Development of individual learning paths system in engineering education

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I. INTRODUCTION. TECHNOLOGICAL PROGRESS; CHALLENGES AND FACTORS THAT CHANGE THE EDUCATIONAL SYSTEM.

The formation of a new economic and industrial order invariably entails changes in most areas of human life. Science and education are no exception in this regard – the transition of industry to the "industry 4.0" model and the emergence of the "service economy" model in a number of sectors of the economy have created a new environment for cooperation of all participants in the process: universities, research centers, industrial enterprises, and business partners. The key characteristics of the new interaction system are:

- formation and implementation of complex scientific and technical programs in interests of the industry;
- development of interdisciplinary approaches;
- application of modern management technologies that are understood by all participants in the process of knowledge, goods, or services production;
- widespread implementation of IT technologies, including the use of artificial intelligence, the Internet of things, AR/VR, computer vision, etc.

Factors outlined above have created new requirements not only for the competence of future engineers, but also for the system of their training. Whereas before the industry formulated the tasks and the university formed the proposal, now it is a bilateral view and joint work based on the analysis of future markets in various areas. The university should take a proactive position and form integrated programs along with the industry for the entire product life cycle – the technology and its service model with predicted operation, as well as personnel capable of implementing, operating, and developing this technology. Moreover, we are talking about training line specialists and managers of all levels, as well as entire project teams. A logical result of the maximal practical orientation of an engineer's education is the individualization of his educational path – beyond high-quality basic training, an engineer must be trained in the hard and soft skills that he will require in his work, since the industry today expresses the need for "handpicked" specialists who are ready to solve specific tasks.

We are implementing this philosophy at Moscow Aviation Institute.

II. REVIEW OF INTERNATIONAL EXPERIENCE; EXAMPLES OF SUCCESSFUL NEW APPROACHES TO ENGINEERING EDUCATION.

Today, an extremely competitive environment has been established in the field of education around the world.

Abstract— This Innovative Practice Full Paper presents development of individual learning paths system in engineering education using the example of the Moscow Aviation Institute (MAI). A set of technological approaches, called Industry 4.0, appeared about 10 years ago. The modern technological era is inextricably linked with project management, integrated programs and research, IT solutions, including the use of artificial intelligence in all areas of activity, as well as with interdisciplinary approaches. Therefore, a new interactive environment of education and science is emerging among universities, research centers, industry and enterprises.

The new environment puts forward new personnel training requirements. Taking into account the explosive pace of development and introduction of technologies, today advanced engineering universities together with the industry form a real-time forecast of personnel needs and the map of competencies of the future. The system of engineering education is based on the principles of individualization of educational and professional paths, practical orientation, development of soft skills, mobility. Personal education path - it's not just a student's choice, but it's very labor-intensive, properly designed work of educational institution, where not only the whole university is engaged, but also its partner employers.

The Moscow Aviation Institute is implementing the integrated concept of "personalization". The peculiarity of individual learning path at the university is that at the first stage of its formation the potential direction and place of professional activity are determined, the necessary competencies to be acquired are accounted, and an individual development plan is formed. The holders of the typical student paths at Moscow Aviation Institute are the internal employer-divisions - Competency Centers, which have become the integrators of forward-looking technologies and are conducting a large number of projects commissioned by the industry. Also, the MAI Competence Centers help students to form the path to the professions in demand in the future, providing an opportunity for practice and mastering additional engineering, technological and managerial competences.

Students comprehend their personal learning pathways at three levels. First at the level of the educational program through the identification of elective courses and places of practice after consultation with the tutor. Second, at the academic level, they master the chapters and topics that are the most relevant to student's current or future professional activity. Finally, a committed student can use internships, hackathons, Academic exchange and many other ways to form a unique path, outside the formal learning process.

At the same time, an important task is the formation of healthy competition between students in obtaining access to certain modules of individual path.

Keywords— individual learning path, individual development plan, competency center, map of competencies, Industry 4.0, forecast of personnel needs
Leading universities have implemented different strategies for the training of engineers [1]. One of the most interesting cases, from our point of view, is the MIT NEET (New Engineering Education Transformation) [2] program, which is based on 4 basic principles of engineer training:

1. The principle of "New Machines and Systems" involves preparing students to work with complex machines and systems that are interconnected and form part of larger systems that have a high level of autonomy.

2. The principle of "Makers and Discoverers" is based on the ability of students to act as both creators and researchers, and the fundamental knowledge obtained at the university should serve as a strong basis for this. NEET provides flexibility in selecting projects that meet the interests of students.

3. The principle of "The Way Our Students Learn Best" is built around the idea of learning in ways that are most appropriate for students and engaging them in their own learning.

4. The "NEET Ways of Thinking" principle is designed specifically to help students develop in an atmosphere of constant progress. NEET has identified 12 key ways of thinking:

   • ability to learn;
   • creation;
   • research;
   • interpersonal skills;
   • personal qualities;
   • creative thinking;
   • systems thinking;
   • critical and metacognitive thinking;
   • analytical thinking;
   • computer thinking;
   • experimental thinking;
   • humanistic thinking [2].

Another vivid example of restructuring its own educational process is the approach of TU Delft [3], which determined that higher engineering education should evolve not only to benefit from innovation, but also to meet the wishes and capabilities of modern students and employers. The University emphasizes the need to learn how to predict future changes in order to train engineers that are in demand in the modern world:

   • "design engineers" who are technically competent in creating, improving and operating machines and systems of the future;
   • "engineering scientists" who choose an academic career;
   • "holistic engineers" who are able to make important decisions in a critical situation.

In addition, TU Delft highlights the most important ability of engineers of the future – a positive attitude towards lifelong learning. In the new economic order, it is not the knowledge itself that matters, but how the engineer acquires knowledge and is able to apply it in practice.

The role of specialists who combine deep knowledge and skills in a particular field with interdisciplinary skills is becoming increasingly important. To train such specialists, appropriate changes are needed in the curricula, pedagogy, and training of teaching staff [4].

In order for our new educational environment to meet the stated principles, modern students are involved in research and project activities, and practical research serves to accumulate experience and the ability to work in various teams. The role of a professor in this approach is to be a "mentor" rather than a "teacher". At the same time, the experience gained is more appropriate for future professional tasks. The University of California, Berkeley, for example, offers an immersion in so-called "experiential design", where students choose their own methods of working on practical projects.

Georgia Tech has developed the Vertically Integrated Projects Program in which interdisciplinary teams of students – from sophomores to PhDs – function as project teams in real-world industry and work on long-term collaborative projects.

The orientation of students to the projects of research teams, industrial and business partners inevitably leads to the individualization of the student's educational needs [5].

With all the variety of different approaches used by universities in building a system of engineering training, there is no universal technology. Educational institutions face the task of finding the best approach for themselves, taking into account experience of colleagues from other universities, the specifics of training areas and trends in the development of high-tech markets.

III. FORMING AN INDIVIDUAL LEARNING PATHS SYSTEM FOR ENGINEERS. PREDICTING PERSONNEL NEEDS AND TECHNOLOGICAL DEVELOPMENT; INTERACTING WITH THE INDUSTRY; FORMING RELEVANT PRACTICE-ORIENTED PROGRAMS. THE SFSMB SYSTEM.

Modern industry requires not only good basic knowledge, command of information technology and the ability to implement it, but also soft skills – creativity, leadership, the ability to comprehensively set and solve problems, etc. The examples mentioned in Chapter II show us that majority of foreign universities put an important emphasis on precisely this aspect. One of the most important requirements today is the need to train personnel for future markets and projects – leaders of digital transformation of industries that are at different levels of their development [6].

Experience in managing large high-tech industrial organizations shows that the most effective project teams involved in the development of complex technological systems are formed of professionals with basic engineering training. Thus, all project participants, including managers, are "grown" from engineers who know the specifics of the work. At the same time, managers without knowledge of engineering, as a rule, demonstrate a tendency to look for standardized solutions without taking into account the specifics of individual tasks.

In such conditions, it is impossible to effectively meet the personnel needs of industrial partners, which involve training of specialists in any area of expertise required by companies to solve innovative problems, without creating within the university an environment for the development of talents that
will determine the role of future engineers in future project teams and, in a broad sense, throughout their career path. To solve this problem, we have developed the SFSMB system – additional paths embedded in the individual learning pathways of each student. The initialism SFSMB if formed from the names of the following additional paths:

- Engineer in a Specific Field (SF);
- Scientist in Engineering (S);
- Manager in Engineering (M);
- Businessman in Innovation (B).

The peculiarity of the system is that university students receive an additional wide range of practical skills, the composition of which is determined by the role from the SFSMB system that a student chooses as his main one. Similar approaches to higher education models are used, for example, by such strong universities as MIT (NEET) and TU Delft (for more details see Chapter 2). It helps to prepare not only qualified engineers, but also specialists who are able to solve cross-industry and organizational issues, to make decisions, to research and to manage. It is important to keep in mind that the process of determining the role by a student is gradual, occurring with the participation of mentors during the first years of training. For students at various stages of their own career goal setting, the determination period can range from 1 to 4 years. This is also due to the fact that a large portion of practical activities related to the chosen roles falls on the master's degree period. While the majority of undergraduate students are high-quality line or basic engineers, IT specialists, etc., MAI master's degree graduates claim major positions in industry programs.

Among the key structural units carrying out the transformation of MAI are centers of excellence. These are divisions of the University that organize commercialized R&D activities through the implementation of joint projects with industrial partners. The effectiveness of such units of the world's leading universities involving students directly in practice and research is beyond doubt. MAI students get the opportunity to understand what are they going to work with much better, to gain practical experience, to understand teamwork, and better adjust their further educational process with the knowledge and experience gained in the centers of excellence. Digital transformation imposes fundamentally new requirements for the speed of a technology transitioning from the stage of basic research to the stage of implementation. Due to the fact that the focus of the centers of excellence is Technology Readiness Level (TRL) 4-6 [7], their activities are aimed at overcoming this so-called "valley of death" with promising technologies and their implementation into the real economy.

The functions of the centers of excellence also include technologization of industry requests to MAI, personnel training, the formation and implementation of comprehensive scientific and technical programs in the interests of the industry, the development of multidisciplinary approaches among others.

The place of the centers of excellence in the system of working with innovations at MAI is shown in Figure 1.

![Figure 1. The position of the centers of excellence in the MAI innovations implementation system](image-url)

The MAI centers of excellence are formed in accordance with current technological trends that determine the main tendencies in industrial development. Their list is regularly updated, and today the centers of excellence work in the following complex areas:

- math modeling;
- engineering systems electrification;
- propulsion and power plants;
- integrated design;
- high-tech products service;
- electric rocket engines;
- unmanned aerial vehicles;
- artificial intelligence, Big Data, Internet of things;
- hypersonic technologies;
- additive technologies;
- composite structures;
- robotic technologies.

The interdisciplinarity of the environment is determined by the wide scope of the MAI centers of excellence. This is especially important because engineering knowledge is interdisciplinary, applied in a variety of areas. For example, composite structures have been introduced to sports equipment, and unmanned control systems have been introduced to maritime navigation. And the dialogue with partners and customers is based on a joint market forecast and identification of critical technologies that will determine the competitiveness of new products.

In addition, the formation of an interdisciplinary environment is facilitated by the involvement of specialists with different backgrounds. Specialists come to the centers of excellence at different stages of forming their own career – from the first year of bachelor's degree to having experience in management work at industry enterprises.

We are building the education system at MAI in such a way that every student can:
- obtain extensive basic engineering and IT knowledge with a focus on specific topics handled by teams of students and faculty members at the request of the industry;
- develop common soft skills necessary for creative work on present and future projects.

The General scheme of the MAI student paths is shown in Figure 2.

![Figure 2. The General scheme of the MAI student role paths.](image)

Additional areas of study for students include:
- for the Engineer in a Specific Field – internships at enterprises, internships at the MAI centers of excellence as part of project teams that solve tasks for enterprises, participation in professional conferences, and academic exchange programs;
- for the Scientist in Engineering – internships at scientific organizations, R&D departments of industrial organizations, and laboratories within centers of excellence engaged in in generating new knowledge and scientific foundations for breakthrough technologies;
- for the Manager in Engineering – internships at enterprises and as part of project teams at centers of excellence, training using business cases at the MAI School of Management;
- for the Businessman in Innovation – internships as part of research teams at laboratories engaged in generating new knowledge and foundations for breakthrough technologies, training using business cases at the MAI School of Management, development of their own project in a business accelerator, additional business education (MAI Business School, workshops, speeches by successful entrepreneurs, etc.).

Representatives of the excellence centers become mentors for students and prospective applicants, helping to form an understanding of the area of professional interests and possible role in the SFSMB system. Students can interact with the centers of excellence from the earliest stages of their studies at MAI, and in some cases even before entering the University. Practical experience shows that if a student, participating in the implementation of projects, clearly understands his future path while at the training stage, then his adaptation and growth as a specialist become much faster and more efficient. The earlier the student is involved in real work, the more conscious the learning process becomes. Therefore, MAI holds numerous informational and welcoming events for students and schoolchildren. The official acquaintance of students with the centers of excellence occurs in their first year in university with welcoming courses implemented into the curriculum and
visiting centers, watching their work first-hand and possibly meeting potential mentors. After that the student can sign up for practice to the chosen center of excellence, with selection of dedicated mentor. Mentor’s role is to help the student with choosing a role (which can be changed in the future) and to make a training plan for the semester:

- helps to choose an existing scientific project in which the student can take part, or helps to start the student’s own projects;
- helps to determine electives and additional courses at the university;
- helps to determine additional courses outside the university.

During the semester the student studies according to developed curriculum simultaneously working on the selected project, and the mentor accompanies the student in order to guide student’s educational and professional experience through the obstacles. The results are summed up after the semester, while mentor evaluates the student’s work. Based on the assessment results and new possible projects appearance, the further training plan is adjusted. As the result of such interaction in the centers of excellence, 95 patents and patent applications were received by MAI with the participation of the students in 2019.

The basic scheme of student’s individual learning path in MAI is presented on Figure 3.

Excellence centers serve not only as a place for forming a significant part of a student's individual training program, but also as a customer for personnel who study on individual learning paths at the University. The staffing of the centers of excellence with key specialists is based on a chain principle – at each level of management and work/training, key employees prepare a reserve from the employees/trainees at the level below. Thus, the core of the staff is formed, and each employee, in addition to performing direct duties, learns from a more experienced one. We can observe a similar approach in many world universities, for example, The University of California, Berkeley and Georgia Tech, which we discussed earlier in Chapter II, as well as the "The Enterprise program" [8] of the Michigan Technological University, where students work in large teams that organized like engineering companies, where they take on greater responsibility throughout the project they involved.

The set of further professional education programs as an element of the individual paths system (Figure 4) performs an important function in the formation of individualization of engineering education. Further professional education programs allow students studying in different basic specialties to add to their paths the acquisition of modern skills in the field of digitalization, new materials, management skills, etc.
Taking into account the fact that one of the most important skills in the modern world is the ability to manage large complex scientific and technological programs and relying on the principles of close interaction with partners from business and industry and the experience of a number of foreign universities, for example, the “Center for Engineering Paths to Innovation” (Epicenter) [9] of Leland Stanford Junior University, we opened our technological business school.

The MAI School of Management implements cross-corporate programs, similar to the MBA, for the personnel reserve of Russian corporations, in real large-scale management projects that these corporations plan to implement. The School of Management is a platform for developing product lifecycle management approaches and learning new management tools.

Students and employees of MAI who have demonstrated leadership qualities and managerial skills take part in the training and work process. Thus, students who have chosen the roles of Manager in Engineering and Businessman in Innovation and have successfully proven themselves in the course of study, take management courses that are also closely related to the real life of the industry, using current, rather than past cases. In parallel, individual projects within the School of Management framework are developed by centers of excellence. Studying at the School of Management increases students’ confidence in their professional skills, and combines the study of engineering topics with the ability to apply engineering skills to solve community problems, promotes both the ability to use an interdisciplinary systems approach and understanding the wider context and the impact of engineering on modern society.

The interaction of the School of Management with the centers of excellence, as well as inter-center interactions, form an interconnected environment where a student has opportunities to individualize their "role" path. The key characteristics of such an environment are creativity, interdisciplinarity, and a focus on solving complex problems. However, the most important characteristic to be recognized is the orientation of the described environment on innovation. Experience in managing corporate structures, universities, and numerous R&D departments shows that many teams live for a long time, but not all can maintain their state and keep introducing new products, rather than endlessly modernize outdated technologies. For those who are creative, it is important to immerse themselves in the right innovative environment, because for a creative person, a reactive environment limits growth. And if a person is focused on stability, it will be difficult for him to exist in an innovative environment.

An example of a new approach to professional development programs is the School of Service. The task of forming an effective product service model plays a key role within the framework of the PLM ideology. Based at the "High-Tech Products Service" Center of Excellence, the "Customer Service and After-Sales Service" program for leading Russian aircraft manufacturers has been launched. During the course, student groups work together with leading global experts to develop management and engineering solutions to improving operational efficiency and managing the operational costs of aviation products, study and suggest new approaches to costs optimization.

A special feature of the program is the comprehensive approach to service not only as a system for ensuring operability and condition monitoring, but as a key business process that affects the competitiveness of an object in the course of operation. The final goal of the program is to launch projects aimed at increasing the competitiveness of both
products and manufacturers on the market through a more efficient system of aircraft operation.

Another example is the joint further professional education program with COMAC (Commercial Aircraft Corporation of China), a Chinese company that develops and manufactures civil aircraft. MAI and COMAC demonstrate a vivid example of joint training and product support throughout the entire product life cycle. This example perfectly illustrates the university’s active stance in shaping industry-integrated programs. Taking into account the fact that the new Russian-Chinese wide-body long-haul aircraft relies on the use of composite materials, the "Polymer Composite Materials (PCM) in Aircraft Construction" program was developed for COMAC specialists by MAI. The implementation of the program yielded several results. First, the barrier that always occurs in international cooperation has been removed. Second, the international team began to communicate "in the same language", which made it possible to form tasks and plans more clearly, linking them to the stage of program implementation. Third, the result of this program was the formation of a specification for performing scientific and technical work in the most topical areas.

In the context of globalization, international experience and language skills are of key importance.

When creating unique educational products that include international experience, we also rely on the principle of maximal practical orientation and focus on skills that will allow graduates to immediately get involved in working on a real industrial project. Thus, together with industrial partners – the Russian corporations UAC and UEC, and the Chinese corporations COMAC and AECC – MAI and Shanghai Jiao Tong University has launched a number of joint English-medium bachelor's and master's degree programs in the areas of PLM, propulsion design, and composite materials in order to provide personnel for the international project of a wide-body aircraft. The main feature of this program was the formation of full-fledged international project teams based at both universities at the training stage.

In order to ensure the influx of quality personnel into the industry, as well as into the centers of excellence, we work with future students starting from middle school. Our communication with school students shows that they are already seeking to get practical skills and trying themselves in various areas at an early stage. To this end, we are creating an environment in the form of a children's Technology Park, school research groups and project activities, and our own school – the "MAI Pre-University". This makes it possible to identify people who are passionate at the earliest stages. Experience has shown that the earlier such a passion appears, the easier it will be to form an individual path for the student.

However, the system doesn’t inherently exclude students, who are more comfortable with taking time for making career decisions. The system itself implies the possibility of determining areas of interest at any stage of training until the start of working on the graduation project. We offer options for entering a narrow specialization during a fairly long period of education, and during this period we conduct a number of familiarization activities with the centers of excellence, including the basics of their research fields into the curriculum in early years of education. In addition, students have the opportunity to change their profiles during education, this being one of the reasons why we ensure that centers of excellence closely communicate and interact with each other.

IV. CONCLUSIONS.

The introduction of new education systems in MAI is already yielding results. In recent years the demand for graduates of our university has been steadily growing. In 2019 there were 5900+ students and graduates who received jobs at partner enterprises, which requested MAI to train specialists for their needs with only 2900+ of them in 2015. According to HeadHunter, the largest Russian recruiting aggregator, in 2019 MAI's institute "Control systems, informatics and electric power" was ranked in the 2nd place of demand of graduates among Moscow universities' IT institutes, and MAI itself took the 5th place among Moscow universities.

In the conditions of technological progress, the task of creating an efficient environment for training engineering personnel is particularly relevant. This problem can only be solved in close cooperation between educational and scientific organizations and industrial enterprises.

Leaders of the future industry grow only in the process of solving new problems. We believe that they should come to the industry with not only theoretical and soft skills, but also real experience in implementing projects in the field of new technologies and new services at centers of excellence. Then the introduction of new technologies and processes will be much faster, and the engineering university will become a true driver of industry development. This approach inevitably leads to mass individualization of the educational process. All the transformations described above are aimed at achieving this goal.

In order to solve important tasks encountered by the industry of the 21st century, we need teams of hard-working professionals who are able to set and achieve clear ambitious goals under the guidance of talented leaders. The formation of such teams is the main goal of modern engineering education.

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