Organizational and pedagogical conditions for network training of teachers of engineering education for pupils

L V Shkerina and A V Bagachuk
Krasnoyarsk State Pedagogical University named after V.P. Astafiev, 89 Ady Lebedevoy St, Krasnoyarsk, Russia

E-mail: bagachuk@mail.ru

Abstract. Nowadays the problems of vocational guidance of pupils for engineering professions corresponding to the modern technological paradigm are particularly significant. The problem of preparing teachers for the design and implementation of engineering education programs for schoolchildren is one of these issues. The purpose of the article is to define the organizational and pedagogical conditions for network training of teachers of engineering education for pupils. The research involved 900 students of the 10th grade and 80 headmasters of secondary schools. In order to identify the students’ attitude to their engineering training and the shortage of teachers of engineering education of pupils, the testing has been carried out. The analysis of the test results by means of descriptive statistics and content analysis has confirmed the feasibility of implementing a network approach in the practice of training teachers of engineering education for pupils. According to the results of the study, it has been found out that these conditions identified by the authors allow organizations forming a networked educational space to purposefully integrate their resources in providing opportunities for students to master both pedagogical and engineering competencies necessary for a teacher of engineering education for pupils.

1. Introduction
For each technological paradigm the problems of secondary school students’ choosing engineering as a career has its own special features. In 2010, the beginning of the sixth technological paradigm with new knowledge-intensive industries was recorded. These industries require a new generation of engineers with systemic interdisciplinary competencies, capable of solving new problems with new means and methods. The training of such engineers begins with the vocational guidance of schoolchildren which must correspond to the modern technological paradigm.

In this regard, there is an increasing demand for a school-leaver with a high level of theoretical training and stable motivation to receive engineering education. However, the analysis of school leaving exam results of first-year-students entering engineering training areas shows that for most educational institutions of higher education in such areas of training, those who enter a university have low average points for Unified State Examinations.

The Strategy for innovative development of the Russian Federation defines modern requirements for the results of graduate training in the following way: “Education should form a new level of technological competence and high creativity in students” [1]. Such training can be realized both through specialized training and in terms of additional education.
In 2015, the strategic initiative “New model of the system of children additional education” was launched [2]. The need for changes is caused by the challenges of the innovative economy and strengthening of global scientific and technological development. As a part of the initiative, the task of educating the leaders of the future is solved. Their training begins with the development of skills of the 21st century, such as technological competencies, the ability to work in a team and effective communication. To achieve this, new forms of education taking into account the motivation of children and adolescents to learn are used. Among them, the so-called children's technological clusters are especially widely used.

Currently, there is a shortage of teachers for both engineering classes of training schoolchildren and teachers of additional engineering education.

To solve new problems of vocational guidance for the profession of an engineer and the engineering training of schoolchildren, teachers with modern knowledge and technologies of motivation and training in the context of modern engineering education and the professional activity of an engineer are required. The search for ways to implement such training of a teacher is an urgent scientific pedagogical problem. The purpose of the study is to substantiate the expediency of network training of teachers of engineering education for schoolchildren and to determine the organizational and pedagogical conditions for its implementation.

2. Literature review

Solving the problems of engineering training for comprehensive school students is one of the strategic directions of education development. The opportunities for their solution are studied in the works by local and foreign authors. A.V. Isaev, I. L. Gonik, and L.A. Isaeva offer a special form of additional engineering education for schoolchildren - an "Engineering class" [3]. D.V. Grigoriev et al. think that the problems of engineering training of pupils can be solved by creating children's technological clusters [4, 5]. T. Vossen, I. Henze, R. Rippe, J. Van Driel suggest using STEM projects to develop students' engineering skills [6]. The articles by P. Hudson, L. English, L. Dawes, J. Koh discuss the practicability of an engineering orientation in teaching mathematics, physics and other school subjects [7, 8].

Several years ago with the state support, the so-called children's technological clusters aimed at developing the engineering and technological education of schoolchildren in our country were created. They were defined as an educational environment “integrating the capabilities of scientific and technical and industrial and technological environments” [4].

Today there are children's technological clusters in Russia that are created according to the "Quantorium" model developed and supported by the Agency for Strategic Initiatives (ASI) within the framework of the "New model of the system of additional education for children" initiative. The institute of tutoring is in demand in technological clusters, as it allows to develop the necessary "hard-competencies" in the field of pedagogical support of engineering and technological training of schoolchildren among students-future teachers who have the opportunity to undergo practical training on the basis of technological clusters. T.O. Mishina and S.M. Konyushenko substantiate the possibility of training teachers for work in technoparks through the implementation of programs of additional professional education on the basis of "Quantoriums" [9].

On the basis of some of the country's leading universities, STEM centers, laboratories, and clusters are created, and the design and research activities of students are successfully implemented under the guidance of teachers, university professors, graduate students and undergraduates in these centers. However, they do not carry out professional training of teachers-mentors of engineering education for pupils, including people without basic pedagogical education [10].

In the United States, there is a special "National STEM Clubs Program" organization, interacting with schools and being a resource center for science and technology clubs. Another non-profit organization, the National Association for the Education of Young Children, is engaged in the private accreditation of educational programs in engineering and technological field [11].

All authors note significant shortages of personnel and material resources required for the successful implementation of school engineering education.
The issues concerning professional training of teachers of specialized engineering education have not yet been sufficiently developed and currently they are in the focus of attention of local and foreign scientists, teachers and educational practitioners.

At present, many scientists are actively studying the didactic potential of STEM-learning (Science, Technology, Engineering and Mathematics) as a means of learning that affects the quality of students' mastering natural sciences, mathematics and computer science as ways to solve the problems of practical and engineering focus [12, 13, 14, 15, 16, 17, 18, etc.].

Some of the possibilities connected with using STEM-teaching in training teachers-mentors of school engineering education are described in the works [19, 20, 21, 22].

S.G. Grigoriev and N.N. Mikhailova suggest creating so-called STEM-parks as a target association of the education system and business in the Moscow State Pedagogical University to prepare teachers of engineering education for pupils [19].

Abroad the problem concerning professional training of teachers of specialized engineering education is revealed in the research topic of "pedagogical content knowledge of teachers", which integrates the basic principles of both purely subject and purely didactic paradigms in training teachers of exact science, physical and mathematical profiles [23].

As one of the means of training teachers of engineering education for pupils, a number of authors consider additional educational programs as a way to improve the qualifications of a subject teacher [24, 25]. J. Utley, T. Ivey, R. Hammack, et al. explore the possibilities of getting acquainted with the specific characteristics of the engineering activity of primary school teachers during their professional development. According to the authors' point of view, this will increase the teachers' confidence in teaching and explaining engineering concepts to their pupils [26].

A special role in solving the problems of professional training of teachers of school engineering education is assigned to network learning. Most researchers emphasize that in the context of globalization of the modern educational system, integration processes in the form of creating network communities are necessary for solving strategic issues in this area [27, 28]. Currently, there are effective practices for implementing network interaction in the context of the highlighted problem [3, 25, 29, 30].

The coordination of network activities in the field of pedagogical practices is carried out either through scientific and methodological centers, the functions of which are regulated at the national level in the Asian model of vocational training of engineering education teachers, or with the help of professional communities which have become widespread in Western countries. Despite the steps taken in local and foreign educational practice, the issue of the lack of methodological personnel in specialized engineering education of pupils remains relevant [11, 24, 25].

When implementing each of these models, network interaction is widely used. It involves the universities that accumulate methodological research and offer solutions for educational practice; large technological companies solving the problems of sustainable innovation development.

In the works by V.V. Vikhman, S.S. Demtsura, A.V. Zolotareva, Z.S. Kurbyko the authors models of organizing network interaction with the participation of universities for the purpose of training and improving professional skills of teachers are presented [24, 31, 32, 33]. The specific features of training mentors in specialized engineering education are reflected in the research by N.V. Gafurova, V.I. Lyakh, S.I. Osipova, A.N. Solovyov, I.P. Chernova. The authors propose the approaches and techniques for the implementation of specialized engineering training of students in the context of educational resources integration and social partnership of universities, manufacturing companies and comprehensive schools [5, 34].

The analysis that had been carried out made it possible to conclude that nowadays in pedagogy an active search for effective solutions of the problems concerning providing engineering education with qualified teachers takes place.

Some of the authors study the possibilities of integrating educational resources of universities for training teachers of school engineering education (V.V. Vikhman, Z.S. Kurbyko, E.Yu. Gurtovaya, R. Ruhf, M. Jenness, D. Oppliger, etc.).
Other authors suggest using the potential of integrating universities and non-educational organizations to train teachers of school engineering education (S.G. Grigoriev, I.O. Kotlyarova, N.N. Mikhailova, M.V. Potapova, A. Kukreti, J. Broering, etc.).

The third group of scientists explores the possibilities of the educational network based on the integration of the universities and secondary schools potentials (organizations of additional engineering education for pupils) for preparing teachers and engineering training for pupils (A.A. Zobnina, E.A. Sukhanova, K. Neumann, V. Kind, U. Harms, etc.).

Based on the synthesis of the results of studying the problems of training teachers of school engineering education by other authors, we come to the conclusion about their fragmented (one-sided) character and the expediency of a systematic approach to creating network educational spaces for training teachers of engineering education for pupils.

3. Materials and methods

The methodological approach to defining the organizational and pedagogical conditions of network training of teachers of school engineering education is based on a comprehensive analysis of local and foreign experience in networked training teachers of engineering education of pupils and conceptual solutions in the field of dealing with training such a teacher.

The objects of the research are the potentials of educational organizations, the integration of which creates the basis for creating a networked educational space for training teachers of engineering education for pupils.

The materials for the study were statistical data of employers' expert assessments and self-assessments of students in the field of conditions of school specialized engineering education. The received materials were processed with the use of classical scientific research methods: descriptive, analytical, tabular, statistical, complex, comparison methods.

The analysis of the results of the pupils' self-assessment of the intentions and conditions for choosing an engineering profile of education or additional engineering education outside school and the estimation of the real conditions and deficiencies in the organization of specialized education of schoolchildren made by school principals has been carried out. Relying on this analysis, a hypothesis has been made, it considers the idea of possibilities to create effective conditions for the network training of teachers of engineering education for pupils based on the integration of a pedagogical university, an engineering university, a general education school with specialized or additional training for schoolchildren and the organization of additional engineering education for schoolchildren.

The authors of the study have analyzed the local and foreign experience in solving the problems of training teachers of engineering training for pupils. During the analysis the absence of a systematic study aimed at identification of the conditions of network training of teachers of school engineering training has been revealed. As a result of the analysis, organizational and pedagogical conditions for network training of teachers of school engineering education have been substantiated and formulated, their expert assessment has been carried out by the representatives of the employer - secondary school headmasters and heads of technological clusters.

4. Research results

4.1. Dynamics of students' interest in engineering training profiles

A specially developed questionnaire has been used to identify the attitude of 10th grade students of a secondary school to the possibility of acquiring the basics of engineering knowledge. The key questions of the questionnaire are aimed at identifying the needs of pupils in the field of specialized engineering training and the real conditions of their implementation. The study had been conducted for five years, starting in 2016. The survey was conducted in 2016, 2018 and 2020. In total, 900 students of the 10th grade of secondary schools in Krasnoyarsk Territory and the city of Krasnoyarsk took part in the survey (300 people each year). The poll was anonymous. The results of the survey will be presented in the form of a table (table1).
Table 1. Results of revealing the attitude of pupils to engineering training.

| Basic characteristics                                      | Respondents’ answers, % |
|------------------------------------------------------------|-------------------------|
|                                                            | 2016 | 2018 | 2020 |
| Study in classes of engineering profile                    | 6%   | 8%   | 8%   |
| Want to study in classes of engineering profile but do not study yet | 5%   | 6%   | 8%   |
| Take optional courses in engineering programs              | 3%   | 10%  | 15%  |
| Want to take optional courses in engineering programs but do not study yet | 2%   | 8%   | 13%  |
| Get engineering training in additional educational programs outside school (technological clusters, etc.) | 2%   | 10%  | 15%  |
| Do not have any engineering training, do not plan to have it | 65%  | 42%  | 35%  |
| Doubt, cannot make a decision                              | 17%  | 15%  | 6%   |

The results presented in table 1 indicate that after 2016 the situation in the attitude of 10th grade students to engineering training has changed significantly. There is a growing number of pupils wishing to study in engineering classes, receiving engineering training at elective lessons and in organizations that implement additional educational programs in engineering. Such a growth is caused by the importance of engineering education for pupils as an initial, motivating stage of professional engineering education, carried out at the state level, also in terms of the implementation of the National Technology Initiative [35]. The growing interest of students in obtaining additional engineering education could not but become one of the reasons for the emergence of various forms of this education as conditions that provide opportunities for students to satisfy such an interest. This situation requires appropriate staffing, the shortage of which is recorded in this study.

The analysis of the results of a survey of secondary school headmasters and organizations of additional engineering education has shown the shortage of teaching staff to ensure the appropriate engineering training of pupils. Heads of 80 secondary schools took part in the survey. The survey was anonymous and was conducted in 2016, 2018 and 2020. We present the results of the survey in the form of table 2.

Table 2. Characteristics of the shortage of teaching staff for engineering education of schoolchildren.

| Basic characteristics                                      | Respondents’ answers, % |
|------------------------------------------------------------|-------------------------|
|                                                            | 2016 | 2018 | 2020 |
| The school has an engineering class                         | 2.5% | 2.5% | 5.0% |
| The school implements optional engineering training for students | 5.0% | 12.5% | 20.0% |
Students have the opportunity to study in the structure of additional engineering education outside the school.

| Students have the opportunity to study in the structure of additional engineering education outside the school | 7.5% | 10.0% | 15.0% |
| Engineering training of students at school is carried out by a specially trained teacher | 0.0% | 2.5% | 5.0% |
| Engineering training of students at school is carried out by subject teachers (teacher of mathematics, physics or computer science) | 7.5% | 12.5% | 20.0% |
| There is no sufficient material and technical support for the implementation of specialized education at school | 75.0% | 75.0% | 70.0% |
| The school does not implement or plan to implement additional engineering education for students | 45.0% | 40.0% | 30.0% |

The analysis of the results of the survey shows that over the past five years, the situation with the material and technical support of schools, necessary for the implementation of engineering training of students, has practically not improved. Although in 2020 the number of general education schools offering elective engineering training for schoolchildren increased by 15% compared to 2016, most of this training in 2020 is carried out by subject teachers.

The survey data have made it possible to state that, on the one hand, there is a tendency of growing students' interest in engineering training and an increase in the number of general education schools that implement engineering education of students, and on the other hand, these schools are still not provided with qualified teachers of additional engineering education.

4.2. Organizational and pedagogical conditions

Based on the generalization of the results obtained, deficiencies in the implementation of additional engineering education for students of secondary schools have been determined:

- extremely weak provision of engineering training for schoolchildren by qualified teachers;
- extremely low level of material and technical support for school engineering training of schoolchildren.

Leveling these deficits is a long process, and it is necessary to implement engineering training for schoolchildren now. There is a need for this from the state, society and the students themselves. In such a situation, it is advisable to integrate the process of training teachers of engineering education and the process of engineering training of secondary school students.

This integration should enrich the material and technical potential of secondary schools for the implementation of engineering training for students and provide it with qualified teachers. In this regard, the subjects of integration should be the following: firstly, educational institutions that train teachers, i.e. pedagogical universities; secondly, educational institutions that train engineers and have the material and technical basis necessary for the engineering school training; thirdly, secondary schools that implement or plan to implement additional engineering training for schoolchildren; fourthly, organizations of additional engineering education for schoolchildren.

The integration of these subjects is possible in case of their network interaction. The complex use of all educational resources is possible only in a network. The networked educational space created on the basis of integration of the subjects mentioned, can be considered both an educational space for
engineering school training and an educational space for training a teacher of additional engineering education at school. Relying on this, we will determine the organizational and pedagogical conditions for implementing network training for teachers of additional school engineering education which should provide future teachers with opportunities to master both pedagogical and special engineering competencies.

Condition 1. Integration of pedagogical universities; universities training engineers; secondary schools implementing or planning to implement additional engineering training for schoolchildren; organizations of additional engineering education of schoolchildren in the networked educational space. This condition is tactical, it underlies the solution of major organizational and management issues.

Condition 2. Interaction of subjects of the networked educational space on the issues of unification and distribution of management, personnel, technological and educational resources of institutions and organizations included in this space. The innovative essence of the tasks for creating a networked educational space for training teachers of additional engineering education for schoolchildren requires from the subjects of this space collective project development results in the field of modeling and designing new training results, curricula and practices, industrial practices, technologies of learning and managing its results, etc.

Condition 3. Enrichment of the educational material (subject of students' educational activity) on the basis of the principles of biprofessionalism, modularity and variability.

The principle of biprofessionalism reflects the specifics of the requirements for the results of graduates' training - mastery of teacher's competencies in the format of the federal state educational standard requirements, the training program "Pedagogical Education" and additional competencies in the field of fundamentals of engineering education and methods of implementing additional educational programs for engineering training of students.

The principle of modularity requires structuring the educational material of theoretical and practical training in order to create a professional context focused on providing activities that result in the required competencies.

The principle of variability allows to design alternative training modules, both pedagogical and engineering. This will make it possible to design educational programs aimed at teaching people with both pedagogical and engineering education directions (people without basic pedagogical education).

Condition 4. Involvement of students in active educational activities based on the priority use of blended learning technology as a technology for combining traditional, digital and distance learning technologies.

An expert assessment was made of the prospects for the implementation of the formulated conditions, i.e. the reality of the organization and implementation of network training of teachers of additional engineering education for schoolchildren in the implementation of these conditions.

The assessment was carried out on a five-point scale:

- "1 point" - the condition is not promising;
- "2 points" - the prospects of the condition are below average;
- "3 points" - average perspective of the condition;
- "4 points" - the prospects of the condition are above average;
- "5 points" - high prospects of the condition.

The experts were 32 headmasters of secondary schools, already implementing additional engineering education in this or that way, and those who plan to implement it in the near future. These headmasters, on the one hand, are real employers for teachers of additional engineering education, and on the other hand, they are potential subjects of the networked educational space for training such teachers. The results of this assessment are presented in the form of a table (table 3).
Table 3. Results of an expert assessment of the organizational and pedagogical conditions of network training.

| Conditions | 1 point | 2 points | 3 points | 4 points | 5 points |
|------------|---------|----------|----------|----------|----------|
| 1          | 0       | 2        | 11       | 16       | 3        |
| 2          | 0       | 2        | 11       | 15       | 4        |
| 3          | 0       | 1        | 7        | 17       | 7        |
| 4          | 0       | 0        | 10       | 15       | 7        |

The analysis of the results given above has shown that none of the experts considers these conditions unpromising. Less than 50% of experts have rated the outlook for these conditions as medium. "Condition 1" and "Condition 2" have been rated high and above average by 59% of experts; Condition 3 — by 75% of experts; 'Condition 4' — by 69% of experts.

Based on the complex analysis of publications by local and foreign scientists on school engineering education and the training of teachers for its implementation, as well as the experience of organizing such education in schools and the students' attitude to the possibility of getting additional engineering education, the approach to create a single network educational space for engineering education of schoolchildren and training teachers for its implementation has been proposed. According to this approach, the following subjects that form the networked educational space are determined: pedagogical universities; universities training engineers; secondary schools that are implementing or planning to implement additional school engineering training; organization of additional school engineering education. The networked educational space with the subjects listed above can be considered as a single networked educational space for engineering school education and the training of teachers for implementing such education. The main organizational and pedagogical conditions under which it is possible to implement the network training of teachers of engineering education of schoolchildren are formulated. An expert assessment of these conditions has been carried out. The majority of experts presented by headmasters of secondary schools highly and above average assessed the prospects of the proposed organizational and pedagogical conditions for the implementation of network training of teachers of additional school engineering education.

5. Conclusion
It is established that in recent years there has been a growing interest of pupils in additional engineering education, as well as the number of schools that implement this education in one form or another. Classes with students, as a rule, are conducted by subject teachers. The demand for teachers of additional engineering education for schoolchildren is growing every year.

For the successful training of teachers of engineering school education, it is advisable to use network learning; to ensure the effectiveness of its implementation, it is necessary to create appropriate organizational and pedagogical conditions. It is advisable to create a networked educational space in which it is possible to implement both additional school engineering education and teachers training needed for such education.

Networked training of teachers can be implemented according to educational programs that offer alternative educational technologies for students both with pedagogical education and for students with engineering education and without pedagogical education.

The proposed approach to creating a networked educational space can be implemented both at the level of training bachelors and masters - teachers of engineering school education.

The obtained results can be improved due to a more detailed study of the composition of the competencies of a teacher of school engineering education and the principles of integrating the potentials of organizations that form a networked educational space.
References
[1] Strategy of innovative development of the Russian Federation till 2020 (approved by the decree of the Government of the Russian Federation, December 8 2011 No 2227-p)
[2] Strategic initiative “New model of the system of additional education” (approved by the President of the Russian Federation on May 27, 2015)
[3] Isaev A V, Gonik I L and Iaseva L A 2018 Urgent problems of vocational education 3(18) 44-7
[4] Grigoriev D V 2016 Educational work at school 2-3 19-25
[5] Soloviev A N Automobile Road Infrastructure 1(11)
[6] Vossen T E, Henze I, Rippe R C A., Van Driel J H and De Vries M J 2018 International Journal of Science Education 40(13) 1629-52
[7] Hudson P, English L D and Dawes L 2009 Australasian Journal of Engineering Education 15(3) 165-74
[8] Koh J H L 2019 Int J of Sci and Math Educ 17 1195-212
[9] Mishina T O and Konyushenko S M 2017 Scientific research: theory, methodology and practice. Collection of materials of the III Int. scientific and practical conf. (ChEbkays: CNS «Intaktiviy plyus») p 137-9
[10] Sopin V I and Varkovetskaya G N 2013 Man and Education 4(37) 43-9
[11] Kukreti A R and Broering J 2019 Education Sciences 9(1)
[12] Graskin S S and Graskina E E 201 School Headmaster 2 45-9
[13] Strizhak A E, Slipukhina I A, Polyhun N I and Chernetsky I S 2017 Information technology and teaching tools 62(6) 16-33
[14] Kelley T R and Knowles J G 2016 IJ STEM Ed 3
[15] Kuen-Yi L, Hsien-Sheng H, Williams P J and Yu-Han C 2020 Research in Science & Technological Education 38(1) 1-18
[16] Leung A 2019 Int J of Sci and Math Educ 17 1339-58
[17] Nadelson Louis S and Seifert Anne L 2017 The Journal of Educational Research 110(3) 221-3
[18] Radloff J and Guzey S 2016 Journal of Science Education and Technology 25 759-74
[19] Grigoriev S G and Mikhailova N N 2017 EDexpert Journal
[20] Ward L, Lyden S, Fitzallen N and León de la Barra B 2015 Australasian Journal of Engineering Education 20(2) 145-56
[21] Ruhf R J, Jenness M and Oppliger D 2015 A Summary of a Panel Presentation at the American Evaluation Association Evaluation 2015 Annual Conference (Chicago)
[22] Ruhf R J, Jenness M and Oppliger D 2015 A Summary of a Panel Presentation at the American Evaluation Association Evaluation 2015 Annual Conference (Chicago)
[23] Neumann K, Kind V and Harms U 2019 International Journal of Science Education 41(7) 847-61
[24] Shernoff David J, Sinha S, Bressler Denise M and Ginsburg L 2017 International Journal of STEM Education 4 13
[25] Neumann K, Kind V and Harms U 2019 International Journal of Science Education 41(7) 847-61
[26] Zolotaryova A V 2017 Yaroslavl Pedagogical Bulletin 1 21-8
[27] Kotlyarova I O and Potapova M V 2019 Bulletin of SUSU. Series “Education. Pedagogical Sciences ” 11(4) 21-9
[28] Utley J, Ivey T, Hammad R and High K 2019 School Science and Mathematics
[29] Neborskiy E V 2017 Problems of modern education 4 84-93
[30] Nemirovsky M V 2019 Bulletin of the Surgut State Pedagogical University 2 191-6
[31] Sukhanova E A and Zobolina A A 2017 Pedagogical image 2(35) 77-85
[32] Cheryomukhin P S and Shumeiko A A 2017 Successes of modern science and education 2 143-9
[33] Vikman V V 2018 Scientific notes 2(46)
[34] Demtsura S S Networking in education 2017 Academy of professional education 3 7-10
[35] Kurbyko Z S and Gurtovaya E Yu 2017 Traditions and innovations in pedagogical education
Collection of scientific papers of the III International round table 251-6
[36] Chernova I P, Osipova S I, Gafurova N V and Lyakh V I 2012 Higher education today 8 10-6
[37] National technological initiative http://www.nti2035.ru/nti/