to the improvement of comprehensive chemistry courses for Batchelor's programmes in technical majors. Also considered are the objectives of the engineers' practical activity in various science and production fields covered while students master the system of fundamental chemical knowledge.

Research methods

The study is based on the data of first-year chemistry studies in the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" as pertains to the students of the Institute of Mechanical Engineering and the faculties of Heat and Power Engineering, Welding, Aerospace Systems, and Biomedical Engineering. The study spanned three years and covered about 1,500 students.

The official data of the Ministry of Education and Science of Ukraine on the results of the secondary school graduate achievement testing was analysed too.

The applicants' chemistry grade average was compared with the initial subject mastery of first-year students of engineering specialities (based on the results of the review conducted over the first weeks of study at the University).

The employers' feedback on the quality of National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" graduates' training provided by Ukrainian social NGO "Socio +" was analysed.

Research results and discussion

While the students' basic knowledge is formed, the need for maths and physics education of specialists is often justified. Meanwhile, the problems of improving the students' training in the chemistry domain are often overlooked, even though it is among the natural sciences that constitute a solid fundamental scientific component for the specialist training to a large extent. The connection of the fundamental sections of chemistry as a discipline with the applied aspects of engineering is illustrated in Fig. 2.

A thorough basic scientific training in physics, chemistry, maths, and biology forms a realistic worldview base, which can help tackle a variety of tasks in the creation of the latest technology, devices, materials, and even in natural and technological fields (El'tsova V.A., 5).

In the modern research and development, the conventional borders between branches of research tend to blur. On the contrary, when problems in the material production are tackled, the nature of phenomena as seen from the viewpoint of physics must be considered in the context of the fundamentals of chemical knowledge during the assessment of construction material properties and description of processes. In addition, compliance with environmental requirements must be ensured.

The combined advances in chemistry and physics enabled the formation and development of the important scientific and technological research areas like surface physical chemistry, metal physics, solid-state physical chemistry, chemical catalysis, plasma physics and chemistry, semiconductor material science, and nanotechnology.

Clearly, the description of the physical and chemical aspects involved in the operation of technical devices or closed production cycles requires an engineer to have a sufficient maths mastery to analyse the essence and the stages of the process study and give practical recommendations for optimisation of the processes in question.

Outstanding achievements in the development and application of the methods for obtaining new materials with the required physical and chemical properties have made their way into industrial production through the application of the classical laws of molecular and statistical physics and chemical thermodynamics/kinetics in conjunction with the latest research methods like spectrophotometry, chromatography, and different types of spectroscopy. The objectives of specialised training disciplines can be achieved if the methods and principles of mathematical modelling and physical research are applied in combination with the ideology of the modern chemical science.

Chemical education has another important aspect—the environmental one. While developing designs, the future technical engineers must have a deep understanding of the physicochemical process laws and the skills to manage their optimal conditions. They also need to learn to prevent man-made impact on natural processes and have mastery of management methods applicable to possible sources of environmental pollution with harmful substances.

Metallurgy, energy, transport, microelectronics, and other non-chemical industries are known to make 96% of harmful emissions. It is beyond doubt that the relationship between humans and nature must be manageable and rationally balanced based on the environmental competence of the future engineers. Environmental problems can be successfully solved provided environmental competence of the technical major undergraduate students is established during the chemistry course (Pidgornyy A.V., 6).

In the light of the role the chemistry plays in modern life, the diminishing level of chemical education and extremely low chemical culture in Ukraine raise concerns.

Specifically, the analysis of students' performance during the chemistry course in academic years 2005–2008 found that introduction of the new credit system in the ECTS grade-rating system resulted in students' better performance due to the much-improved organisation of unsupervised activities.

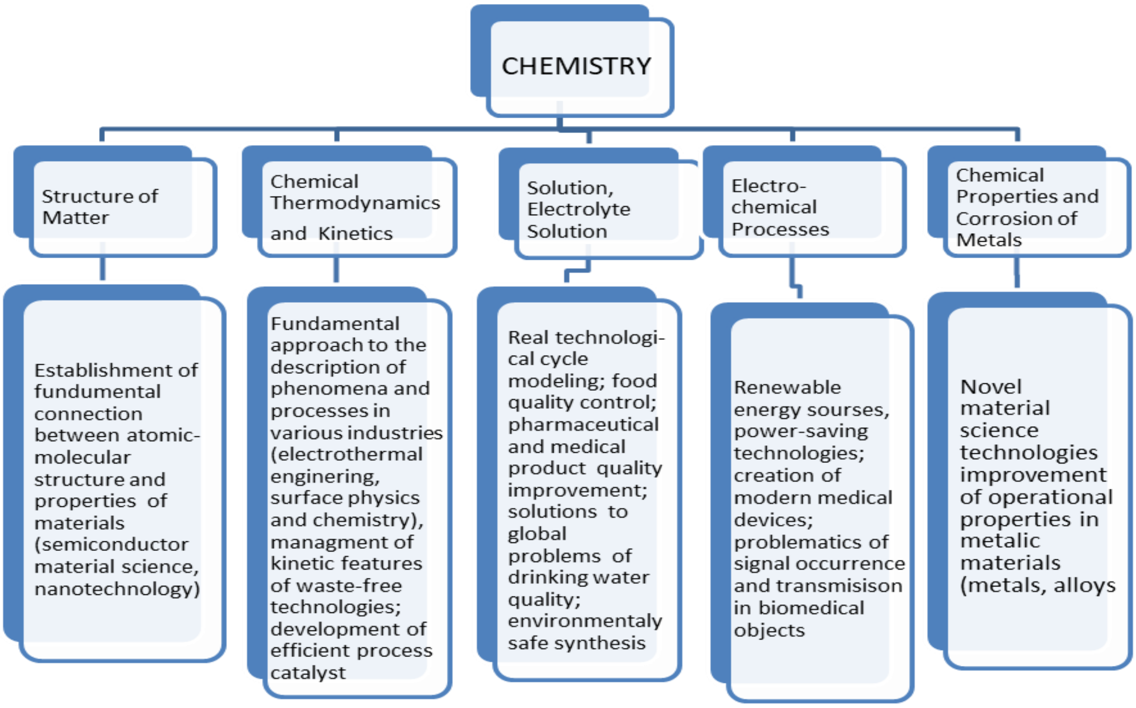


Fig. 2. Applied aspects of engineering as related to the main sections of the chemistry curriculum

However, from 2009 on the growth of the Education Quality index lacks dynamics, especially when it comes to first-year students.

This trend can be explained as follows.

First, the level of school education in chemistry largely falls short of the performance requirements for the first-year university syllabus. Thus, the initial chemistry knowledge assessment in the first weeks of study was found to have a correlation of about 60–70% with the chemistry grades in school certificates as compared to the corresponding requirements of the university.

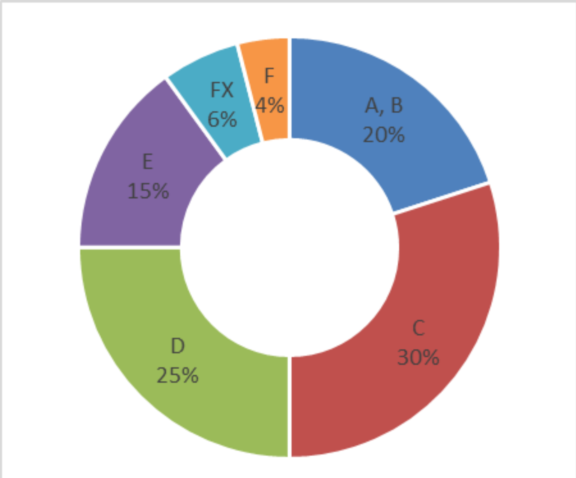
Table 2.

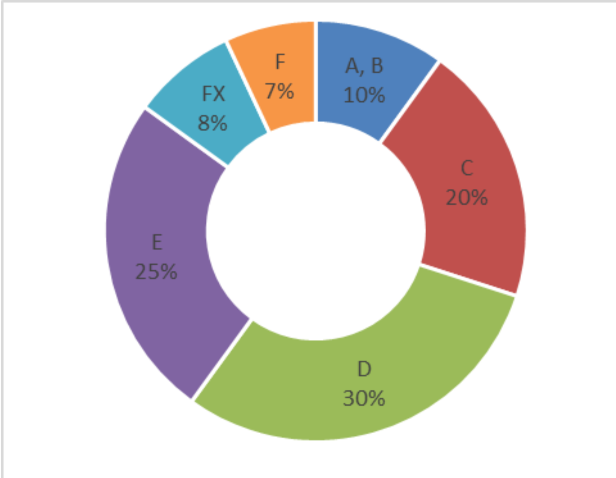
Comparison of the Basic Chemistry Mastery index as calculated from the grades in the entrants' secondary education certifications with the results of initial knowledge assessment among the students of engineering specialities of NTUU "KPI"

School certificate grade averages (12-point scale)					
2015		2016		2017	
8,1/12	0.675	7,3/12	0.61	7,2/12	0.60
Initial assessment grades (5-point scale)					
2.4/5	0.48	2.2/5	0.44	2.1/5	0.42

Second, most first-year students were found to have underdeveloped skills of unsupervised work and independent thinking; to be incapable of establishing the relationships between various natural processes; and to fail to generalise and systematise the previously acquired knowledge.

Third, with a somewhat formalised grading based on the rating system, we can get a "satisfactory" grade (D, E) without putting a proper effort into studying the credit module materials. The provisions for catching up with missed laboratory classes and performing individual assignments for submission are far from adequate too. Notably, credits and class hours devoted to natural sciences have been cut substantially in the engineering syllabuses as of late. Over the past 2–3 years, the planning of credits-based volume of studies has stabilised. However, with the approach most NTUU "KPI" departments use, the volume of physics studies exceeds that of chemistry ones by the factor of 2.5–3. The future engineers get to study chemistry for just one semester in the first year nowadays. The academic hours scheduled for laboratory practicums keep shrinking; some departments even replaced the chemistry semester exam with a differentiated or even a regular test (Fig. 3). In such an unfavourable situation, even the most hard-working students are usually unable to organise their knowledge during just one semester, so it remains fragmented and unsystematised.





а) **a)** **б)б** **b)**

Fig. 3 Comparison of the retention of chemistry material by students depending on the type of summative assessment: a) an exam; b) a differentiated test.

There is also a huge disconnect in the assessment of the concepts of "prestigious occupation" and the one sought-after in the labour market. The prestige of engineering professions urgently needs a boost if the scientific and technological progress and the consequent improvement of the socio-economic situation are to be achieved in Ukraine. So, the school graduates with a sufficiently educated in natural sciences should be led to choose to major in technology—this way, they will get great opportunities for creative development and improvement while studying at the leading Ukrainian higher educational institutions.

In 2016, the number of state-funded openings for Bachelor degree in the updated list of technical specialities increased and a nationwide competition with a single passing grade was introduced, increasing the likelihood of enrolment. However, higher education gained such a mass character because over 70% of school graduates enrolled on the basis the EIT, not 15-20% like before, when entrance exams were a must, which hardly makes it easier for the technical university students to achieve the desired performance in studies. Besides, there is a significant gap between the requirements of university curricula as to the education in natural sciences and the actual knowledge of secondary school graduates because more forms of knowledge retention assessment are required for chemistry, physics, and biology in the 11th form of secondary school. Studying in a technical university takes more than the knowledge of humanitarian disciplines. The introduction of the EIT system enabled admission of secondary school graduates of varying ability, often unclear motivation, and unformed views on their future, which became a huge problem for natural science departments. The analysis of math grades in school certificates based on the external testing results showed that almost 85% of the students who enrolled to NTUU "KPI" had a math passing score above 160 points out of 200 possible: 40%—160–180, 45 %— 180–200. However, the initial assessment found the freshmen's residual math knowledge to be very low (1.6–1.8 out of 5). The correlation is even weaker between the chemistry score in school certificates with the results of the initial knowledge assessment (the external testing results for this discipline are not among those compulsory for consideration in the enrolling competition). Therefore, hardly over 50% of first-year students show sufficient performance when it comes to fundamental disciplines (mathematical analysis, physics, chemistry) during the first part of the autumn semester. As a result, there is a wide gap between the requirements for natural science competency in the universities and the actual knowledge of secondary school graduates. The existing education methodologies and training programmes fail to take this into account, complicating the work for teachers (Yakymenko Yu. I., 7).

Most maths, chemistry, and physics teachers on freshmen courses find themselves in a situation where they need to go over the school curriculum to create a groundwork for the Bachelor's cycle studies. It takes numerous consultations to for freshmen to start analysing the information and understand the importance and necessity of studying the discipline consciously.

Deeper mastery and retention of the chemistry material is provided through experimental laboratory assignments. Integration of theoretical knowledge and practical experimental experience during laboratory practicums not only enables a deep reproductive learning of the educational material but also develops creativity and innovative thinking and imparts an active and systematic character thereto. No other kind of training demands such an initiative, observation, responsibility, and autonomy in decision-making from the student as a laboratory and experimental practicum. Besides, the relevance and value of laboratory practicums have significantly increased in the light of the inevitable need for a competency-based modular approach to higher professional education. Cao Cu Giac et al. point to an even deeper integration of theoretical training and practice, considering the latter in the context of not just a lab-experience, but a real-life experience: "Experiential activities organisation is the implementation of the principle of 'learning coupled with practice, education combined with labour production, theory connected with practice'. By encouraging students to participate in real-life experiences, learners will have the opportunity to view the subject from different perspectives and approaches, avoiding imposition; and have the opportunity to bring innovative solutions bearing the individual signature." (Cao Cu Giac, 8)

The well-known methodologist D. Kolb has even developed a theory of knowledge acquired through experience. He emphasises that experience plays a crucial role in the learning process: "Learning is the process in which knowledge is created through the transformation of experience." (Kolb D., 9)

Professional competence is the ability of a specialist (graduate of an institution of higher education) to use his knowledge, abilities, skills, inclinations, and personal qualities to analyse and assess the situation and find a generalised method for solving professional tasks productively and in a quality manner. Essentially, the content of professional competencies is determined by educational standards in terms of specialist type or function like scientific research, design development, organisational management, etc.

Performing the laboratory experiment, a student develops and forms competencies efficiently because they are shaped in during the educational activity, as well as that close to the professional one, which combines intellectual work with motoric activity and established procedures.

Solving practical tasks by means of experimental techniques combines educational activities and scientific research, especially when a complex of interdisciplinary connections is required to solve problems of applied nature.

Let's analyse the procedure a student uses to conduct a laboratory experiment assignment as a certain system consisting of a series of interrelated elements, each with its own functional purpose. The general structure of such experiment process is presented in Fig. 4.

Performing a laboratory experiment, the student must realise and understand its multifunctional purpose, explain the experiment plan, select measuring instruments or devices per the experiment requirements, acquire personal practical experience of experiment performance, understand and evaluate the results of his experimental activity, master the experimental data processing methods and skills, do technical reporting on the activities performed (create tables and diagrams, formulate conclusions) and defend the experimental assignment using theoretical and lecture materials.

The laboratory practicums enable the acquisition and mastering of new theoretical knowledge through the development of students' logical thinking, skills in solving specific practical problems, and ability to find optimal problem-solving methods, analyse in detail the research results, and come up with an acceptable engineering solution based on application of the known solution algorithms and principles of analogy.

The analysis of data in Fig. 5 shows that allocating few credits for laboratory assignments has no impact on training quality, whereas bringing those up to 2.0 enabled a significant improvement thereof.

Consequently, laboratory experiment assignments as a part of chemistry module enable the formation of students' solid professional competencies (knowledge → ability → skill) within the framework of the educational strategy aimed at preparing specialists to innovation work.

As the analysis of the engineering personnel training at NTUU "KPI" in recent years, favourable conditions were created for its graduates to be competitive in the labour market. According to the data of the student progress monitoring by the semester assessment results and those of rector's assessment of residual knowledge quality, the following results of the students' academic work were found (Yakymenko Yu. I., 10).

Students' mastery of academic disciplines per the specialist training plan selected as determined by the academic performance index was determined at almost 74% and the exam success index (percentage of students who passed exams with "excellent" and "good")—at 42% on average.

The generalised education quality index shows that 51% of students during the academic year 2015–2016 meet the highest knowledge quality criteria and can become highly qualified specialists.

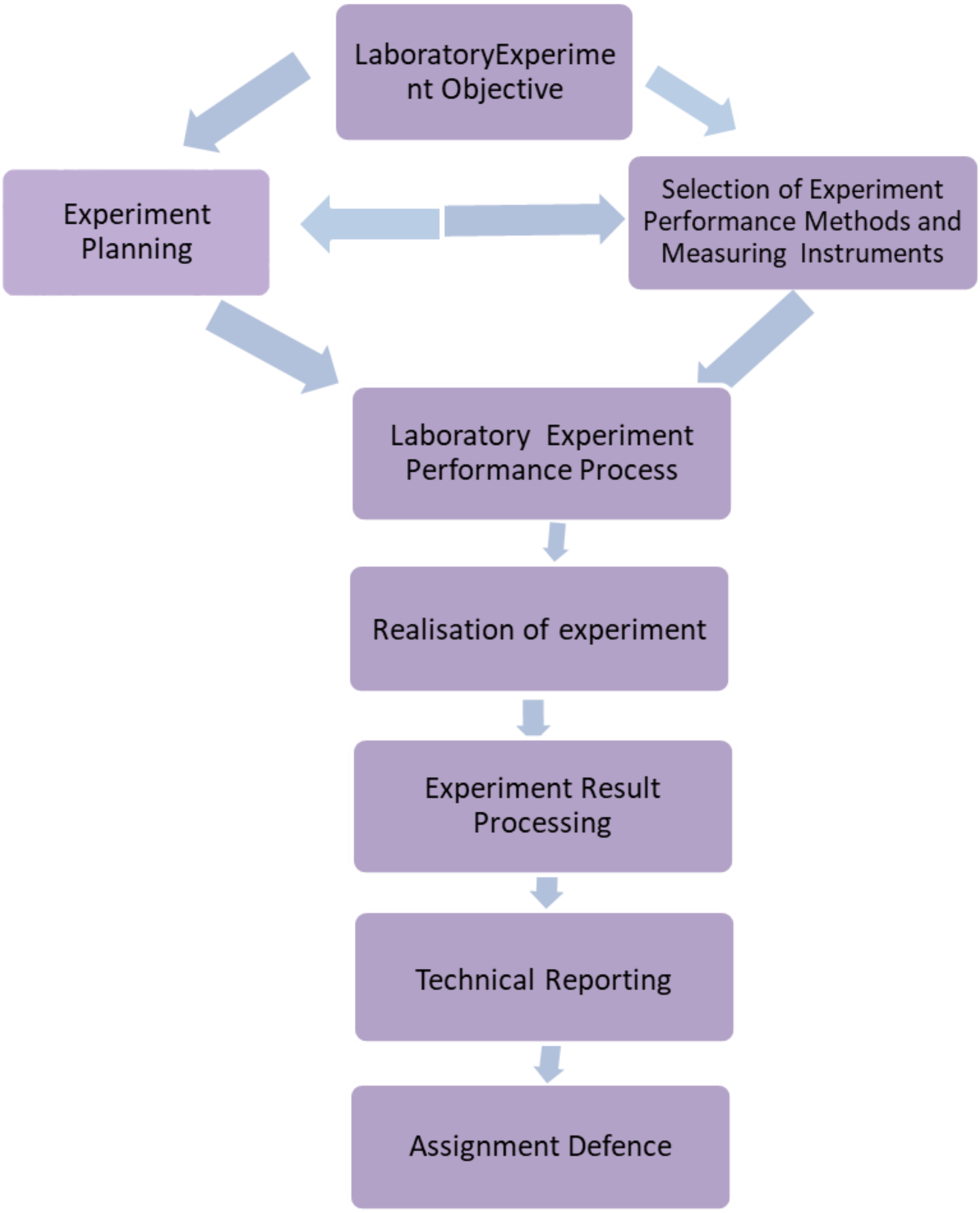


Fig. 4. Generalised didactic structure of the process for performing a laboratory experiment assignment

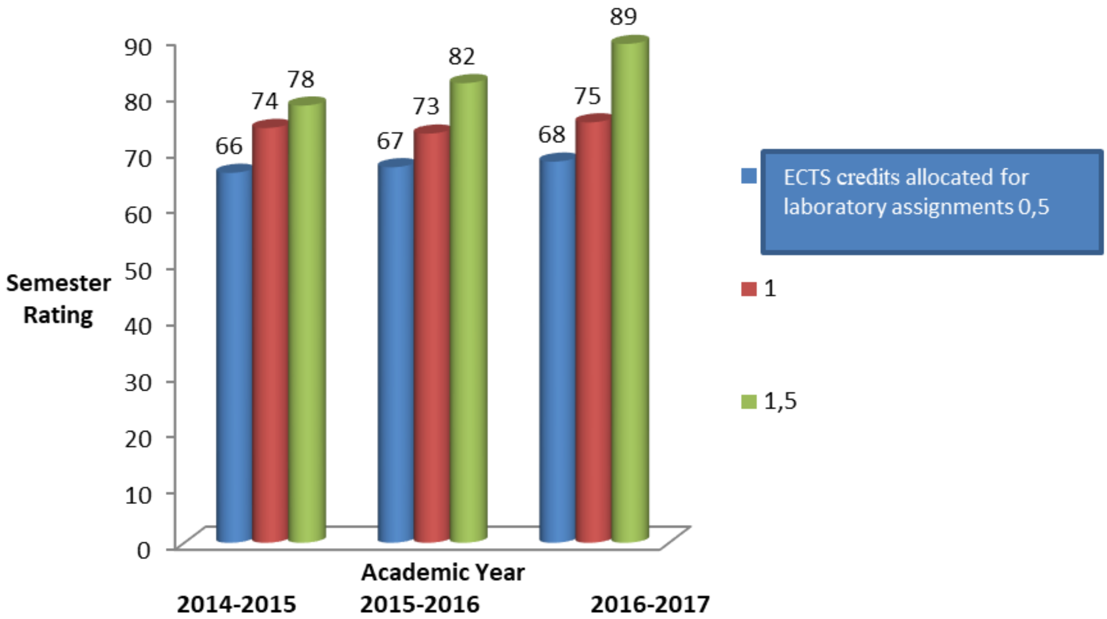


Fig. 5 Semester student rating assessment for chemistry discipline, depending on the number of ECTS credits assigned to the laboratory practicums.

Meanwhile, according to the survey conducted by the students of year 3–5 with regard to the estimates of the Socio+ Center (NTUU “Igor Sikorsky KPI”) the standards and quality of fundamental discipline studies increased as compared to previous years (47% of respondents). Only 35% of respondents valued highly the vocational training they undergo, and 47.2% evaluated this component as “moderately useful”. When asked if the knowledge of NTUU graduates in their field corresponded to the current state of production and business, 38.7% of employers answered “fully corresponds”, 53.3% answered “rather corresponds than not”, and 6.7%—“rather doesn’t correspond”. However, 44.3% of employers indicated that they needed multi-discipline specialists, and the remaining 39.6%—narrow specialists. The university’s orientation on fundamental training in a harmonious combination with enhancing interdisciplinary and innovative learning is thus increasingly justified (Zgurovskyy M. Z., 11).

Conclusions

The current strategy in the educational policy can be implemented only if the appropriate quality of engineering personnel training is provided through completeness of the university training programme with the knowledge of the fundamental and applied special disciplines, which become later an instrument for solving the priority tasks of innovative scientific and technological development of the economy and industrial production. Combined with other natural sciences, the system of fundamental chemical knowledge forms a scientific outlook and a wholesome system of scientific knowledge. On its basis, new problem-solving approaches can be developed in modern high technology, environmental sustainability assessment, and industrial system safety.

It has been established that a proper level of essential knowledge can be acquired within the chemistry course only if ECTS credits in educational and professional training programs are budgeted rationally—at 120–180 hours (4–6 credits). Of these, 1,5–2 credits should be allocated for laboratory practicums. The inclusion of laboratory practicums in the structure of chemistry credit module improves the quality of theoretical knowledge retention by 30–35%. Inadequate allocation of hours within the curricula for studies of natural sciences, as well as the abolition of semester chemistry exams at most departments of technical universities, as well as the outright exclusion of chemistry as a discipline from the curricula at some, makes it harder to achieve the necessary scientific level of the fundamental component of general engineering and narrow specialisation training.

School graduates of most secondary schools in Ukraine have a knowledge of chemistry that is too low and is unfit for being a basis for university studies. The content and quality of the school curriculum need to be changed. Alternatively, classes with intensive training in natural sciences may be created.

To ensure that potential candidates for engineering degrees chose the occupations sought-after in the labour market, the efficiency of informing and promotion of the leading technical universities among pupils must be improved, open days and profession-oriented competitions organised, and information about corresponding measures published in the mass media, as well as on the faculty and university websites. Also, additional work with young people is required within the framework of pre-university training.

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АНАЛІЗ ОСОБЛИВОСТЕЙ ХІМІЧНОЇ ПІДГОТОВКИ ІНЖЕНЕРІВ У КОНТЕКСТІ ЗАБЕЗПЕЧЕННЯ ЦІЛІСНОЇ ПРИРОДНИЧО-НАУКОВОЇ ОСВІТИ УКРАЇНИ

У статті розглядається проблема формування компетентнісного розуміння природничо-наукової освіти, яка є функціонально цілісною тоді, коли всі її складові частини діють узгоджено в рамках майбутньої спеціальності. Відмічається, що якість освіти, яка відповідає актуальним запитам суспільства і держави, базується на її фундаментальності, і головним завданням реформування інженерної освіти є створення умов для підготовки дипломованих спеціалістів, які володіють самостійним критичним творчим мисленням, спроможних до професійного зростання. Аналізуються проблеми складової фундаментальної підготовки з природничих дисциплін студентів технічних університетів, а саме розрив між рівнем підготовки з фундаментальних дисциплін випускників шкіл і вимогами вищих навчальних закладів; відмічаються проблеми вступної компанії 2016 року, які призвели до збільшення числа студентів у технічних ВНЗ із низьким рівнем знань із природничих дисциплін. Показано, що на нинішньому етапі розвитку суспільства неможливо забезпечити його подальше цивілізаційне та технічне зростання без засвоєння фундаментальних хімічних знань як важливої складової природничих наук.

Ключові слова: фундаментальні дисципліни, підготовка інженерних кадрів, моніторинг якості навчання студентів, сучасні засоби мотивації навчання, сталий розвиток і безпека суспільства.

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