Developing pre-vocational profile training in the system of continuous engineering and technological education

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Abstract. The article defines the role and place of pre-vocational profile training in the system of continuous engineering and technological education by analyzing research literature statistical data and the existing experience in building such a training system. The authors consider major tendencies and highlight achievements and current issues. Among hindering factors, the authors name low social status of the engineer, insufficient financial support, absence of individual-oriented approach in career guidance, lack of high-qualified personnel. Studying measures taken to develop schoolers’ interest towards engineering activities and statistical data on secondary general and supplementary education in the recent years allow the authors to infer a generally upward trend. This trend has been achieved thanks to realization of well-targeted state programmes, based on the principles of mobility, integrity, consistency, flexibility, diversification, proactive and individualized training. Tackling the issues of engineering and technological training means its stage-by-stage realization, utilizing effective education technologies and continuity of education programmes.

1. Introduction

The significance of scientific, engineering and technological development, being the key factors for the economy’s growth and increasing competitiveness, highlights the issue of forming highly qualified scientific and engineering workforce capacity as well as establishing an effective nation-wide innovative system. Therefore, scholars single out spending on research and development and on quality of human resources – mostly engineering employees and researchers [1], who are trained within the vocational training system – among other major factors.

Today a rather paradoxical situation has arisen in Russia: while having quite a large number of experts trained in engineering and technical specialties and fields of study (both within the intermediate vocational education and the higher education systems; according to the Global Innovation Index, in 2019 Russia was ranked quite highly – 13th – in the number of higher education graduates in the fields of science and engineering (those highly demanded by the Russian economy), besting many economically-developed countries), employers still say there is an urgent need for engineering employees and the pace of the country’s technical and technological development is apparently smaller than the desired one. This controversy is definitely a systemic issue that can be solved through independent solutions and measures.

One of the most crucial elements of the science and technological environment is the sci-tech educational environment, which can be viewed as a particular reality, a complex of intentionally designed conditions which presence and usage promote formation and development of personal qualities.
suitable for engineering activities. Educational institutions of primary and supplementary kind have been working in this direction for a couple of years. In this regard assessing the level reached, determining existing correlations and development issues in vocational training at the stage of school (secondary level) education seems to be scientifically and practically promising.

2. Materials and methods
The theoretical and methodological basis of the present research lies in the theory of personality and activity – the idea of orienting basis of an action. Statements about patterns in organizing training for professional activity, theoretical foundations for informatization in the continuous professional training, functioning of the educational and information technologies (developed by P Ya Galperin, V V Davydov, N E Astafyev, V G Razumovskiy, N K Solopova, M S Chvanova, A L Denisova, V A Slavtsonin, O Yu Knyazkina and others) were also found significant.

Foreign researchers, such as R Dave (India), D Kidd (Canada) [2] and others, also contributed greatly to the development of continuous education theory.

Russian authors, such as I G Berdnikov, G N Tarasova, V I Stolbov, N P Bakharev, V V Schipanov, Yu K Chernov, A N Yarygin and others, considered theoretical and practical problems of the continuous vocational education. However, pre-vocational profile training within the continuous engineering and technological education, determining its systemic factors and trends in its organization, as well as determining the results achieved, were not the primary concern in their research.

Choice of certain research methods is determined by its goal and tasks. The authors implemented theoretical methods (analysis and synthesis, comparison, historical analogy, generalization, modeling, systemic approach) as well as empirical ones: analyzing the documentation, studying and generalizing operational experience of a continuous vocational training organization, the method of statistical measures (including methods of absolute, relative and average values), methods of data visualization.

3. Results
When addressing the Federal Assembly on January 15, 2020, V.V. Putin highlights “one’s passion for profession, creativity” which “is formed in one’s youth” [3], as a key condition for the younger generation to be involved in modernization processes, creating high-tech industries and forming the digital economy.

So far, the accumulated experience allows us to single out the following stages in training high-qualified experts via the national system of continuous engineering education, which is available for all children starting from pre-school age:

- Getting acquainted with elements of design in a pre-school educational facility (developing fine motor dexterity, spatial awareness and accurate color perception; trips to schools; participation in contests, exhibitions; consulting within joint classes on modeling with primary schoolers, preschoolers and others).
- Within the framework of primary general education – acquiring general understanding of technology, basic design and programming skills (solving design, creative engineering and technological problems when introducing robotics, for instance, to learners’ extracurricular activities along with clubs of supplementary education, holding robotics lessons integrated with subjects like Mathematics, Computer Science, Science, Foreign language or Russian language). At this stage inviting experts to extracurricular career-guidance events and organizing field trips to enterprises with engineering specialties appear to be among the most efficient forms.
- At the stage of basic general education - forming the basics of engineering and innovative mentality (professional career fairs, festivals, exhibitions, etc.).
- At the stage of secondary general education when cooperating with higher education institutions – advanced profile training in the fields of electronics, prototyping, mechatronics and robotics.
- At the stage of secondary vocational education – receiving vocational training within the secondary vocational education programmes. This stage presumably involves carrying out
engineering and research projects, participation in skill contests and events held by universities, enterprises and organizations: professional skill contests, chain projects like “Your step into the future”, elective courses such as “The profession is an engineer”, etc.

- Finally, receiving higher engineering education is defined as the fifth stage.

Year 2015 saw a milestone in evolution of this system, when vocational training of engineers was defined as an essential condition for the country's economic development. With large-scale projects being realized, we can now acknowledge certain achievements: a structure of higher engineering education has been formed, adequately to current requirements of the innovative economy; training of a significant number of future engineers is financed from federal budget resources; mechanisms for admission and education of employer-sponsored students has been optimized; various competitions and skill contests are held, which – on the one hand – allows us to boost professional commitment of the trainees, and – on the other hand – makes talented and promising young experts stand out; the grant system for those training in engineering fields has been improved; cooperation with core businesses and organizations is growing, etc [4].

Rethinking contents and technology of engineering training in technical universities is bound to affect development of pre-vocational profile training in general education schools, where (provided the learning and extracurricular processes are carried out well enough) learners can initially grow interested in the field of study and develop those metadisciplinary educational competences, that would allow them to enter a university, study there successfully and – finally – meet the requirements for modern production and R&D activities.

One of the directions such activities took has become the formation of profile classes in general education schools. These profile classes are meant to provide advanced training for corresponding core ("profile") subjects (table 1).

**Table 1.** Advanced training for subjects in state and municipal general education institutions that carry out education within the primary, basic general and secondary general education programmes [5].

| Indicator name                        | Primary school programmes (grades 1-4) | Basic general (compulsory) education programmes (grades 5-9) | Secondary general education programmes (grades 10-11) |
|---------------------------------------|---------------------------------------|---------------------------------------------------------------|-----------------------------------------------------|
| Number of students undergoing advanced training for subjects (not less than 1) | 251 083                              | 824 157                                                      | 226 946                                             |
| Including those trained within profiles: Arts and humanities | 186 891                              | 464 671                                                      | 89 131                                              |
| Science                               | 7 259                                | 72 760                                                       | 33 032                                              |
| Social and economic studies           | 1 342                                | 16 314                                                      | 23 519                                              |
| Technology                            | 1 089                                | 13 854                                                      | 7 642                                               |
| **Engineering**                       | **2 622**                            | **17 260**                                                  | **6 752**                                           |
| Agriculture                           | 748                                  | 3 949                                                       | 1 485                                               |
| Mathematics                           | 15 295                               | 136 611                                                     | 33 458                                              |
| Others                                | 27 826                               | 95 921                                                      | 42 387                                              |

Considering the number of school students who are engaged in advanced training in Technology and Engineering fields, we see quite a positive tendency. In the time period under consideration the increase in number of learners in Engineering and Technology subjects constituted 55% whereas the total number of learners with advanced programmes in particular subjects saw 13% increase. However, this growth has been achieved mostly by a significant increase in the number of students who study Technology, and Engineering profilization (which would be more preferable) is far from being the leading one. Among 1-9 grade schoolers, the number of those engaged in advanced training for Engineering profile decreased in absolute (approx. 12% decrease) as well as relative values. It is only with high-schoolers
(10-11 grades) that we see a growth in the number of Engineering profile (though the number remained the same in relative terms). As far as high-schoolers (10-11 grades) are concerned, we point out the following positive trend: the number of those engaged in advanced training for Engineering subjects shows a somewhat larger growth in comparison to a total growth in the number of 10-11-grade students. In 2018 the growth in the number of students choosing Engineering for their profile field of study constituted a bit more than 15% compared to 2016 numbers, while the total number of 10-11-grade schoolers grew just by 5%. Nevertheless, it is worth mentioning that, when compared to other profiles, the Engineering one ranks next-to-last in terms of the number of students, leaving only the agricultural profile behind.

To a certain extent this absence of a prominent upward trend in pre-vocational engineering education within the mainstream education programmes of general, basic general and secondary education can be linked to the problems of financial and logistical support, lack of appropriate labs and equipment in schools, making it hard to hold modern-level classes on Engineering. Low prestige of Engineering activity as a future career choice is also one of the major factors. Thus, in recent years schools have been developing their cooperation with vocational education institutions. In particular, such networking cooperation allows schools to tackle problems of resource allocation at a higher level, which promotes schoolers’ interest. Moreover, an even more apparent effect manifests itself when schools cooperate with core businesses as well as vocational education institutions [6]. There is an opinion that fruitful results of career-guidance work can be achieved with a maximum number of interacting agents involved, which promotes interest to engineering sprouting among schoolers [7, 123].

In this regard, the data on supplementary child education look quite promising: according to federal statistical studies, supplementary education is gaining more and more impact on developing children’s interest for engineering activities and involving children in engineering creativity.

**Table 2.** Realization of engineering programmes in supplementary education for children.

| Indicators                                                   | Year       |
|--------------------------------------------------------------|------------|
| Total number of organizations realizing supplementary education programmes | 2016      |
|                                                             |            |
| including: those realizing engineering education programmes | 44 918    |
|                                                             | 54 932     |
|                                                             | 58 296     |
| Total number of students being trained                       | 2016      |
| including: those trained within engineering education programmes | 13 425   |
|                                                             | 16 894     |
|                                                             | 18 772     |
|                                                             | 22 163 593 |
|                                                             | 25 137 964 |
|                                                             | 26 489 217 |
|                                                             | 1 548 712  |
|                                                             | 907 003    |
|                                                             | 2 120 151  |

According to the data presented in table 2, supplementary education of the engineering direction is developing at a more dynamic pace than all the other directions. Within the time span considered the number of organizations realizing supplementary education programmes in Engineering has grown by more than 5000 units, and the number of trainees in these organizations has grown by 36.9%. The majority of trainees (87%) are children between 7 and 17 years of age. It is worth mentioning, though, that children of the senior school age (15-17 y.o.) are the smallest group. This apparently indicates that in general senior schoolers have already made their decisions on their future career directions and their choice was mostly against engineering and technology fields. In this regard an earlier start of pre-vocational training of engineering kind increases the chances for interest towards such kind of activity to be reinforced.

Among problems demanding our attention there is one concerning organization and further development of engineering activities by learners in rural areas. Considering the number of trainees as an indicator of schoolers’ interest, we can conclude that children living in rural areas exhibit significantly smaller interest than those living in urban areas (see table 3).
Table 3. Realization of engineering programmes of supplementary education in urban and rural areas.

| Area | Number of organizations realizing supplementary education programmes in engineering | Number of trainees in engineering supplementary education programmes (aged 7–17) | Number of learners in mainstream education programmes of primary, basic general and secondary general education |
|------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| urban | 12 485                                                                          | 1 563 653                                                                       | 12 058 763                                                                                        |
| rural | 6 287                                                                           | 288 959                                                                         | 3 881 619                                                                                        |

As the data in table 3 shows, while rural areas do relatively well – and even better than urban areas – in terms of the number of supplementary education organizations per 10000 learners in general education (mainstream) schools, the difference in numbers of trainees is rather significant. Proportion of urban schoolers involved in engineering programmes of supplementary education is almost 13% of the total number of students in general education schools, whereas this figure for rural areas is merely 7.5%.

An important factor for more active involvement of schoolers into engineering activities is creating a wide network of associations (clubs) and scientific societies in supplementary education institutions, which leads to higher availability of this form of work with schoolers. In this regard it is particularly interesting to look into the network of clubs and scientific societies in supplementary education organizations (table 4). The data indicates that with the total number of science clubs and societies decreasing, the number of structural units (subdivisions) realizing programmes connected with engineering creativity has risen by 5816 (15%) for the previous 2 years.

Table 4. Data on the network of science associations and societies in supplementary education organizations for children (state and municipal institutions) (as in the end of 2018) [5, 8].

| Type or institution | Number of associations | Including those of engineering creativity | Number of scientific societies |
|---------------------|------------------------|------------------------------------------|--------------------------------|
|                     | 2016 | 2018 | 2016 | 2018 | 2016 | 2018 |
| Total               | 574 042 | 546 338 | 37 070 | 42 886 | 3 028 | 4 008 |
| including: centres | 229 346 | 227 847 | 23 086 | 26 272 | 553 | 483 |
| palaces             | 45 422 | 48 043 | 3 015 | 3 991 | 2 201 | 2 957 |
| Clubs (youth centres) | 73 393 | 70 077 | 5 635 | 6 211 | 186 | 150 |
| stations            | 19 472 | 18 737 | 5 222 | 6 205 | 58 | 76 |
| schools             | 87 822 | 96 683 | 98 | 148 | 22 | 254 |

The development of engineering direction in supplementary education for children in Russia is promoted through creation of a network of core facilities centres that are designed to realize projects requiring expensive equipment (technoparks for children, youth innovative-creativity centres, etc.). Projects that are aimed at creating digital education environment, innovation centres in universities, etc., are prioritized in realization. We see a significant growth in the number of engineering and science clubs utilizing technoparks, which are notable for their problem-project approach.

In the nearest future our country will increase the number of student places available in supplementary education system by around 1 mln via extending the network of technoparks for children, quantoriums, information, science and arts development centres. Support centres for gifted children will appear in every region of the country.

4. Discussion

Current issues of training engineering experts include such widely-discussed ones as: poor training quality, salary expectations of young engineering specialists being inadequate to the real rates of
remuneration, hard working conditions, outdated equipment used and many others. In this regard the question of commitment to engineering activities, professional involvement of those choosing engineering specialties as their future profession, fades into insignificance. The situation is getting even worse with a well-organized Soviet-time system of vocational guidance (which used to contribute greatly to professional motivation) being neglected for so many years.

High social demand for vocational – mostly higher – education and a relatively large number of state-funded student places in engineering directions of training have led to a large number of school graduates entering universities while lacking the very passion for engineering activities. Surveys among school graduates show that the majority of those enrolling in vocational education institutions do lack not only expertise in STEM sciences (a very important aspect in training an engineer), but also the desire to gain and develop such expertise in the future [7, 124]. This situation at the stage of entering a university has yet to manifest itself in future training results, quality of (professional) competence acquisition, future employment prospects and professional performance.

One of the possible solutions to this problem of training high-qualified engineering personnel is to intensify working with schoolers, developing their interest towards engineering from early stages and involving them in project activities. We need to “complete” the educational chain at the secondary stage with effective links, which would allow profession-motivated youngsters to make a proper choice when deciding upon their vocational training routes. In this regard one can hardly disagree with the opinion of academician O L Figovskiy – a well-known Israeli expert in innovation studies and inventor: “In order to develop high-tech solutions one needs to thoroughly create scientific and engineering environment beginning with schoolers and students. Neither can one buy, import or adopt such environment into the indigenous “soil”, nor can one expect massive return of compatriot scientists back from foreign countries. Care for the scientific environment, for preservation and further development of intelligence and culture in its society should lie in the foundation of any governmental concept for scientific and technological development of the country” [9].

5. Conclusion
For a long time, low social status of the engineer, insufficient financial support, absence of individual-oriented approach in career guidance, lack of high-qualified personnel was the hindering factors for establishing pre-vocational profile training within the system of continuous engineering and technological education. However, in recent years some significant results have been achieved due to realization of well-targeted state programmes, based on the principles of mobility, integrity, consistency, flexibility, diversification, proactive and individualized training. Tackling the issues of engineering and technological training means its stage-by-stage realization, utilizing effective education technologies and continuity of education programmes.

In order to establish an effective system for continuous training of high-qualified engineering personnel that has both basic fundamental knowledge and professional competences required to solve priority tasks of nation-wide scale, we need to allow for systemic work of educational institutions alongside with governmental organizations of all levels, scientific organizations and businesses. Involving as many participants as possible into this work, cooperative development and realization of programmes for orienting the young towards the most sought-after professions will ensure success. This will not only help to improve training quality but also fuel schoolers’ motivation for self-realization and professional identity.

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