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Advance Management Education for Power-Engineering and Industry of the Future

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Abstract: The objectives of this study are to substantiate the principles of advance education and the requirements for the new generation of educational programs aimed at developing competences for the design, manufacture, operation and maintenance of complex industrial systems integrated into intellectual production, environments, and robotic systems. The study included formulating a hypothesis, refining the conceptual framework, creating the necessary empirical base, reviewing the cases of world leading universities, and presenting and substantiating the main features of advance management education that meet the current challenges. A flexible modular architecture of the educational process was developed which allows making timely adjustments to the content and teaching methods to include new knowledge. The experience of testing the results obtained in consulting practice, in teaching master's degree students at Ural Federal University (Russia) and in educational projects for leaders and breakthrough teams of large energy corporations is described. The academic novelty of the results lies in the comprehensive examination of the issue of advance education, the conditions and the tools for its implementation within the framework of the proactive management methodology developed by the authors for sustainable business development in a revolutionary and changing industrial landscape.

Keywords: power engineering; industry of the future; advance education; proactive management; modular architecture; interdisciplinarity; digitalization; agility

1. Introduction

Massive changes are taking place in business, due to digitalization, artificial intelligence, smart manufacturing, systems for guaranteeing safety, reliability and environmental friendliness, energy-saving technologies, and a variety of new tools for working with consumers. Undoubtedly, connections with continuously updated information technologies will be strengthening, and breakthroughs will mostly occur at the intersection of IT, engineering, social and natural sciences [1,2]. Breakthrough technologies will continue to rapidly penetrate even the traditionally conservative sectors, radically changing the production landscape, business models and enterprise economies [3,4]. An illustration of this trend is the size of the global market for "clean" information technologies (for example, software). According to estimates of consulting companies such as IDC, CompTIA and Gartner in 2019, it will amount to $3.8–4.0 bn, and considering convergent solutions and the so-called "emerging technologies", the market can be estimated at approximately $5bn [5–7].

Smart technologies not only change the essence of competition in industries [8], but also expand the very concept of "industry"—its borders shift, and new sectors appear [9]. The main competitive advantage is no longer the products as such, but the system that connects them, and the efficiency of the smart equipment service within it [10].

The new industry (or in other words, the "industry of the future") will define new society standards, the image and infrastructure of all economy sectors in 8–10 years [11].

The authors include the following in the concept of "new industry":

1. manufacturing industry, namely its part that includes high-tech industries that are under technological modernization and digitalization;
2. Industry 4.0 that is created within the framework of the current global Industrial Revolution based on the mass introduction of the Internet of things, the industrial Internet, artificial intelligence, big data analysis, etc.;
3. the electric power industry as the material basis for a new stage of electrification, penetrating almost all modern high-performance technologies and processes through the most progressive energy carrier—electricity: this industry itself is undergoing revolutionary changes due to large-scale intellectualization (Smart grid and Smart metering), the transition to Internet energy, digital platforms, multi-agent management and the emergence of so-called active consumers. In the future, it is these consumers who will define a fundamentally new energy world with a radically different paradigm: they will manage the consumption, production, and storage of electricity; the characteristics of its availability, reliability, quality, and integration into power systems of various sizes.

It is important to emphasize that the segments of the new industry demonstrate the convergence of the electric power industry and advanced scientific and technological achievements (smart cities and green technologies, the Internet of things, digital health care and telemedicine, intelligent transport and logistics systems) [12]. The industry is likely to undergo a systemic change in the next 10 years—a transition from "generator–network–consumer" models, with a clearly defined technological and commercial infrastructure with insurmountable barriers to changing the role of a market agent, to the "atomic" distributed energy model [13,14], when a consumer can simultaneously become a generator and owner of grids, and, owing to new technologies, be a part of the technological and commercial infrastructure [15,16].

All this, to some extent, is the current reality, which affects managers, management personnel in the first place and to the greatest extent, imposing serious demands on them that are not always fully understood and clear.

New management objectives are non-linear, lack knowledge or qualified personnel, their outcomes are uncertain, and they carry various risks. Today, managers need different abilities and competencies: a broad vision and understanding of the market context (global trends), its dynamics and driving forces, mastery of tools to improve the quality of human resources and work with personnel considering completely different values and models of communication, organization of innovative processes and teamwork, entrepreneurial initiative, the ability to quickly implement innovative business models and various changes.

Big data analysis, cloud computing, the Internet of things, smart environments, machine learning, and self-learning robots—all these tools become an integral part of a manager's work [17]. But their main purpose is increasing demand in the face of rapid, often chaotic changes, acting ahead of market competitors [18]. Time is becoming a decisive factor in strategic business behavior.

Proactive management is clearly impossible without the advance training of professionals. These closely related objectives are becoming critical to successful technological breakthrough. At the same time, if certain aspects of the proactive management issue are discussed to varying degrees of depth in scientific research (mainly, the discussion is centered around the concept of "proactive management" [19,20]), the issues of advance education are virtually outside the researchers' scope.

Nevertheless, proactive management as a response to the high dynamics of the external environment has a completely different content and scale of activity (objectives) compared to what managers had to do before. The dominant management requirement is foresight and anticipation: predicting the organization's future, the changes in context, the ability to adapt systems to unexpected changes throughout the life cycle, manage their stability and ensure the transformation into a self-learning organization. The traditional functions, methods and management tools are radically changed and filled with completely different intellectual content and meaning.

The world is becoming different and is no longer described by a linear paradigm, and human intelligence is not enough to describe the complex dynamics of changes. Under such conditions, research that reflects on what is happening is at the cutting edge of the breakthrough in changing the content of the managerial paradigm, which should become flexible, opening a choice of opportunities, and, of course, aimed at the future, at proactive strategies. A manager has to become a researcher and developer: they must analyze the organization as a system and the external and internal trends and forces affecting it. They need to anticipate the changes that will occur in the near future and prepare for them in advance.

Managers will have to participate in a wide variety of studies, including:

- the identification of global trends, threats and new opportunities that they bring, and quick adaptation to changing circumstances;
- the analysis and foresight research of global, national and regional markets for technologies, capital, knowledge and competencies;
- the design and life cycle management of integrated systems with innovative characteristics: engineering, organizational, economic and socio-technical;
- finding optimal solutions, taking into account the dramatically increasing uncertainty and multi-factor risks, when managing large international projects that involve virtual teams;
- working with experts representing various fields of knowledge and practice.

A manager will first of all need to devise "learning" questions that will help all employees of the organization understand the upcoming changes [21]. Thus, consequently, in training and competency development, the emphasis is also shifted to research and project work.

What competencies are needed for the future? How to anticipate them for 5–10–15 years ahead? Obviously, their advance development becomes a key competitive advantage, the basis of leadership and sustainable development.

Despite the vast and ever-expanding body of literature on scientific and technological achievements and recent technologies, and the new industrial revolution [22–24], the issue of the demand for new competencies and new principles of professional education has so far been studied insufficiently, especially in a holistic way that would conceptualize new challenges. However, one positive example is the study [25] that presents the methodological and instrumental principles for creating competency maps and closely reflects our position.

2. Conceptual Basis for the Study

The authors' hypothesis predicts that in industries with super complex technologies, which include, for example, electric power engineering, nuclear and aerospace industries, the transport sector, urban engineering and telecommunications infrastructure, a manager will be able to work successfully only after mastering the most complicated interdisciplinary connections between technology, economics, ecology, and human factors. Since these industries are prone to inertia and, on the other hand, have rapidly developing markets with active consumers who become demanding customers of increasingly sophisticated services, the importance of anticipatory measures increases significantly.

A modern manager needs a variety of professional competencies to be able to form a vision of the future related to the unique technical and economic features of a particular industry. For example, in the electric power engineering industry, in strategic management, the following issues are becoming relevant with regard to creating and maintaining flexible power reserves and maneuverable generation to remove the uncertainty of electric load schedules; of energy companies' technical policy in terms of completely different approaches to renewing fixed assets; of demand management, environmental safety and reliability. The intellectualization of electric power production based on digitalization and

Smart Grid significantly complicates the scientific, technical and engineering components and their interaction in influencing the efficiency and timeliness of managerial decisions. Consequently, the following should be regarded as proactive measures in the electric power industry.

1. The development of non-capital-intensive (small-scale) distributed generation with various types of plants, including those as close as possible to consumption centers—mobile plants.
2. The use of progressive demand management mechanisms on the part of power grid and vertically integrated companies, devising standard financial contracts for disconnecting peak consumer loads.
3. Maneuverable generating capacities (peak and half-peak) to level off the load curve.
4. The introduction of smart grid elements, both in the field of transmission and distribution (with optimizing their cost), installing the so-called smart meters with two-way communications on consumers' sites, including households.
5. Strengthening inter-system electrical connections to reasonable optimal values (including possible and direct current ones).
6. Advance innovative development of power engineering and the electrical industry to provide technologies for new and modernized power facilities, organizing full after-sales maintenance (servicing) for the equipment supplied by manufacturers throughout the entire life cycle (including all types of repairs).
7. Responsible work with human resources to maintain the required level of qualification.

It is these measures that enable the industry's sustainable development and reduce the severity of future crises.

The above examples reflect the characteristics of the electric power industry. But for almost every industry and sector of the national economy, equally complex issues to be solved can be identified. It is important to note that the increase in the number of various challenges and their decisive role in the industry development leads to a certain intellectual response: increased importance of proactive management as an answer to these challenges, which can either open new opportunities for development and increasing efficiency or transform into threats.

It is obvious that managers will have to constantly learn a lot and organize advance training for their employees themselves, to guarantee they are ready for the upcoming changes.

The Conceptual Apparatus

The study required the clarification of some terms and concepts, with the following worth noting.

Proactive management is a set of technical, organizational, resource and economic measures implemented at all levels of an industry, of a business, aimed at preventing the negative impact of internal and external factors threatening sustainability, functionality, competitiveness, economic and environmental efficiency.

Proactive management seeks to address in advance the challenges and threats generated by external instability and identify emerging opportunities as a result of monitoring technological trends, observing weak signals and structuring complex priorities [26]. The target function of proactive management is to prepare management for unexpected changes and planned innovations (from 5 to 10–15 years ahead), including research and development (R&D), human capital development, the introduction of flexible organizational structures, and building a creative corporate environment. The proactive management model is shown in Figure 1.

Proactive management means an intellectual revolution in management, radical changes in its paradigm, methodology, organizational systems and processes. This revolution is impossible without deep transformations in the infrastructural institutions surrounding management: research and service centers, consulting organizations and especially universities that produce new knowledge about future technologies and upcoming changes in global and national markets, organize advance training for young professionals.

Advance training (education) is an organized process of generating knowledge and competencies to solve future problems that are consistent with global trends and national development programs. The purpose of advance training is to provide professionals with knowledge essential for working in engineering, organizational, economic, socio-humanitarian systems, created in the foreseeable future, based on new principles and operating in an external environment characterized by increased turbulence and uncertainty. It should be emphasized that advance learning is impossible without proactive management.

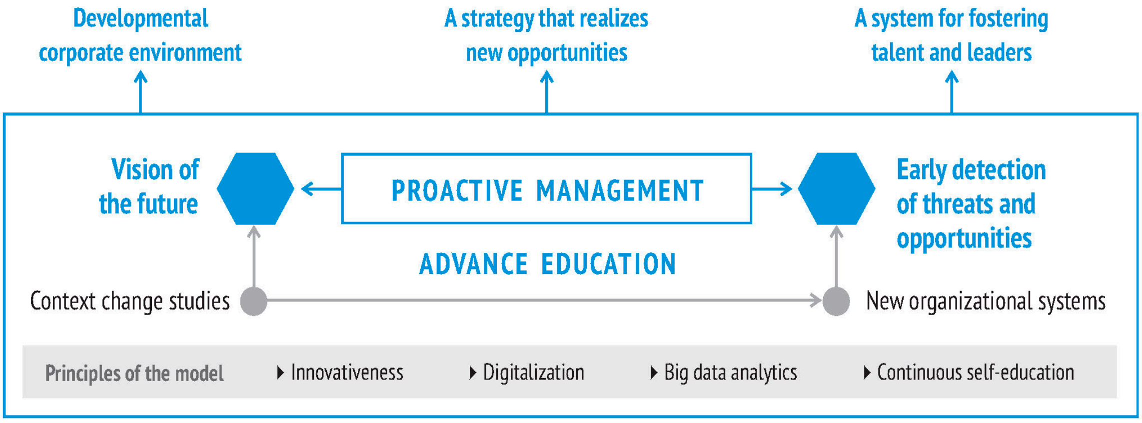

Figure 1. A management model oriented towards proactive management and advance education.

The key objects of advance learning are the following.

a. The methodology for designing complex systems full of innovative elements. For example, an electric power system with fully automated control and regulation, including at the consumer level, structurally flexible to introduce new elements based on the latest information technologies. Another example is the wholesale energy market and facilities with automatic protection against violations by market participants, with pricing mechanisms adequate to the efficiency of generation, transmission and use of electricity, with strong motivation to attract investment in the construction of new power facilities.
b. Changes in the industry context, primarily, global trends in scientific and technological progress and scientific developments. For example: distributed generation; smart grids; safe nuclear power plants; economically competitive renewable energy sources; poly-model concept of the wholesale and retail electricity markets.
c. Forecasts of resource constraints and external environment turbulence: personnel, fuel, technology, financial and currency volatility, etc.
d. Proactive management methods that neutralize the turbulence of the external environment, overcome resource and environmental constraints and stabilize the competitiveness (financial and economic efficiency) of the business.
e. The quality of the human resource and its readiness for change.
f. Leadership development, wherein new trends are observed:

- a general shift from "outstanding individuals" to organizational systems and a collective mind that contribute to achieving high results;
- the spread of distributed forms of management;
- the increasing importance of a visionary approach based on global thinking and taking into account a wide context.

g. Interdisciplinary teamwork that involves professionals from different subject areas of science and practice in solving the issues of increased uncertainty and complexity, including on the basis of virtual communications [27].

It should be noted that advance training can be organized at various levels of education (undergraduate, master's and bachelor's degree programs, MBA, PhD, DBA programs), but in different proportions. It is obvious that the higher the program level, the more issues of advance training it considers.

3. Materials and Methods

The authors' research plan was implemented in combination with practical testing following a logical sequence of stages.

1. Reviewing scientific literature on the issues of creating the industry of the future, proactive management and advance education, interdisciplinarity, and flexibility (in relation to complex industrial systems).
2. Systematizing ideas about educational models used by leading universities and business schools in the world when training managerial personnel.
3. Conducting a survey of experts (operating leaders, teachers and students) using a questionnaire on various aspects of advance education (proportions of traditional and advance content at different educational levels and levels of company hierarchy, the most demanded topics and subjects in the context of mastering proactive management, and barriers to the introduction of advance training).
4. Defining requirements for the content of modern managers' competencies based on the integration of the results of the survey, the study of the experience of leading universities in management education, and theoretical analysis.
5. Forming a holistic view of the structure of advance training for implementing proactive management. Developing principles and conditions for the implementation of advance education at university.

The methods of decomposition, structural-logical and visual analysis, content analysis, and conceptual design were used at various stages of the study [28–30].

The empirical base of the study was the data from surveys of students and teachers of Ural Federal University, one of the largest universities in the Russian Federation (internal experts), and the heads of Russian energy companies (external experts, professionals the authors have long been collaborating with on issues of business development and corporate training, as well as the development and testing of innovative educational products and training methods). The main criteria for the selection of experts were their interest in the issue (willingness to take part in achieving the objectives set), their competence (academic degree, length of working experience, position, publishing activity and the focus of their publications), their general scope of knowledge, views and creative abilities.

The survey focused on identifying the interest of different audiences in advance education as an innovative educational technology, its optimal proportions in comparison with other methods, as well as clarifying specific issues (relevant areas of knowledge, topics, courses) of advance education which are in increased demand at undergraduate and graduate levels. The respondents' profile is presented in Table 1.

In addition, to determine the trends and systematize ideas about the current state of global management education, an analysis of the qualitative characteristics of educational process organization models in world leading universities was carried out. The sample (Table 2) included universities that hold top positions in the Quacquarelli Symonds World University Rankings (QS) and Times Higher Education World University Rankings (THE) in 2019 in the subject area of Business and Management Studies, as well as several universities in Asia and the Middle East that demonstrate high research (R&D) dynamics [31]. In the analysis, special attention was paid to the structure of the masters' degree and MBA programmes, and to research projects related to the directions of educational activity.

Table 1. Respondents' distribution by category.

Organization	Industry	Respondent Category	Number of People
Ural Federal University	Higher education	Students	30
		Teaching staff	30
"Bashkir Electric Grid Company" LLC	Power engineering	Middle managers	36
		Top managers	11
"Bashkir Power Generation Company" LLC	Power engineering	Middle managers	41
		Top managers	13
"Rosseti Ural" PLC	Power engineering	Middle managers	38
		Top managers	15
"T Plus" LTD	Power engineering	Middle managers	32
		Top managers	9
"Ekaterinburg Electric Grid Company" PLC	Power engineering	Middle managers	23
		Top managers	12

Table 2. Leading world universities—the object of analysis. (THE = Times Higher Education World University Rankings.)

University	Country	Ranking	
		QS	THE
Harvard University	USA	1	7
Massachusetts Institute of Technology (MIT)	USA	4	1
INSEAD Business School	France	2	
Stanford University	USA	6	2
London Business School	USA	3	-
University of Oxford	UK	10	3
University of Cambridge	UK	7	4
University of Pennsylvania	USA	5	10
Duke University	USA	43	5
University of California, Berkeley	USA	12	6
London School of Economics and Political Science (LSE)	UK	8	8
Bocconi University	Italy	9	
Yale University	USA	24	9
Swiss Federal Institute of Technology Zurich (ETH Zurich)	Switzerland		20
National University of Singapore	Singapore	13	17
Hong Kong University of Science and Technology	Hong Kong	16	22
Nanyang Technological University	Singapore	27	65
Tsinghua University	China	39	18
The University of Tokyo	Japan	51–100	26
Peking University	China	32	23

4. Analysis of Changes in the Educational Products of Leading Universities from the Perspective of the Research Topic

To verify the hypothesis outlined in Section 2, an analysis was conducted of the directions of world management education development and how universities respond to new challenges, which made it possible to identify key characteristics of the educational models in leading universities. These include a focus on breakthrough technologies, a research and development component, and an orientation toward interdisciplinary educational products. The results of the analysis, along with surveys of academic experts and heads of business structures, allowed us to determine the content of interdisciplinary competencies for a technological breakthrough and to formulate the principles of advance education, which is an organized process of generating knowledge and competencies for solving future tasks that are consistent with global trends and national development programs.

It is only logical that radical changes in universities that train highly qualified personnel should correspond to the scale of technological changes. In this context, some experts [32–34] highlight the need for developing university ecosystems built in the center of scientific and educational clusters, and certain breakthrough technologies. It is these ecosystems that play the role of market integrators, with the digital scientific and industrial environment forming around them. No wonder the leading innovation clusters in the world are formed with the participation of universities: Silicon Valley around Stanford and Berkeley; New England around MIT and Harvard; University of Paderborn, University of Bielefeld and Hamm-Lippstadt Graduate School in the OWL IT cluster (Germany); Cambridge in the UK; Technion and Vetsman Institute in Israel; Aalto University in Finland [35–37]. As a result, the organizational models of universities change accordingly, increasingly aiming to integrate advanced scientific achievements into educational content faster than competitors.

The educational products for managers in leading universities have, as the analysis shows, several features, with the following are worth highlighting as being the most fundamental for advance training.

1. *A key trend—management education—is becoming more focused on research and breakthrough scientific developments.* Almost all leading universities in the world pay increased attention to research activities [37–39]. Thus, in the total pool of 179 master's degree programs at Cambridge University, the majority (86) are completely research-focused, 67 of them have a 50 percent research component, and only 26 are applied, but they too contain some elements of research. At the University of Oxford, the two-year master's degree program "Managing large-scale programmes and projects" is designed in such a way that students only have 10 weeks of full-time classes. The rest of the time is devoted to scientific research and consulting. Its effectiveness is controlled through weekly written reports: essays where students reflect on progress in their work.

A university research agenda typically focuses on promising technologies. Thus, the University of Hong Kong has a portfolio of priority research topics that determine its global competitiveness. These include smart buildings, the formation of the digital world, human-machine interfaces for the production of the future, biological data analysis, and knowledge-based entrepreneurship. These topics are actively promoted among master's degree students majoring in management, as the university expects that some graduates will continue their research in the university (or in outside corporations) and, thus, a university ecosystem will start forming, ensuring its leading position in science and education.

Another example is the "Energy Management and Sustainability" program at the University of Lausanne, which was created at the intersection of power engineering, economics, technology, management, and IT. The university views the program as a research and educational platform for training professionals to work in complex energy and industrial systems of the future. The program consists of five modules: "Biological Process Engineering", "Ecosystem Engineering", "Modeling of Environmental Protection Activities", "Technological Features of the New Power Engineering", and "Technology Management" plus more than 20 separate courses that include research.

2. *There has been an increase in interdisciplinary educational programs in the field of management.* More and more independent researchers note that a manager should have a wide range of competencies. According to the Institute of the Future at the University of Phoenix (USA), in terms of managerial competencies required for the industry of the future, the key ones are: a holistic vision of organizational processes and business development potential, which is formed primarily due to a clear understanding of the global context, of the impact of technological modernization on the business model configuration, strategic thinking, mastering the methods of creating flexible organizational structures [40].

The need for multidisciplinary professionals led to a steady decline in demand for "pure" managers and engineers [41]. As a result, engineering and management education start converging. A study by the European Commission that focused on forecasting the competency structure of engineers working in the field of nanoelectronics and microelectronics, showed that in the master's degree and PhD programs, a substantial share should be allocated to issues of economics and management (at least 20–25%) [42,43]. Other experts hold the same view [44–46]. The related developments are carried out by international consortia: for example, the "Skills Center", the international consulting company EFESO Consulting Russia, in collaboration with the Russian Academy of National Economy and Public Administration, are implementing the project "X People: a fusion of competencies as a new technology for training managers and engineers." The aim of the project is to train professionals with engineering and economic competencies, able to organize and optimize technological business processes in a manufacturing organization.

Examples of interdisciplinary programs in the universities analyzed are: the main master's degree program at MIT, "System Design and Management", created at the intersection of engineering and management; Stanford's master's degree program, 50% of which consists of a wide range of elective courses, from neuroaesthetics to industrial philosophy; programs at the University of California (Berkeley) including "Industrial Engineering and Operational Management", "Energy and Resources", "Information Management in Complex Systems", and "Business and Biology"; the master's degree program at the Swiss Higher Technical School of Zurich, "Management, Technology, Economics".

Universities create special institutes for interdisciplinary programs (including managerial ones). Examples of such universities are the University of Pennsylvania (USA), Oxford (UK), the Graduate School of Interdisciplinary Information Education at the University of Tokyo, and the Institute of Interdisciplinary Information Sciences at Tsinghua University. Other educational institutions have similar structures, including the University of Amsterdam (Netherlands), the University of Texas (USA, Dallas), and the University of Toledo (USA).

The educational process includes both engineering and managerial subjects, and humanities, in particular, those related to issues of design thinking, visual analytics, and cognitive technologies. It is believed that including a share of humanities in the educational program helps to reduce the complexity of integrated systems, their comprehensive perception and understanding by managers and engineers.

The organization of the educational process can be described using the example of the University of Texas. Students who study at the Institute of Interdisciplinary Sciences must choose one main (base) and two related sciences. They have a choice of six areas (arts and humanities; behaviorism; computer science; economics and political science; management; natural sciences and mathematics); inside each area, there are many flexible trajectories that can be selected in the form of separate modules and creative workshops.

Management programs at the intersection of management and art are gaining ground. For example, the "Strategic Leadership and Design" program at Indianapolis University, USA, wisely combines the following modules: "Theory of Leadership and Design Thinking", "Cognitive Systems and Learning Organizations", "Intellectual Capital Development", "Information and production technology management", and "Management mathematics". Stanford University's master's degree and MBA programs include courses such as "Leadership in Art and Creative Industries", "Design as a Way to Create Inclusive Enterprises", "Business Evolution: a Literary Metaphor", and others. Saint-Petersburg National Research University of Information Technologies, Mechanics and Optics (Russia) implements a similar model in its Art and Science master's degree program, which is a synthesis of engineering, management and art education.

3. *The business models in management education are restructuring.* Now its most important object is technology, and the degree of product individualization and geographical distribution is increasing. Interesting alliances form on the market. Thus, INSEAD Business School implements an international MBA program for top managers in collaboration with Tsinghua University, whereby students get acquainted with high-tech industries in France, China, Singapore and the UAE. Bocconi University (Italy) has launched a double-degree MBA program in which students can choose a partner school

from Denmark, Russia, Austria, Portugal, Amsterdam or Norway, while the main program profiles are not quite typical for classical business education, namely: environmental management, technological innovation management, IT consulting and working with big data. Similar models are implemented by business schools such as Instituto de Empresa (IE) (Spain), Waseda (Japan), the European School of Management and Technology (ESMT) (Germany), and others.

Strengthening collaborations between the educational market players is associated not only with its general globalization or marketing. Such collaborations allow students to grasp the main concept that permeates, as a rule, all modules in the programs: the in-depth study of the scientific and technical context that forms the industry of the future, and its impact on socio-economic models of different countries.

This also helps to increase program flexibility, tailoring it to the individual interests of its customers—that is, product customization. It is no accident, for example, that the National University of Singapore offers the option of "educational tailoring", where customers can design a complete MBA program for themselves: from the content of the modules, their sequence and duration, to the geography of various design and educational events.

In most cases, customization is achieved either through including a separate "self-adjustable" module with a limited number of hours (an example is the classical MBA program of the IMD business school), or by significantly increasing the share of project work in the curriculum. Within the framework of the master's degree program in social management at Cambridge Business School, students carry out four joint business projects: a) a venture project, b) a global consulting project, c) a central project, and d) a research project. Projects "c" and "d" must be within one of the subject areas: culture and art; digital conversions; energy and the environment; global entrepreneurship; health strategies; social innovation. In the project work, teachers act as students' consultants on the development of their entrepreneurial initiatives, which, thus, makes it possible for the university to integrate educational and consulting activities in the educational product. Besides Cambridge, a good example is the so-called Seed Transformation Program of the Stanford Graduate School of Business.

Thus, the modern leading universities view management education as oriented towards advanced scientific and technological achievements, as a demonstration of best practices in the areas (and at the intersection) of management and engineering, with flexibly organized educational process, and involving students in active project and research work, built on the principles of active communications, teamwork, compliance with the university's priority research areas. Therefore, the hypothesis we formulated can rightfully be considered as a conceptual basis for the implementation of advance learning principles.

5. Results and Discussion

5.1. Interdisciplinary Competencies Become Crucial

In the current period of super-dynamic changes, serious fundamental education is essential. The question arises, however, what fundamental knowledge, what content and depth of study are needed? How to transform this knowledge into the necessary competencies? Should a wide range of knowledge be gained and specific (at least initial) experience and the ability to reflect on your actions be acquired to develop the essential competencies and to successfully operate in the conditions of uncertainty and changeable external environment? Leading universities are actively developing research and managerial training in such areas as systems engineering, future technologies, complex systems' stability and adaptability, network technologies and distributed architectures, data science, conceptual design, chaos management, self-organization, etc. [47–49].

The fundamental principle of modern university education is the application of an interdisciplinary approach that integrates subject knowledge into a new quality (mathematics, physics, biology, engineering and technology, economics and finance, ecology, law, management) [50]. Moreover, it is technology in a broad sense, from targeted research and engineering to the introduction of innovation, that interdisciplinary interrelations concentrate on [51,52]. Therefore, knowledge of the engineering fundamentals of production and scientific and technical trends is an indispensable condition for a manager to successfully fulfill their functions. Hence, in management education, the share and content of scientific, technical, engineering and technological, technical and economic training should be substantially strengthened, as this is what contributes to the development of the relevant competencies [53].

We should emphasize that interdisciplinarity is not so much a joint consideration of problems by experts from different fields of science and practice, but a synthesis of various knowledge in order to obtain a new solution to a complex problem [54]. It can be assumed that the trend towards interdisciplinarity will become stronger as the flow of new complex tasks, differentiation and integration of knowledge intensify [55]. When training managers, it is important not only to demonstrate the capabilities of an interdisciplinary methodology as a way of organizing teamwork for a comprehensive analysis of the situation and increasing heuristic efficiency, but also to provide them with the tools for interdisciplinary decisions [50,56].

The continuously arising new tasks, the need for their understanding, systematization and schematization, taking into account the requirements of numerous stakeholders, frequent restructuring of teams to adjust to the changing requirements, makes relevant the interdisciplinary competencies that are crucial in achieving strategic goals of technological breakthrough: engineering-managerial, engineering-economic competencies and the ability to take anticipatory action (Figure 2). The latter becomes a priority and a decisive factor in leadership. However, it cannot be mastered without acquiring engineering-managerial and engineering-economic competencies.

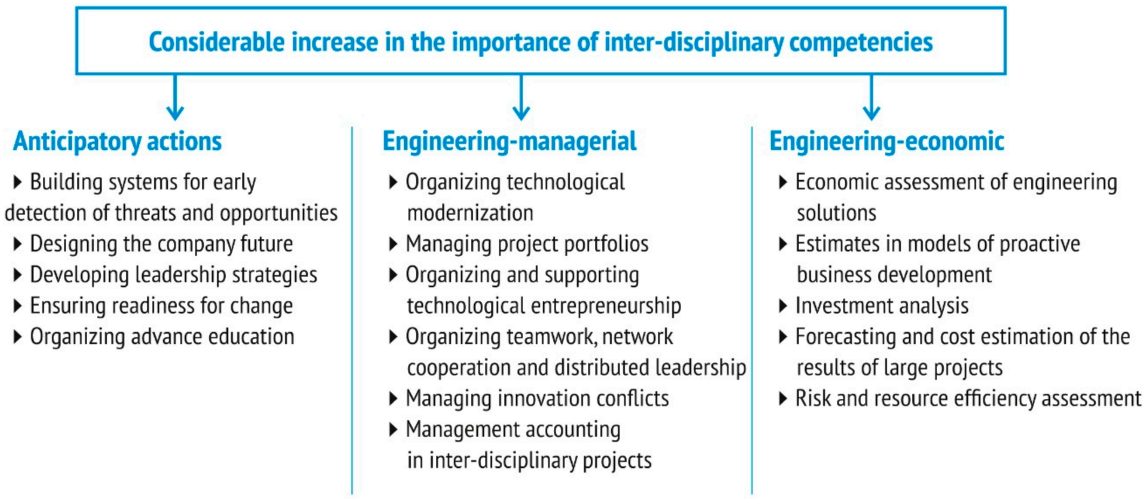

Figure 2. Content of interdisciplinary competencies.

Even with local technological modernization, there is an acute need for the following competencies:

- development of investment projects with rationalized technical and economic standards that characterize its target results;
- technical and economic analysis of the applicability of individual models of new machines and equipment, various suppliers and forms of service in the specific context of the enterprise;
- a comprehensive assessment of external risks (investment and technical) and ways to minimize them;
- implementation of organizational change programs in connection with the technical re-equipment of manufacturing;
- selecting innovations that can be obtained from foreign partners and carrying out transactions in the world markets;
- analytical work with large amounts of information of various subject content.

As the systems become more complex, the contradictions increase between the objectives of research and technological activity (the field of science), users of technology (the field of exploitation) and the interests of business as the main customer of high-tech innovations. As a result, coordinated work of different professionals is required, joining the work at its various stages and performing different functions (Figure 3). Under such conditions, it is impossible to predict the consequences of decisions made at early stages that have a significant effect on the efficiency of the development process and on the characteristics of the system being created [57]. It is necessary, on the one hand, to evaluate options taking into account the entire life cycle of the system and the changes in the external environment that can significantly influence it [58,59] and, on the other hand, to separate the design process of the system as a whole from the detailed work on its individual components and develop iteratively, testing and refining solutions as new information appears [60,61]. Thus, these clusters of competencies must be mastered by professionals of different profiles, but to a different extent, depending on the tasks they are to deal with.

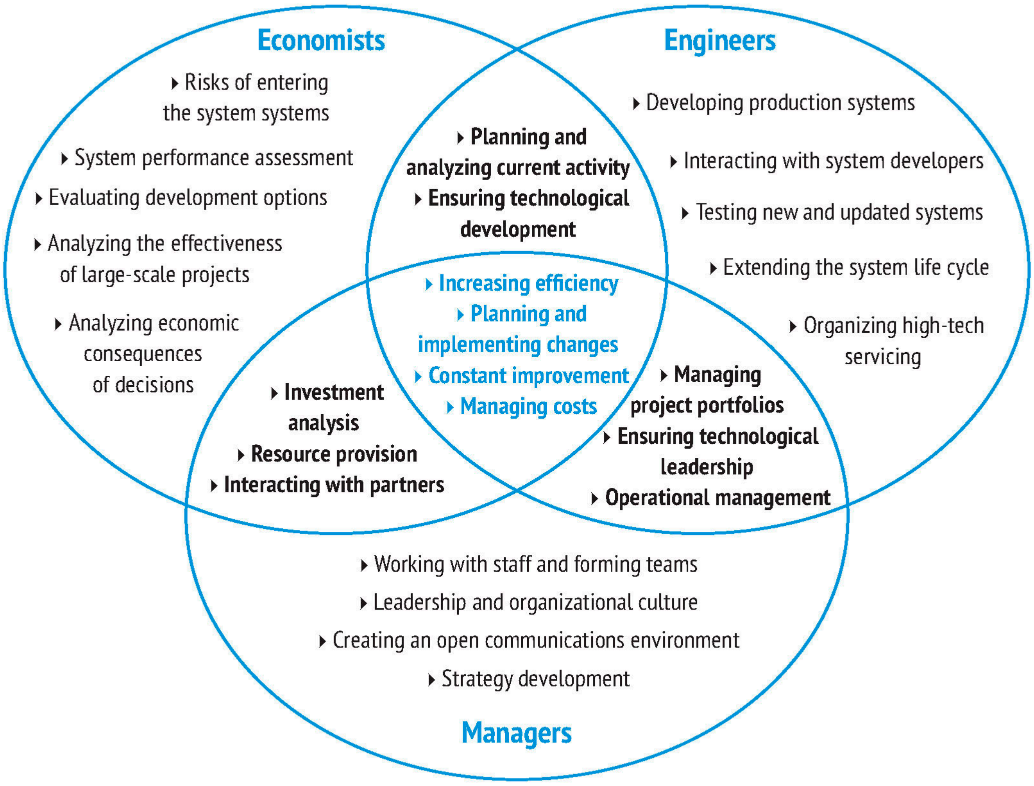

Figure 3. Tasks that determine the content of competencies for technological breakthrough.

The empirical data obtained during the surveys also focus on a number of aspects of advance management education and allow their rational proportions to be implemented in educational programs. For example, among the most relevant courses for modern managers, such courses as "Proactive Management", "Prospective Industry Technologies", "Tools for Forecasting the Future" stand out. These courses equip managers with the tools they can use when making decisions in the face of uncertainty and focus on linking managerial activities to the technological context (Figure 4). The optimal share of advance training, according to the respondents, does not exceed 30% of the total educational program content (Figure 5), while for senior managers and specialists of innovative profile, this share should be significantly higher than for managers at lower and middle levels (Figure 6).

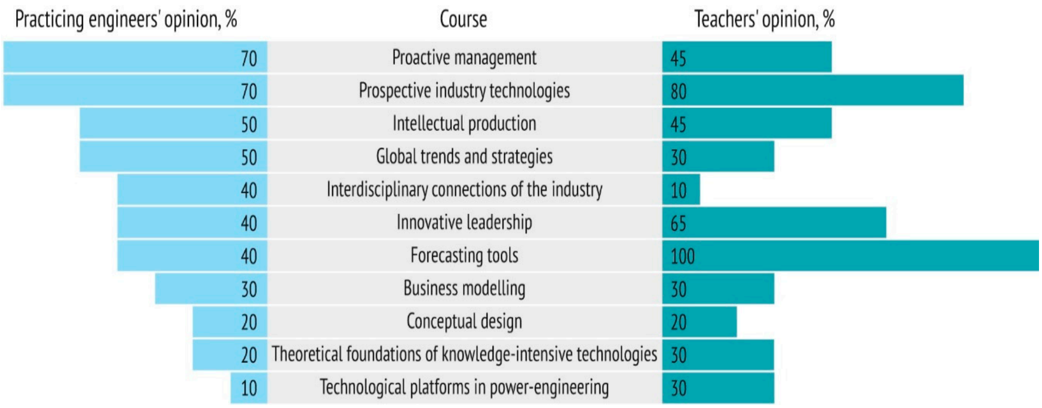

Figure 4. Most demanded courses according to the respondents.

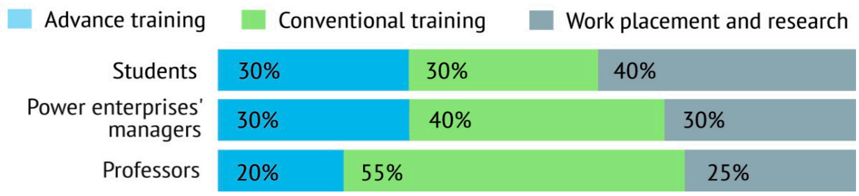

Figure 5. The proportion of advance training in the total volume of master's degree programs.

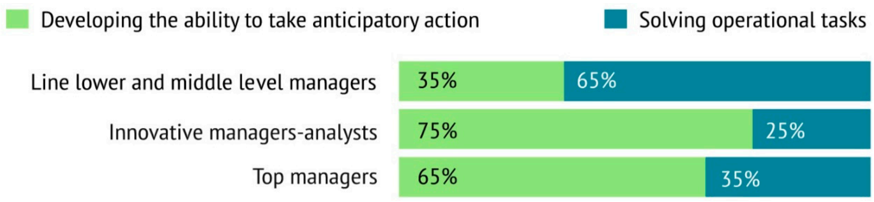

Figure 6. The share of advance training in educational programs for managers of different categories.

The objectives and the methods of professional training for managers at different levels from the standpoint of an interdisciplinary approach also differ. Thus, for lower level managers, it is essential to master the relationships between management systems and the ability to tackle non-typical tasks. For top managers, the priority is developing a comprehensive vision of the future, mastering competencies for large-scale transformations, human capital management, and the transformation of strategic priorities (Table 3).

Table 3. Enhancing the interdisciplinary approach when training managers.

Goals of Professional Training	Interdisciplinary Directions
Management students Mastering basic competencies, the ability to apply it in non-standard situations.	• Understanding the variety of technologies and the complexity of management activities • Summarizing reports using research results and information from different areas of knowledge • Encouraging the development of value thinking • Conceptual design • Business games and teamwork
Low-level managers Understanding managerial tasks and basic management systems. The ability to solve non-typical tasks for the level. The ability to work with people and small groups. Mastering the basics of value thinking.	• Demonstration of multidimensionality and complexity of managerial knowledge (for graduates in engineering degree courses) • Learning best practices through case studies • Business games, strategic sessions, and teamwork

Table 3. *Cont.*

Goals of Professional Training	Interdisciplinary Directions
Middle managers The ability to solve non-typical tasks for the level, analyze problem situations, formulate and solve problems. The development of systemic thinking.	• Comprehensive mastery of managerial knowledge • Learning best practices through case studies • Conceptual design • Business games, strategic sessions, and teamwork
Top managers The ability to integrate economic, industrial, environmental, political and cultural goals and solve complex problems. Developing the ability to change vision, strategy and priorities. Creating and developing growth points and breakthrough teams. Organizing large-scale transformations.	• Developing a vision of the future • Methods for generating ideas • Behavior in extreme situations • Development of professional reflection ability • Conceptual design • Business games, strategic sessions, and teamwork

Finally, worth noting is the need for educational programs in the field of management for the energy sector and the new industry to pay much more attention to:

- engineering and technical issues of the industry and its scientific and technical prospects—up to 20%–22% of the total curriculum for bachelor and master' degree programs;
- readiness for innovative activity—10% for bachelor's degree and 14% for master's degree programs;
- methods of self-education—13% both for bachelor's and master's degree programs (Figure 7).

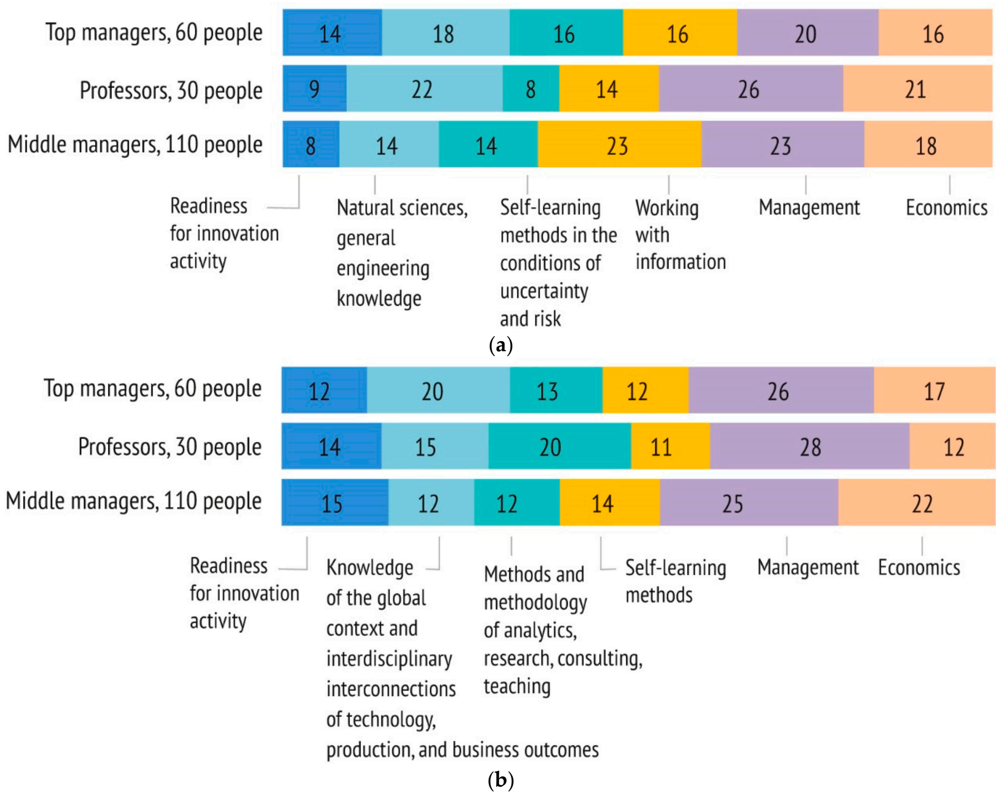

Figure 7. The proportion of courses in (**a**) bachelor's degree programs and (**b**) master's degree programs.

5.2. Active Participation in Research is the Imperative of Advance Education

The very essence of advance education determines the need for the constant generation of new knowledge about the emerging trends, their nature, and development factors. The teaching materials inevitably become rich in scientific information, the basics of research and innovation, progressive solutions in the field of engineering and management. A lot of attention is paid to mastering the principles and methods for constructing the future: foresight research, determining prospects, development strategies, developing new technical, socio-technical, organizational and environmental systems. The competence of active influence on the external environment (context management) becomes crucial [21].

The theoretical, methodological and organizing basis for involving students in research is created within the framework of the "Proactive management in actively developing industries and sectors of the economy" research project that the authors conduct at Ural Federal University. This includes a broad research agenda and an implementation part in the form of a multi-project "New Leaders for a Technological Breakthrough" (Figure 8), where the scientific and educational platform of advance education plays an integrating role [62].

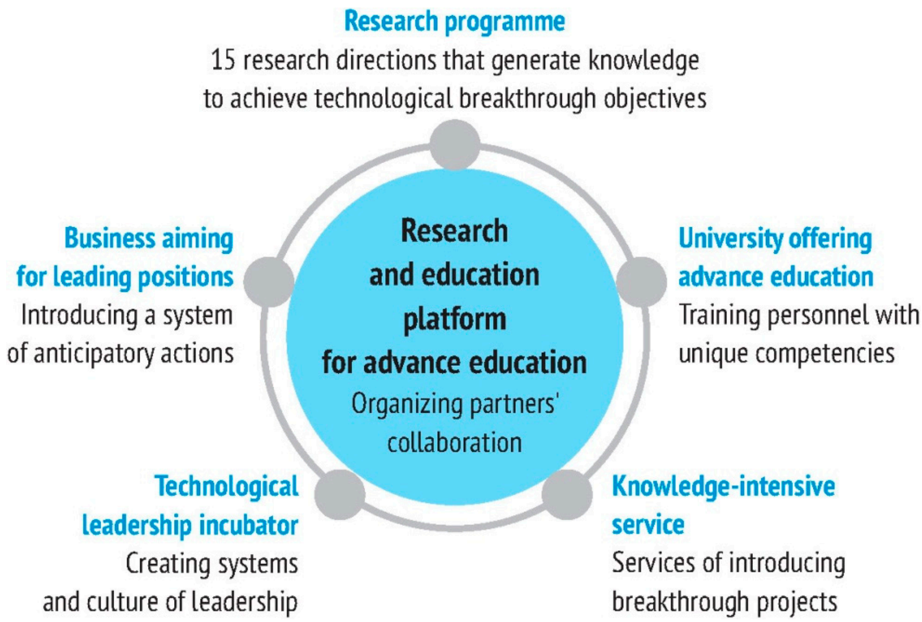

Figure 8. The structure of the "new leaders for the technological breakthrough" multi-project.

The uniqueness of the multi-project consists in the organization of the interaction of science, education and business, based on a common interest and objective—sustainable development and leadership, which in the modern world is impossible without taking actions to be ahead of the competitors. Establishing such a partnership, according to a number of experts, is a key success factor in training professionals for the industry of the future [63,64].

The new educational paradigm in our practice provides for the priority of the teaching method that encourages involvement in research and project work, develops flexible professional thinking and behavior, helps master interdisciplinary connections, and readiness for change. To this end, the Research, Consulting, Advance Education (RCAE) methodology was developed by the authors: an integrated system of research, consulting, advance education and transformative actions [65].

RCAE is a set of tools for actively immersing students and practicing managers in a problem-oriented environment that contains intellectual and motivational mechanisms for achieving managerial objectives of the future—from searching for ideas and researching relevant areas, to implementing innovative solutions. The teaching model in this methodology is radically different from the traditional one in that students actively discuss various issues with each other and their professors, share information, collaborate and model situations together and master new concepts and meanings. As a result, the educational process is perceived not as a set of abstract academic subjects, but as a holistic practice-oriented complex that contributes to the solution of real problems and their conceptual implementation.

5.3. Agile Architecture of the Educational Process

Fundamentally important for advance education is the possibility to quickly reorient educational content to new realities, bypassing inertial processes and bureaucratic procedures related to educational activities. To achieve this, the study summarized the experience of systems engineering in terms of ensuring the agility and resilience of complex systems [66–70]. These systems engineering methodologies are being actively developed and demonstrate the convincing effectiveness of the modular approach for restructuring engineering and socio-technical systems. Thus, in [70], the conditions for the effective application of the modular approach in terms of agile systems architecture (Table 4) are formulated, and these recommendations were used by the authors when designing the modular system of advance training.

Table 4. Enhancing the interdisciplinary approach when training managers.

Module Component Type	Application Conditions
Technical components	• Each module is designed to perform a specific set of interrelated functions • The functions are controlled and regulated locally inside the module • Modules can be quickly added to and removed from the system • Interactions between modules are regulated by rules (standards) • When standards change, all modules (built into the system or in standby) are adjusted to the new standards
Documentation	• The format of all documents used for the exchanging information between the participants does not allow for discrepancies and is interpreted by compilers and performers in the same way • When making changes to the documentation, all the participants are informed about the changes, and, if necessary, are taught new rules
Personnel	• Both teams of professionals and individual employees can be considered as modules • Interdisciplinary teams form the core of the system; each team is responsible for a key function that determines the result of the system • All specialists are highly qualified in their field. The composition of the team is determined by the tasks being solved. Each team member has a good understanding of the activities of the others and the criteria for evaluating the work of the team as a whole • When a new member joins the team, their qualifications are checked, and a mentor is assigned to them at the initial stage (to adapt the new member to the team and quickly integrate them into the overall process) • Specialists who work at the integration level should see the big picture, quickly identify emerging problems and find solutions, change the system by introducing and removing modules from it, and ensure standard interaction between modules

In advance education, the industry context, the trends in the markets of knowledge, technology, labor and, of course, the specifics of development objectives of a business are processed taking into account the research area. In turn, specific research projects and topics appear that change and develop the educational content. The master's degree program as an integrated educational product (Figure 9) does not include a single course/module that is not consistent with the research direction, and a knowledge base is formed for each course/module in the form of articles, monographs, analytics, empirical data, and teaching methods are selected that are radically different from the traditional ones.

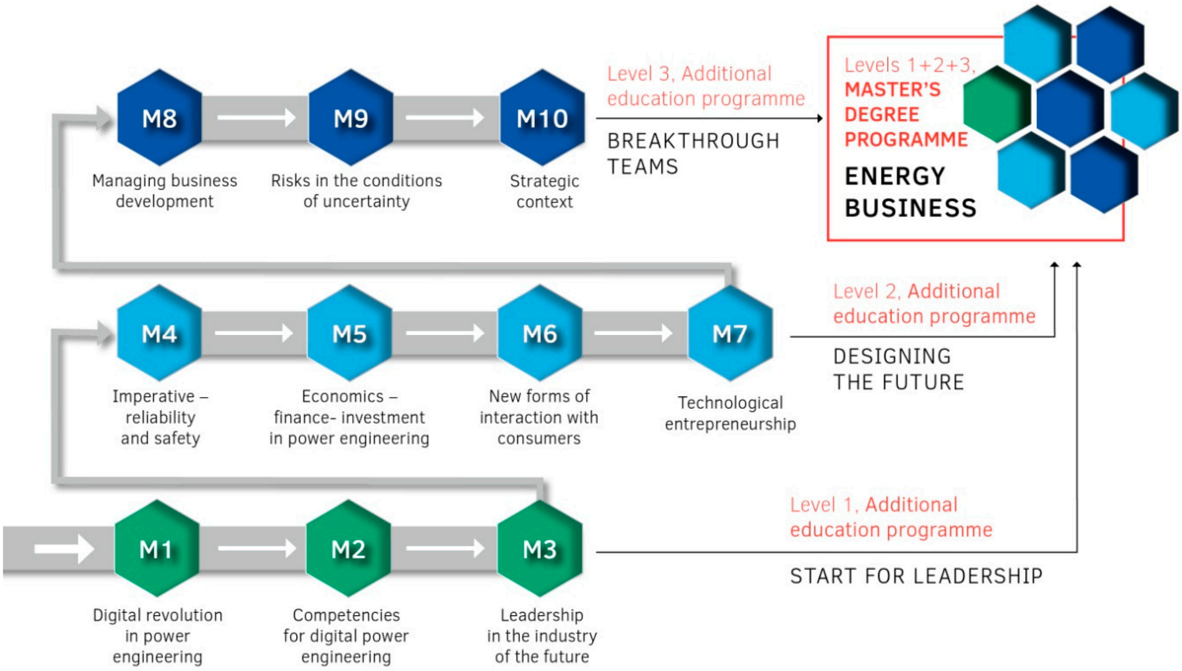

Figure 9. An example of modular architecture master's degree program designed using conveyor logic.

In our practice, each module:

- develops relevant competencies;
- is put on the market as a separate product or as part of a larger product—an educational program;
- is consistent with specific research topics developed by the authors;
- has a powerful service support in the form of a knowledge base, numerous already developed projects, and mentoring by business leaders.
- is built into a certain conveyor logic, providing a controlled process of continuous learning and competency-oriented professional development.

The module structure we developed and use ("modules in a module") significantly increases the flexibility and elasticity of the entire architecture (Figure 10). There is an opportunity to adjust the content and training activities during the learning process, quickly rebuilding it depending on the students' professional interests and preferences.

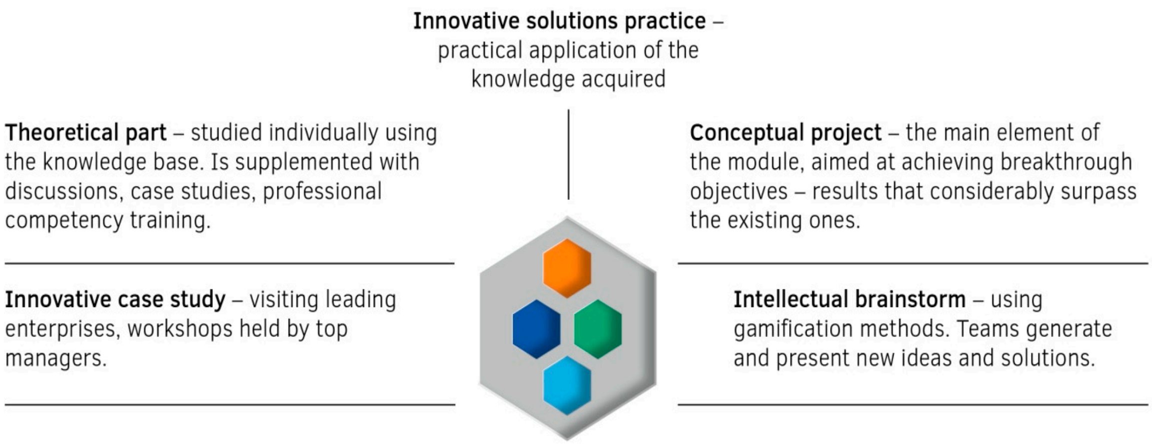

Figure 10. Module structure.

5.4. Principles and Conditions for Introducing Advance Education

It was evident even at the initial stage of the study that such a major innovation as organizing advance education will face certain resistance at universities. Of interest are the barriers that educational reformers have to deal with first. To identify these during an expert survey, the respondents were asked to indicate one or more of the most significant barriers to the introduction of advance training. The results of the survey are summarized in Figure 11.

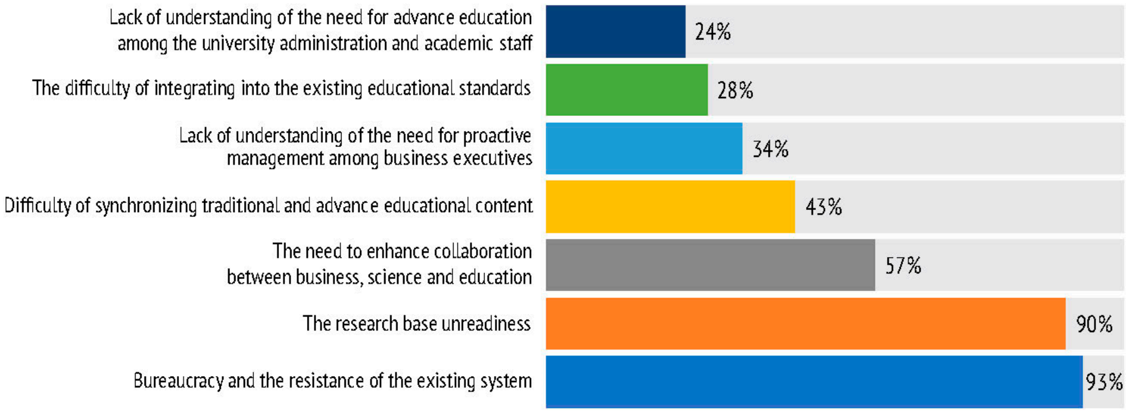

Figure 11. Assessment of factors inhibiting the introduction of advance education.

It is natural that, according to experts, bureaucracy was the most critical factor hindering the introduction of innovation in universities; this feature of the university structure is described as a serious barrier to innovation in a number of publications (with [71,72] worth noting as the most fundamental studies of this issue that involve a wide selection of universities). However, it is not less important to involve business in the implementation of advance education projects [73]. Moreover, it should be emphasized once again that the practical need for advance education can only be satisfied through introducing proactive management based on digitalization and the mechanism for early detection of threats and emerging opportunities. This organizational system will be able to function and develop with the knowledge about the emerging trends in the global environment constantly being expanded, deepened and updated, and the potential for their development and implementation in breakthrough innovations being assessed.

Below are the basic principles and conditions for the introduction of advance education at universities and in the business context.

1. *Advance education is impossible, and this should be highlighted, without the targeted research component integrated into the educational process*: context analysis, monitoring scientific and technological achievements, foresight forecast of competencies, structural changes in the economy (global, national, regional), the constant generation of new knowledge regarding emerging trends, their nature, and development factors.

Thus, the teaching materials should include scientific information, methodological foundations of research and innovation management, and progressive practical solutions in the field of engineering and management. Moreover, this should be done in the general context of changes in markets and business models.

Advance training is carried out in a separate scientific and educational circuit and sets the vector of knowledge aimed at creating a new image of the industry (company): vision and construction of the future, embodying the latest scientific and technological achievements, and organizational and economic innovations. An important emphasis in advance training is placed on mechanisms that protect the industry from external challenges and threats. Unlike the conventional training of managers who solve routine (tactical) tasks, advance training aims to develop a new type of manager: innovative designers capable of conceptual design of new management systems and of introducing them in production. It should again be emphasized that for different categories of managers, different proportions of advance and traditional training are needed. This conclusion is confirmed by empirical data obtained by the authors (see Figure 5).

2. *The method of training managers changes radically and becomes a priority.* Active participation, interdisciplinary teamwork, situation modeling, research, and project training are integral elements of modern management education, which place the main emphasis not so much on the acquisition of knowledge, but on its generation, updating and application. As a result, the role of research in managerial education increases: it virtually becomes the dominant of the educational process, especially in master's degree courses.

3. *Educational models* are transformed towards the students acquiring the competencies of professional behavior in the conditions of uncertainty; working with digital technologies and huge amounts of information; interactions in the global network; monitoring a wide range of the latest production, telecommunication, and management technologies.

4. *The need to acquire self-learning competencies by managers considerably increases.* Priority is given to the ability to continuously develop own methodological culture, critical thinking, to constantly keep up to date with the changes in the context, the latest scientific and technological achievements in both the main and related industries.

6. Conclusions

The radical changes in production technologies transform management systems, management methods and tools and require high-quality transformations in management education. In the conceptual language of a manager, new terms gain priority: uncertainty, risks, complex systems, constructing the future, interdisciplinary solutions, and proactive measures.

Traditional approaches to education are obviously outdated not only in terms of content, but even more so in terms of methods. When developing an up-to-date educational paradigm, one should be guided by a fundamentally new development management model—proactive management, as time becomes a decisive factor in business survival. The goal of proactive management is to prepare management for unexpected changes and planned innovations (5–10–15 years ahead), including R&D, human resource development, the introduction of flexible organizational structures that actively interact with consumers, and building a creative corporate environment based on new values of the youth.

The relevant competencies are developed based on advance education through educational programs, where great attention is paid to leadership strategies in the face of uncertainty, foresight research, the design of prospective technological, socio-technical, organizational, economic and environmental systems and their interaction. Great importance is also attached to specialized scientific research which supplies new knowledge aimed at predicting development, developing a methodology for designing complex systems saturated with innovative elements, and integrating research, educational and innovative activities. Advance education is not possible without rapidly including their results in its content and methods.

The analysis of how realistic advance education is convincingly shows that it can be fully implemented only based on targeted research aimed at forecasting technological and socio-economic development, forming a vision for the future and integrating this activity with educational and innovative activities. Thus, smart partnership plays the key determining role: science and its interaction with education and business within the framework of a comprehensive system focused on continuous generation of new knowledge and innovations, and on constant readiness for changes. This partnership allows enriching the proactive management methodology from the standpoint of different fields of activity and stages of the innovation life cycle, different visions of upcoming changes in global and national markets.

Each subject of the partnership triad performs certain functions. Thus, universities produce new knowledge about future technologies and upcoming changes in global and national markets and organize advance education for young professionals. High-tech service provides services for designing the future and creating systems for early detection of threats and opportunities. And finally, business leverages the new knowledge for proactive management.

The introduction of advance education and proactive management is a large-scale, complex and poorly studied issue that will constantly need a large amount of new knowledge in various fields. This makes it relevant to work on further active development in the above scientific direction. It is planned to finalize the methodology for identifying key trends in the global environment that determine the prospective industrial landscape and new competency requirements; testing and implementation of a prospective management model based on early detection of threats and opportunities; the development of a method for designing the future that would ensure the right direction of proactive measures.

The authors' further research is also aimed at studying the role and optimal proportions of the humanities component in the new paradigm. The experience of the best foreign universities has recently demonstrated a high interest in subjects at the intersection of design, art, and visualization as a driver of individual and team creativity and a method for making complex solutions less complicated. This issue requires discussion and developing a common approach by the academic and expert community.

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