Journal of Education and Learning (EduLearn)
Vol. 20, No. 2, May 2026, pp. 998~1006
ISSN: 2089-9823, DOI: 10.11591/edulearn.v20i2.23462

Formation of science and research competence of future engineers in higher technical educational institutions

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Article Info

Article history:

Received Sep 30, 2024
Revised May 19, 2025
Accepted Jul 18, 2025

Keywords:

Competence approach in education
Future specialists in engineering industry
Professional competence
Professional training
Science and research competence

ABSTRACT

The professional activity of an engineer is connected with the necessity to perform research tasks in the field of industrial production, which makes relevant the problem of formation of the skills for science and research activity (SRA) in the training process in higher technical educational institutions. The aim of the article is to investigate the effects of the proposed method of organisation of research activity of future engineers on the formation of their science and research competence. The observation, questionnaire, survey and interview are the methods used in the research. The research demonstrated a positive impact of the designed conditions of training of future engineers on the formation of their science and research competence. These conditions are: formation of motives of research activity, acquisition of relevant knowledge of scientific research methodology, involvement of engineering students in university scientific communities (scientific schools, scientific clubs, problem laboratories), and acquisition of experience of SRA. The research's novelty lies in the exclusive focus of the developed methodology on future engineers of shipbuilding industry. The proposed method of formation of science and research competence of future engineers can also be applied for the students of human sciences. Subsequent investigations of the stated problem could be directed towards the influence of SRA on other aspects of training of future specialists such as motivation to study and the level of professional skills.

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1. INTRODUCTION

Current social and economic challenges that emerge for the state of Ukraine, the necessity of post-war reconstruction, and modernisation of industrial production make relevant the problem of training of highly qualified, competent, and competitive engineering specialists [1], [2]. The society requires a responsible, nationally conscious, socially active patriotic citizen of the state, a responsible chief, competent and competitive specialist of the technical industry, capable of effective teamwork on the world standard level [3]. Modern professional activity of engineering specialist involves the organisation of production

process based on implementation of new technologies and equipment [4]. These factors require the awareness of the engineer of its operating features and the ability to provide the work of the team with new mechanisms and devices [5].

The relevance of the research of the problem of science and research activity (SRA) skills formation is caused by the necessity for future engineers to conduct scientific research aimed at both modernisation of existing technical tools and design of new tools [6]. Despite the increase of research intensity of theoretical and methodological basis of future engineering specialists training, the problem of formation of science and research competence in the training process in higher technical educational institutions is not sufficiently explored, so it requires a further and in-depth research. The hypothesis is based on the assumption that the process of formation of science and research competence will benefit from the following conditions: formation of motives for research work, study the methods of organisation of scientific research, acquisition of the experience of SRA.

According to the stated hypothesis, the objectives of the research were to study the motives of students of technical majors to conduct SRA, to determine the level of knowledge of forms and methods of organisation of SRA, and to identify the skills and experience of SRA. The other objective of the study was to identify the characteristics of science and research competence and the factors that influence the effectiveness of this process, based on the analysis of literature and practical experience in training future engineering specialists. The obtained results demonstrated the positive impact of involving students in university scientific communities (scientific schools, scientific clubs, and laboratories) on formation of motivation to conduct SRA. The teaching of the specialised course "The basics of scientific research" proved its effectiveness in acquisition of the methodology of scientific research organisation. Presentations at scientific seminars, round tables, conferences, and symposiums proved their effectiveness in providing students of engineering majors with the experience of SRA.

2. LITERATURE REVIEW

Researchers of modern technologies and the content of engineering education concluded that for effective performance, an engineer should be able to design and construct, to use production tools, management, practical, design, technological, and research activities [7], [8]. Scientists Poyasok *et al.* [9] and Butsyk [10] emphasize that an engineer should be able to conduct scientific activity, to be a researcher, and to implement their own ideas. According to the conclusions of Obukhova *et al.* [11] and Grynova *et al.* [12], engineering specialists are the organizers of the production process and, therefore, they should be able to manage teams of workers and use normative, reference, scientific, technical, and production information to ensure the implementation of scientific and technological advancements in modern industry. Consequently, the essential professional skills for engineers are the design of scientific and technical documentation, the implementation of technological projects, and the organisation of measures to enhance production efficiency based on scientific achievements.

The analysis of works by contemporary researchers indicates that a competent specialist in the technical industry must meet the following requirements: to possess a high level of engineering education, to have a strong morale, to be able to collaborate effectively within a team, and to make conscious and responsible decisions [13], [14]. A future engineer should be able to operate modern technologies and knowledge that meet the demands of the modern information society [15]. The personality of a future engineer should be active, dynamic, innovative, creative, and competence-oriented [16].

A competent specialist in the technical industry is characterised through their readiness to resolve tasks in future professional activity, with the use of innovations to achieve the goal, based on their own expertise in the field of industrial production [17], [18]. Competence is the possession of the knowledge and skills, which are necessary for a specialist in a certain field of professional activity. Also, competence is awareness, expertise, intelligence, general professional training, and the synthesis of cognitive, practical, and personal experience [19], [20]. Professional competence is defined by modern researchers as a skillset of engineering specialists to structure scientific and practical knowledge for effective solutions of research tasks in future professional activity [21], [22]. The conducted analysis confirms the relevance of SRA of engineering students based on the competence approach. The results allow to consider SRA as an integral component of training of competent specialist. It ensures the integration of scientific, educational, and industrial activity in the process of professional training of future specialists.

3. METHOD

3.1. Research design

The study was organised in three stages from October 2023 to June 2024. The first stage included the study of the level of motivation, knowledge, skills, and experience of engineering students in carrying out SRA. Based on the analysis of literary sources and the experience of training future engineering specialists, the

objective of the second stage was to establish the goals, tasks, aspects, and factors that influence the formation of science and research competence as an important component of professional competence of future engineers. On the third stage of research, engineering students and teachers were engaged in experimental work, which involved the implementation of the proposed training conditions into the educational process and check of their effectiveness in developing the science and research competence of future engineers.

3.2. Sample

The experimental base of the research was the Science and Education Institute of Automation and Electrical Engineering, Machine Engineering Science and Education Institute and Shipbuilding Science and Education Institute of the Admiral Makarov National University of Shipbuilding, Ukraine. In 2023, 222,792 future engineers of the specialties "mechanical engineering" and "electrical engineering" were trained in Ukraine. This was taken into account to calculate the size of the representative sample (confidence probability-95%, confidence interval-5%), which included 3278 future engineers of the Admiral Makarov National University of Shipbuilding. The 39 teachers of technical disciplines also participated in the experimental work. The sample was formed with an orientation towards compliance with operational validity, i.e. the aim and objectives of the study. The quantitative and substantive characteristics of the sample ensured the representativeness of the study. The main formal requirements for participation in the study were the major in engineering and consent to participate in the study. The Kolmogorov-Smirnov test was used to check whether a statistical series conforms to a normal distribution of the sample.

3.3. Methods and instruments

The experimental work was based on the implementation of a pedagogically grounded methodology for the professional training of future engineers as an independent variable. Research competence was the dependent variable. The implementation of professional training using the developed methodology involved the active involvement of future engineers in the activities of university scientific communities (scientific schools, scientific clubs, laboratories), their study of the specialised course "The basics of scientific research", presentations at scientific seminars, round tables, conferences and symposiums, and publishing the results of research work in collections of scientific papers. The implementation of the methodology was based on detailed instruction, the formation of feedback channels, and the stimulation of motivation for scientific research. The development of methodological tools was carried out by specialists in the relevant field of engineering.

The collection of experimental data involved primary and secondary diagnostics. Forms were used to collect data. The data analysis involved the use of percentage analysis to establish general trends in the manifestation of the studied characteristics. The SPSS software package was used for data statistical processing. The study used several valid tests, such as the test of the level of individual's development of creative abilities by Guilford [23], and the Torrance tests of creative thinking [24]. To study creativity and intelligence, the test by Getzels and Jackson [25], the Wollach-Kogan creativity test of pedagogical diagnostics of individual's creative potential [26], and the remote associates test of verbal creativity by Mednick [27] were used. Comprehensive observations of future engineers were conducted.

The analysis of the results revealed a relatively high level of motivation of future engineers to conduct SRA: 2574 (78.5%) understand the necessity to conduct scientific work; 656 (20%) of the surveyed future engineers were not able to formulate the goals and motives of SRA but showed interest in this type of activity; 48 (1.5%) respondents did not have clearly developed motives for SRA, as in Figure 1. The research demonstrated that among 3278 future engineers 3075 (93.8%) had weak knowledge but expressed willingness and desire to study the theoretical basis of SRA and to participate in scientific activity at the Admiral Makarov National University of Shipbuilding. The presence of SRA skills and experience was determined through observation and interviews, which revealed that only 203 (6.2%) students had knowledge and skills of organisation of SRA due to participation in scientific associations, such as the Junior Academy of Sciences of Ukraine as in Figure 2.

3.4. Ethical criteria

This study was planned and conducted according to professional ethics and legislation. The respondents' participation in the study was voluntary, and participants were informed about the purpose, plan, and methods of the research. The principles of protecting the rights of research participants, ensuring their safety and data privacy were observed in the data collection process. The participants of the experiment were able to receive necessary consultations and assistance at every stage of the research. The research was built on the principles of impartiality and objectivity.

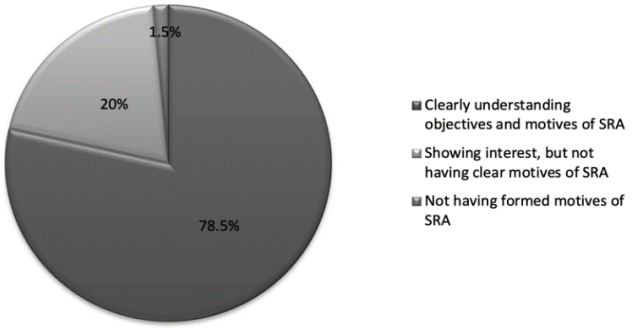

Figure 1. The level of formation of motives of future engineers for SRA

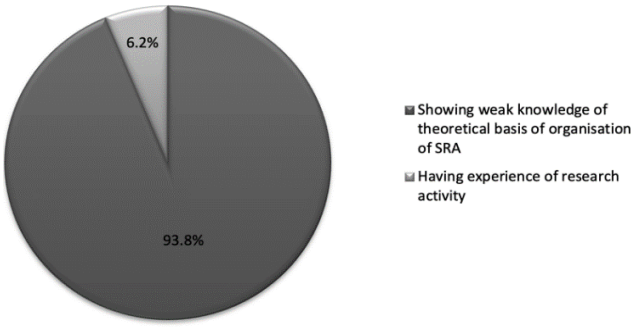

Figure 2. The level of formation of knowledge of forms and methods of organisation of SRA

4. RESULTS AND DISCUSSION

At the first stage of the study, which involved a review of the literature on the research problem and an analysis of practical experience in training engineering specialists at higher technical educational institutions in Ukraine, the following patterns and characteristic features of the training process were identified. These findings were considered in the design of the experimental methodology for formation of the research competence of future engineers. The implementation of the competence approach is a priority task of training technical major specialists in Ukraine. The analysis of a current labor market trends confirmed the demand for specialists with creative and flexible thinking [28]–[30]. Therefore, the main objective of modern engineering education is to prepare specialists with innovative thinking, who are capable of further self-development and self-improvement.

The implementation of the competence approach in the process of future engineers training emphasizes the ability of technical specialists to creatively apply acquired knowledge and experience in the practice of the production process. Therefore, a key feature of training students of higher technical educational institutions is the ability of future engineers of self-organisation and reflection. The study revealed that in order for the training of future engineers to be effective, it should have a value basis. This requires an axiological orientation of the educational process. The importance of considering the axiological approach is emphasized by scientists Kumar [31] and Shetelya [32]. The principle of a value attitude of the future engineer personality toward acquired knowledge is the basis of their professional self-realisation. Competence oriented training of future engineers should be based on the moral values of humanism, democracy, human dignity, patriotism, social activity, responsibility, and national consciousness.

The conducted study identified the following components of the professional competence of a future engineering specialist: professional knowledge; the ability to analyze and forecast work results; to use modern information; and to conduct scientific research in the corresponding field of production. Social, communicative, and individual abilities of the personality of an engineer are also important for their future professional activity, and therefore should be considered in the process of organisation of their training in higher technical educational institutions. The professional competence of a specialist in a technical industry involves: the ability to assess professional situations; creative thinking; science and research skills; initiative in solving production tasks; the ability to organise teamwork; and an understanding of personal responsibility for work results.

The study demonstrated that successful acquisition of professional competences and a high level of self-organisation in future professional activities, is possible due to a combination of science-theoretical training of an engineering specialist and experience of applying acquired knowledge in the field of industrial production. The implementation of the competence approach involves the transformation of the professional competences acquired during the training of future engineers into active professional and creative participation in social activity. This opinion is shared by Shumilova *et al*. [8] and Obukhova *et al*. [11], who emphasise that it is essential not only to teach future specialists of the technical industry to operate knowledge and technologies, but also to prepare them for active engagement in modern society, to meet the current demands of the labor market, to teach to operate and use information, and to apply the achievements of science and technologies for education during the life.

The identified trends and characteristic features of training indicate that the process of professional training of future engineers in higher technical educational institutions will be effective if science and research skills are well-developed. This allowed us, on the next stage of the study, to identify factors that positively influence the formation of science and research competence. We focused on the motivational sphere of future engineers, the formation of theoretical knowledge about methods of research activity organisation, and the acquisition of experience of scientific research in the field of industrial production.

We consider science and research competence as a key quality of a future engineer personality, manifested in their readiness and ability to conduct goal-oriented scientific and research activity in the field of industrial production on the basis of developed knowledge, skills, and experience in organising this activity; personally and professionally significant qualities of the future specialist of the technical industry; and a value attitude to the profession of an engineer, colleagues, work results, and state natural resources. The formation of research competence involves the development of a scientific culture through the engagement of students in fundamental research in industry and the development of their ability to realise innovative technologies of engineering science. Our opinion that the aim of formation of science and research competence is the development of the ability of a future engineer to complete professional research tasks in the process of production and to conduct scientific research aimed at improvement of existing production methods and development new methods is shared by researchers Poyasok *et al*. [9] and Butsyk [10].

The research revealed that the formation of research competence of future engineers is influenced by the following characteristics: the level of professional education; individual aptitude for scientific research; experience of research activity; motivation for self-education and self-development; a creative approach to professional activity; and the skills to perform in non-typical or non-standard situations. Our research demonstrates that the process of formation of science and research competence of future engineering specialists includes the following aspects: the goal aspect, the motivational aspect, the cognitive aspect, the activity aspect, and the reflection aspect. The goal aspect directs the SRA of a future engineer and outlines his achievements at a specific stage of work. The motivational aspect stimulates the research activity of students. It is important to stimulate their interest, to explain the significance of research, to form their attitude to scientific work, and to prove the necessity of scientific activity for an engineer. The cognitive aspect provides engineering major students with knowledge about the methods and forms of science and research work. The activity aspect ensures the engagement of students in the scientific work of the university, participation in events (conferences and symposiums), writing reports and articles, and participation in contests of scientific papers, etc. The reflection aspect involves development of students' ability to analyze and evaluate their scientific achievements, formation of the habit to participate in scientific work in professional activity.

The next stage of the research involved the engagement of students and teachers from the Machine Engineering Science and Education Institute and Shipbuilding Science and Education Institute of Admiral Makarov National University of Shipbuilding into experimental work. The leading approaches that proved effectiveness in the formation of science and research competence included: orientation of activity of university towards the development of research skills, formation of experience of scientific work of future engineers, encouragement of students to solve scientific problems through their involvement in the work of university scientific communities (scientific schools, scientific clubs, and laboratories); presentation of results of SRA at scientific seminars, round tables, conferences, and symposiums, and publishing the results of research work in collections of scientific papers. Our efforts were focused on the development of the scientific vision of a future specialist of a technical industry, the expansion of his scientific erudition and theoretical preparedness to conduct SRA; the acquisition of methodology and methods of scientific research, the formation of creative thinking, the development of individual aptitude of engineering major students to solve both typical and non-standard situations in the field of industrial production. Our conclusions are consistent with the research by Grynova *et al*. [12].

The important principles that we followed and that ensured the effectiveness of formation of science and research competence are the creative approach to the profession of an engineer, the professional direction

of SRA, and the activity of the personality in this process. An effective method of acquisition of knowledge about the methods and principles of SRA organisation, according to the responses of 93.7% of the engineering students, who were involved in the experimental work, was the study of specialised courses such as "The basics of scientific research", special courses, and special seminars. Besides, 96.5% of future engineers noted that the activity of student scientific communities (scientific clubs, problem groups, and student laboratories) promoted the development of their motivation for scientific research and inventive activity and provided an opportunity to specialise their knowledge of certain subjects and to master the methodology of scientific work. The obtained results are consistent with the research by Astutik *et al*. [33] and Reddy [34] regarding the positive impact of research activity on the formation of scientific creativity skills and scientific literacy of students.

The practical implementation of the proposed methodology of formation of future engineers' research competence confirmed the effectiveness of the infrastructure for planning and conducting scientific research. The infrastructure consists of the Scientific-Expert Council of the Admiral Makarov National University of Shipbuilding, Scientific and Technical Councils by research areas, and 30 scientific schools, including: "Study of seaworthiness and design of new types of ships", "Soldering and welding under pressure in vacuum", and "Environmental safety and energy saving". Based on the results of the activity of the industry laboratories and scientific-technical centres of the university, where experimental work was conducted, the following perspective directions for scientific research were selected: i) shipbuilding, ship construction, and equipment for studying the world ocean; ii) physical and technical problems of materials science (metals, ceramics, composite and monocrystalline materials); iii) interdisciplinary problems and system research in energy (energy efficiency and energy saving); iv) information and commutation technologies for project management, analysis and synthesis of systems for management of technical and ecology processes; and v) energy and energy efficiency, research on the seaworthiness of ships and other sea machines.

97.8% of students of engineering majors confirmed the effectiveness of their participation in the work of scientific schools and international cooperation centres at the Admiral Makarov National University of Shipbuilding in formation of their experience in research activity. 76.3% of the teachers, who were involved in the experimental work, noted positive results of future engineers in the research tasks. These tasks were connected with the use of acquired skills in generating rationalisation and inventive ideas to solve analytical, research, design, and engineering problems. Comparison of our results with the conclusions of scientists Shukhailo and Derkach [35], who study the training of future engineers, is consistent in the context of the positive impact of scientific research activity on the level of overall academic performance.

The proposed methodology showed its effectiveness in formation of practical skills of future engineers to summarise the results of their research work. In this experimental work, future engineers participated in preparing reports, presentations, and discussions at the annual scientific-practical conference of teachers and students "Innovations in shipbuilding", held at the Admiral Makarov National University of Shipbuilding. According to the conclusions of teachers and students, this work promoted the acquisition of practical experience in public discussion of the results of SRA.

Turmudi *et al*. [36] confirm our findings on the positive impact of writing scientific articles on the professional development of specialists, which can be applied in the training of future engineers. We also share the point of view of Azizah and Budiman [37], who investigated the problems of writing scientific papers among Indonesian students for international publications. Ismail *et al*. [38] also concluded that writing academic articles is an effective tool for achieving educational goals and stimulates creative activity.

The main limiting factor of the study is a limited period of the experimental work (two semesters). A longer duration may provide a deeper understanding of the ongoing impact of proposed methodology on the formation of the science and research competence of future engineers of shipbuilding industry. Only full-time students participated in the study. The results may not capture all the variations that can occur when students participate in part-time or non-traditional forms of education. Future studies should consider diversifying the participants to make the study more unique.

5. CONCLUSION

The research of the problem of the formation of science and research competence of future engineers is relevant due to the need for scientific solutions of production tasks in the field of industrial production. Therefore, the ability to conduct scientific activity and to organise research work is the basis for the high-quality training of future engineering specialists in higher technical educational institutions. Recent observations indicate that the main objectives of modernising of future engineers training according to the prospective demands of science-intensive production can be solved by developing abilities, skills, and experience of innovative scientific and research activity for specialists in the technical industry.

Our research provides conclusive evidence that the formation of science and research competence, as the basis of the future engineers training in higher technical educational institutions, ensures the development of a scientific worldview, and individual research, creative, and inventive abilities of a highly qualified specialist in the technical industry. The effectiveness of this process is provided by formation of motives for research work, acquisition of knowledge of research methodologies, and active participation of a future engineer in this process through involvement in university scientific communities (scientific schools, scientific clubs, laboratories), which results in promotion of acquisition of experience of conducting scientific research activities. The involvement of students of other majors will provide a broader perspective on the problem of studying the impact of the proposed forms and methods of organisation of SRA on the formation of science and research competence. Subsequent investigations could be directed towards how SRA of students affects their level of knowledge in various subjects and their motivation for learning.

FUNDING INFORMATION

The research was conducted on a free basis. No additional institutions or sources of funding were involved. This research received no specific grant from any funding agency in the public, commercial, or non-profit sectors.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Oleg Savchenko	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓			✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. The authors declare that they have no non-financial competing interests or personal relationships that could have appeared to influence the work reported in this paper.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study. The participants authorized the analysis of the results of their science and research activity (scientific papers, presentations, observations, and findings) during the course of this study. The study was based on the principles of impartiality. Participation in our study was voluntary and did not affect the assessment of the academic progress of the participants of our study.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [NR], upon reasonable request. The science and research activity of participants of our study included involvement in the work of university scientific communities, presentations at scientific seminars, round tables, conferences, and symposiums, and publications in collections of scientific papers. Information on the results of the science and research activity of the participants of our study is available on request from the corresponding authory.

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