

Software Engineering Education: Discovering Future Skills¹

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In the contemporary digital age the majority of industries become very much software dependent, require automation, digitization, and deployment of new technologies. The need for specialists, skilled in software engineering, is in high demand. In this study, we set out to investigate what challenges may arise in IT students' skill sets and new competences in the software engineering context and answer the question "how is skills demand evolving and where the gaps will be?". The paper analyzes what specific knowledge needs to be developed during university education and identifies their evolving skills demand. The paper recommends how students and young specialists in software engineering need to change themselves to adapt to the changing world.

Keywords: software engineering, technologies, IT, education, skills

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Программные инженеры будущего: требования к навыкам

В современную цифровую эпоху большинство отраслей становятся очень программно-зависимыми, требуют автоматизации, цифровизации и внедрения новых технологий. Потребность в специалистах, разбирающихся в программной инженерии, высока. В статье приведены результаты исследования того, какие могут возникнуть проблемы в наборе навыков при обучении программных инженеров и потребности в новых компетенциях при разработке программного обеспечения. Дан ответ на вопрос "как меняется спрос на навыки и где будут пробелы в знаниях?". Приведен анализ того, какие конкретные знания необходимо развивать во время обучения в вузе, и определена потребность в растущих навыках студентов. Даны рекомендации, как студентам и молодым специалистам в области программной инженерии необходимо изменить себя, чтобы адаптироваться к меняющемуся миру.

Ключевые слова: программная инженерия, технологии, ИТ, образование, навыки

Introduction

The future of work will be a race between education and technology.
Mauricio Macri, President of Argentina in 2018

With the transition of business to the Internet, many vacancies opened up, hence, employees with

IT skills and software engineers are in high demand. Employment requirements became more stringent as the workforce needs to understand and become familiar with new technologies and how they affect the industry landscape. Specific knowledge needs to be continuously updated, accordingly, workers need to adapt. In the future, employers will seek out candidates that can continuously acquire and perfect new skills.

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Technical expertise remains critical and in short supply; 65 % of global CIO (Chief Information Officer) survey participants say analytics and data science will be the hardest-to-find technical skills in the next five years, while 54 % named cyber and 49 % named emerging technologies [1].

In the emergent technology context where industry processes become more automated, jobs and roles change accordingly. Most tactical, algorithmic, and structured work will be automated by machines over time, reducing the need to perform several repetitive tasks manually. Many jobs require both routine technical and non-routine tasks that are not easily computerized, such as interpersonal interaction, flexibility, adaptability, and problem-solving skills. The cognitive capacity of emerging technology is increasing to the point where machines will soon outperform humans in many workplace tasks.

Automation allows employees to concentrate on more important tasks, leaving much creative and strategic work for human talent. Today, soft skills are having a breakout moment. These enduring, essentially human skills, are increasing in value in part because they cannot be replicated by machines [1]. It seems that new skills and capabilities should be needed, as tomorrow's technology workforce will be different from today's. This means that software engineering student education and skills development should be redesigned to sustain technological evolution. Emerging information and communication technologies, such as Big Data, Internet of Things, Machine learning, and Artificial Intelligence, demonstrate a dramatic impact on the labor market.

Our paper focuses on software engineers and specialists with digital skills, as they are the ones who create and boost emerging technologies which are so in demand nowadays. Today access to knowledge for IT professionals is virtually limitless thanks to private players in the education market and access to online courses. In the Software Engineering field potential employers look less at university education and more at the experience and practical knowledge, including the presence of soft skills.

The goal of this paper is to understand how the development of skills is approached based on the influence of new technologies and, based on the findings, to propose a high-level approach on how software engineers should develop their future skills. We believe that software engineering students, graduates, and professionals in software engineering, will be better prepared for the current and future IT job market and business requirements relying on the results of this research and analysis.

The study was carried out at HSE University, which is among the top 4 universities in Russia in terms of

IT education, according to the QS World University Rankings, 2020/2021 [2], and 322nd among the 500 best universities worldwide, according to the QS World University Rankings in 2020 [3]. The study was conducted by interviewing IT students, ranging from software engineers to specialists studying information communication technologies, to find out which skills are needed for young specialists in IT and software engineering and what is lacking in the current education system. In order to understand future IT skills phenomena, this study analyzes emerging technologies and related literature in Section 1. In Section 2, we describe the methodology with our data collection and analysis methods and the results of our analysis. Section 3 discusses the limitations and future research avenues. Last section concludes our study with the key findings summary.

1. Emerging technologies impact on the software engineering workforce

1.1. Emerging Technologies and skills demand

We have analyzed the descriptions of many vacancies and made conclusions on which hard skills software engineering specialists should have. As for soft skills, employers and companies rather accentuate the common skills necessary for all areas of emerging technologies, without highlighting any in particular for one technology or another.

1.1.1. Blockchain

Blockchain has moved from the world of crypto currency to business, becoming the solution to many problems. Distributed crypto currency technology is already broadly used in many areas, from trading any commodity to voting in elections.

Blockchain specialists help to integrate blockchain technologies into business operations to improve existing services and introduce new ones. Many companies are searching for specialists with blockchain skills to create internal crypto coins for a company, for which regular customers can receive bonuses.

Blockchain developer requirements include experience with JavaScript, C++, Python, cryptography and machine learning. To make this job more attainable, one needs to be proficient in the Java and Solidity programming languages, know the Oracle Identity software suite, have database management skills and understand blockchain platforms such as Hyperledger Fabric, Ripple and the Bitcoin payment network.

1.1.2. Artificial Intelligence

Artificial Intelligence (AI) is the ability of a computer or a robot to solve tasks that are usually performed by humans. AI learns from the interpretation of external

data and uses the knowledge gained to achieve goals, due to the specifics of learning; this area is closely related to machine learning. AI can be useful in many areas where automation, improvement, process simplification and forecasting are in demand. In this area developers are required to understand neural networks, their areas of application, the ability to program in Python, as well as to be fluent in statistical analysis and mathematical modeling.

1.1.3. Internet of Things (IoT)

This technology consists of physical devices that read external data, upload it to the cloud (the Internet), where the software processes it, hence the connection with big data. An example of such a device is a smart home that adjusts the temperature according to the environment. Use of IoT together with machine learning has spread to sectors like agriculture to monitor plant health [4] which shows that IoT is applicable in all kinds of spheres. With IoT, companies can automate processes and reduce labor costs, leading to better service delivery. IoT specialists must, first of all, have engineering skills: the ability to work with wireless sensor networks, cloud technologies, as well as know how to ensure the security of the products being developed, and be proficient in at least one programming language such as Java, .NET, Python, PHP, Go, C++.

1.1.4. Nanotechnology/Biotechnology

Nanotechnology is an interdisciplinary area at an intersection of science (fundamental and applied) and technology. Nanotechnology includes the development and creation of electronic circuits at the atomic and molecular levels, the development of robots (nanomachines, nanobots) the size of a molecule, as well as methods for studying such objects. Key skills that are required by a nanotechnologist are excellent analytical and problem solving skills, excellent IT skills and being good at mathematics.

1.1.5. Augmented Reality (AR)/Virtual Reality (VR)

Augmented or virtual reality can be useful not only in entertainment, but also in business processes, for example, staff training, project demonstration, as well as medicine, industry and tourism. The development of this direction is very promising. Such a modern use of AR is shown by a prototype system to reduce collision situations by drivers using AR to overlay guidance information and an AI based co-driver as a real-time alternative to the driver [5]. To succeed in this area, one needs to have rich imagination, possess the knowledge of the algorithms of computer vision, be proficient in programming languages, for instance Python, Java, C#, be able to create mobile and desktop applications, and have a good mathematical background.

1.1.6. Robotics

In robotics, the main task is to create automated systems, i.e. robots. The use of machines is multifaceted, including medicine, manufacturing, space industry, etc. To get a better understanding of modern robots, a recent survey on intelligent bots [6] shows their usability and consumer experience with them. In robotics, it is necessary to understand algebra, mathematical analysis, and geometry, have knowledge in the field of automatic control and the theory of designing automatic systems (software engineering).

The above mentioned emerging technologies are summarized in the table 1 with respect to the necessary skill.

1.2. Future Changes in the Software Engineering Skills Workforce: Literature review

The digital era and emergent technologies suggest a greater need to empower skill sets and career development for technology professionals, so they can be familiar with augmented and virtual reality, blockchain, unmanned vehicles, and other innovative technologies.

It is very difficult to predict the demand and success of professions, therefore, constant training and mastering of new competencies will allow specialists to remain in demand. It became more convenient for employers to reskill the current employees instead of hiring new ones. Employees are supporting this as they want to stay employed and can upskill their skills using the convenience of online courses. According to a recent McKinsey Global Survey, 87 % of executives said they are experiencing a skill shortage or expecting it for several years, which is why there is a trend towards online education and retraining [19].

A wide range of technical skills are needed for cloud computing, although security, networking, virtualization skills, and big data analytics are considered to be the key skills for cloud managing and analyzing very large data sets, such as images, text, or speech which are prominent future demanded skills. Competencies like data analysis, data selection, and data security became relevant for all employees in an organization [7].

Conferring to studies of the productivity of skilled workers, there are various factors that contribute to higher job performance. According to Erne [8], those factors are the quality of group interactions and skill development.

Also, a survey by Ahmed et al. [9] discovered, as a result of their survey, the main soft skills requirements for the software market in North America, Europe, Asia and Australia. They surveyed jobs advertised in online portals such as eurojobs.com (Europe), monsterindia.com (Asia), seek.com.au (Australia) and workopolis.ca (North America). According to the study, the main soft

Hard Skill Requirements for Software Engineering Specialists

Skill demanded	Emerging technologies with skill demand (skill highly demanded +/not relevant n/a)					
	Blockchain	AI	IoT	Nanotechnology/ Biotechnology	AR/VR	Robotics
Database	+	+	n/a	n/a	n/a	n/a
Programming	JavaScript, C++, Python	Python	Java, .NET, Python, PHP, Go, C++	n/a	Unity, SLAM, ARKit	Assembly, Java, MATLAB, Python, C/C++
Machine learning	n/a	+	+	n/a	n/a	+
Cybersecurity	n/a	n/a	+	n/a	n/a	n/a
Probability theory, statistics	n/a	+	n/a	n/a	n/a	+
Physics, chemistry, biology	n/a	n/a	n/a	+	n/a	+
Mobile application development/Web development	n/a	n/a	+	n/a	+	n/a
Algorithms and data structures	+	+	n/a	n/a	n/a	n/a
Software architecture	n/a	+	+	n/a	+	n/a

skills necessary for software engineering specialists are analytical and problem solving, organizational skills, fast learning, interpersonal skills, team playing, being open and adaptable to change, the ability to work independently, and being innovative.

Another survey, conducted by Matturro et al. [10] with software development team members and team leaders from the Uruguay software industry, arrived at the conclusion that soft skills, such as communication skills, leadership, interpersonal skills, customer orientation, and teamwork, are the most crucial skills needed for team leaders. Whereas commitment, responsibility, analytics, problem solving, motivation, teamwork and eagerness to learn, are the most important for team members.

During the first semester, students often struggle with their competencies and soft skills. Thurner et al. [11] was able to identify four reasons for this by conducting a learning project that concerns not only technical but also non-technical skills. One of the facts this study revealed is that the soft skills of students can be improved by self-reflection and self-awareness.

A survey by Reis J. et al. describes digital transformation as the use of new digital technologies that enables major business advances and influences all aspects of customers' life [12]. Further, they specify that skills such as communications skills and knowledge of virtual worlds are required in workplaces,

to either virtualize or to maintain control of people working remotely. Peter C. Verhoef et al. highlights in their research, the most essential digital properties and capabilities needed by businesses for digital transformation. They are digital assets, digital agility, digital networking capability, and big data analytics capability. According to them, human resource management views digital transformation as attracting employees with digital and analytical skills [13]. This shows that digital skills do not necessarily mean "tech" skills.

Our main assumption we have arrived at is that generic digital skills are not sufficient for emerging skills. Now employers working with these technologies want to see in their employees not only highly qualified specialists with all the necessary professional skills, but also individuals with such qualities as communication skills, flexibility, and adaptability to change. Currently, in the digital era it has become common to use digital educational and training content in order to overcome existing communication barriers and effectively complement existing and developing online education platforms [14]. The ability to learn fast with such educational platforms and tools becoming more important than acquiring specific knowledge.

We need to change software engineering specialists into digital talents so they can survive in the emerging technologies landscape. One of our crucial

Table 2

Soft Skills and References

Skill demanded	References
Creative thinking	[13, 15, 16]
Flexibility	[13, 17, 18]
Critical thinking	[12, 15, 19]
Adaptability and resilience	[13, 19–21]

recommendations is to improve meaningful skills, based on current labor market intelligence. This would also help IT specialists on furlough (due to the Covid pandemic), or who are worried about their jobs, to gain the skills for which there are current vacancies.

A summary of the most demanded skills associated with emerging technologies are presented in table 2.

A person who possesses all of the above skills will always be in demand in the labor market, and will also be able to negotiate on the conditions on which he will cooperate with companies.

It is quite difficult for an employer to find an employee with all these qualities. It is easier for employers to direct existing employees to improve their qualifications and create an "ideal" employee, rather than looking for one in the labor market. In the near future, companies that want to stay afloat will have to increase the budget for employee training. This, in turn, will help strengthen the company's position in the future and not crash when disruptions occur.

2. Case Study Methodology and Results

This research was conducted by means of a systematic literature review (SLR), following Kitchenham [22], with the purpose of understanding how the development of skills is approached in the existing pandemic and

remote work situation. Based on the findings we analyze the demands for digital skills for emergent technologies and identify the gaps in digital skill development. We propose a high-level approach on how software engineering specialists should develop and grow in their future skills and how to upskill students with a software engineering background.

The research was conducted to answer the following questions:

- RQ1: how do universities approach the development of skills in their curricula?
- RQ2: what hard/soft skills are most important for software engineering specialists to become more successful in their IT or digital career in the near future?

These questions helped in carrying out a systematic review process in order to identify applicable information in papers, journals and reports that can contribute to the goal of this research.

The data collection process was conducted through an online survey to get a better understanding on what students expect and what they need from education vs. what they actually get. We were expecting to discover what skills they learn outside the universities and what skills could help them to survive in employment in their future.

In the following sections we describe the methodology used to perform the research, how we collected data, and the criteria we used when selecting participants. Furthermore, it is described how we analyzed the selected data and the results obtained.

Data was collected from students who studied IT related subjects, such as software engineering, business informatics, and applied mathematics. The choice of students and specialties was based on the author's research on the correlation between specializations and emerging technologies (table 3).

As a result we developed a questionnaire to gather their general information such as the course they are

Table 3

Correlation between specializations and emerging technologies

Emerging Technology	University specialization
Blockchain	Information and Communication Technologies and Systems, Applied mathematics and Information Science, Business informatics, System and Software Engineering
AI	Information and Communication Technologies and Systems, Applied mathematics and Information Science, Software Engineering, System and Software Engineering
IoT	Information and Communication Technologies and Systems, System and Software Engineering
Nanotechnology/Biotechnology	Nanotechnology/Biotechnology
Augmented Reality/Virtual Reality	Software Engineering, System and Software Engineering, Other
Robotics	Applied mathematics, Information and Communication Technologies and Systems



Specialization

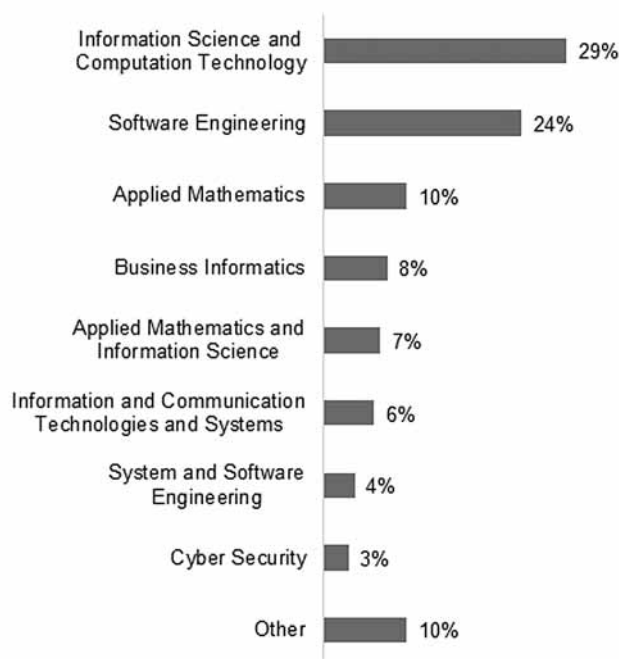


Fig. 1. Participants Specialization

studying, city/campus, and the name of the educational program in which they are studying. We then moved on

to questions related to skills, work experience, future professional expectations etc. The survey was voluntary and strictly anonymous.

The results show a summary of the survey in terms of the course of study; working experience; future IT professions they expect, in their opinion; the most useful IT skills they learned at university, and which skills are not adequate for a successful future IT profession, and more.

The participants (131) are studying under Information science (29 %) and Software engineering (24 %) programs. The rest are engaged in Applied mathematics (10 %), Business informatics (8 %), Applied mathematics and Computer science (7 %) and other programs related to computer science (fig. 1). The survey showed about 31 % of the participants have working experience in a software engineering specialty, while 44 % of them do not have any. 16 % of the participants are recorded as working/ interned but not in the speciality they are studying. A smaller percentage of participants (10 %) are marked as worked/interned but are currently not working.

When asked about their future profession after graduation, the majority chose data analyst (data engineer, data science). In second place, backend developer was chosen, while mobile application developer came third on the list. Professions like game developer, BigData analyst and web developer, respectively, received fairly high responses as well. Less popular choices were PHP, technical writer, and scrum master (fig. 2).

Question: What job do you want to do after graduation, in what role? Choose all the answers that suit you

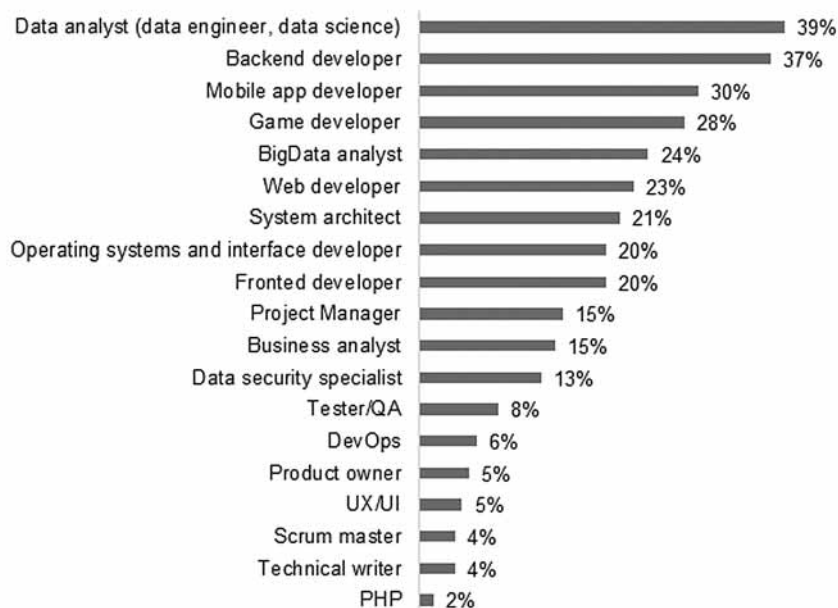


Fig. 2. Expected Future Profession

Question: What useful IT skills have you acquired for your future career while studying at the University? Choose all the answers that suit you



Fig. 3. Most useful IT skills that participants acquired during university studies for their future career

Participants were asked to list three hard skills that were useful during their studies and training period. Algorithms and data structures, object oriented programming, backend/frontend development, mobile application development, and programming languages were the significant choices that stood out among them.

When asked about the most useful IT skills they acquired at university which are beneficial for their future career, 44 % of the participants voted for interaction with the customer, and communication. A hard skill, such as machine learning were voted second, while data analysis and processing along with system design voted for equally. They recorded writing technical documentation as the least useful skill (fig. 3). Because the respondents chose multiple answers, the total amount is not equal 100 %

Most popular hard skills during university studies listed by the participants:

- Backend/Frontend development;
- Mobile application development;
- Machine learning;
- Object oriented programming;
- Programming languages; C#, C++, Java, Python, Js;
- Databases;
- Mathematical analysis;
- Algorithms and data structures;
- Operating systems;
- Web development;
- Quality Assurance and Testing;
- Software architecture;

- Algebra;
- Computing systems and computer networks.

According to the participants, the soft/hard skills that are missing from the university curriculum for a successful IT career in the future, are interaction with real companies and customers, and lack of necessary subjects (isolation of education from the labor market) respectively (fig. 4). The choices voted for the least are practical work (too much theory) and obsolete studying approaches.

Question: What are you missing and what can be strengthened in the current training format?

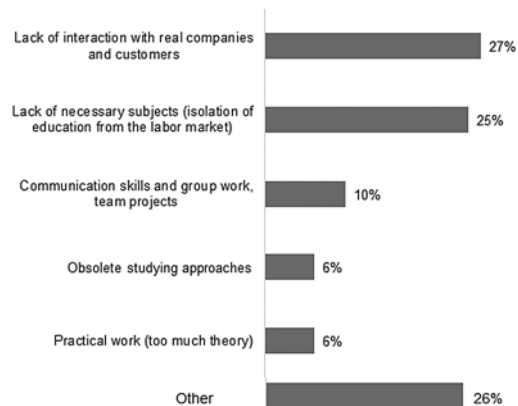


Fig. 4. Skills missing from the university curriculum for a successful IT career in the future

Table 4

Skills summation

Trending skills	IT Students survey (Valid, %)
Programming and development skills	62
Critical Thinking	51
Adaptability and resilience	44
Database	43
Writing technical documentation	32
Flexibility	30
Creative Thinking	25

When asked about the most useful IT skills which participants found most useful during university studies, 62 % of the participants voted for programming and development skills. A soft skill, like critical thinking was voted second (51 %), while adaptability and database was voted as 44 and 43 % accordingly. They recorded technical documentation, flexibility, creative thinking, data analysis and presentation skills, as not the most important skill but also the most highly demanded.

A summation of the main results of the survey and conclusions from the research are shown in table 4. The highlighted rows show that our findings from the survey validate our findings from the research. They are listed in descending order of participant votes from the survey. Some of the hard skills related to the IT area were not specified among general trends.

Adapting to the above skills is the foundation for securing a successful future profession. However, the skills that they cannot acquire during that time can be gained from other means, such as online courses or working as interns. Furthermore, we can propose that at least a portion of the university curricula should be based on what the individual chooses to learn so that they can pursue their interests.

3. Limitations and Future Work

The research was completely remote. Even though we followed a protocol to conduct the survey, the limited number of participants of this empirical study might affect its validity, scalability, and applicability of the results to broader contexts. The survey was circulated only among HSE University students. IT professionals were not included as survey participants as our goal was to discover skills needed by software engineering students and young specialists for their future, to work with emerging technologies. In our future work we are hoping to involve IT professionals to identify

their required skills and to update the research results considering their needs. This will help to leverage the supposed student's career development plans with the IT professionals' expectations.

Conclusion

To adapt to emerging trends, soft skills are a significant part of a student's development as well as hard skills. However, the majority of the higher education institutions generally neglect them in the computer science and software engineering curricula. Considering the importance of soft skills for the process of digital transformation and to keep up with emerging trends, the main question this study aims to answer is how we can improve computer science and software engineering students' skills, preparing them for the future market challenges by using industry emerging practices.

Our study showed that hard skills such as algorithms and data structures, object oriented programming, backend/frontend development, mobile application development, learning programming languages, and soft skills such as problem solving, dealing with uncertainty/adaptability, flexibility and creative thinking, are crucial skills that are absolutely vital for the software engineering specialist's successful career. We were able to confirm our findings using participants' responses. Furthermore, the study showed that soft skills, like interaction with businesses and customers, and a lack of necessary subjects resulting from the isolation of education from the labor market, are missing from the university curricula.

Relying on our literature overview and trends analysis, we concluded that we need to mold software engineering specialists into digital talents because new skills are required as new business opportunities arise. The automation process will change the workforce. We have identified it as being important to develop both soft skills as they are in high demand by employees, and hard skills which are required by employers, as they are the very basic requirements for employment and are crucial to keep up with emerging technical trends.

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ИНФОРМАЦИЯ

Х Международная научная молодежная школа-семинар «Математическое моделирование, численные методы и комплексы программ имени Е. В. Воскресенского»

14—18 июля 2022

Приглашаем Вас принять участие в Х Международной научной молодежной школе-семинаре «Математическое моделирование, численные методы и комплексы программ» имени Е.В. Воскресенского, которая состоится в смешанном формате (очно и дистанционно) с 14 по 18 июля 2022 г. на базе Национального исследовательского Мордовского государственного университета им. Н.П. Огарёва.

СЕМИНАРЫ ШКОЛЫ

1. Принципы построения математических моделей.
2. Численная реализация алгоритмов математических моделей.
3. Динамические системы и качественные методы анализа математических моделей.
4. Математические модели физики, химии, биологии, экономики, социологии, экологии и других отраслей науки.

Подробности: <http://agora.guru.ru/SCHOOLSEMINAR2022/>