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# Structuring the Post-COVID-19 Process of Digital Transformation of Engineering Education in the Russian Federation

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**Abstract:** The temporality of the socio-technological transformations of industry 4.0 has exacerbated the problem of introducing and using digital technologies in the educational process. The development in this area is due to the presence of unique global challenges, the availability of digital devices, and the experience of distance learning due to the COVID-19 pandemic. As part of the work, a statistical study was conducted aimed at establishing the average level of proficiency in the basic skills of independent search for information on the Internet. A classification of digital solutions is formulated, and an attempt is made to synthesize criteria for the successful integration of digital solutions into the educational process, the following groups are distinguished: organizational, auxiliary, structural, and specialized. Independent searching for information is considered an element of the educational process, which changes almost uncontrollably, unlike other solutions in the field of digitalization of education. The process of digitalization is presented as a set of four elements, the successful implementation of which will allow the effective implementation of digital technologies in the educational process. An element of digital infrastructure is highlighted; an element of organization, an element of integrating teachers into a new digital educational environment, and a student element. It is concluded that it is necessary to introduce courses of additional competencies dedicated to working with information; the idea of integrating master's students into research aimed at solving modern global challenges with the help of digital technologies is proposed.

**Keywords:** digitalization of education; COVID-19; pace of scientific and technological progress; engineering education; digital transformation; human capital



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## 1. Introduction

The COVID-19 pandemic has had an unprecedented impact on higher education systems around the world. Thus, as the disease spread, states were forced to urgently change their approach to education in order to prevent the spread of the disease. At first, these measures were limited to wearing personal protective equipment and limiting mass gatherings, and then there was an emergency transition almost all over the world to the distance learning format, which became an unprecedented challenge for the modern higher education system.

At the very beginning of the pandemic, the problems with the education system were the focus of the UN. In particular, the UN Secretary-General António Guterres defined the threat as a unique opportunity to rethink the concept of education, take radical measures based on digital technologies, and introduce new mobile learning methods and curricula [1]. As a result of the widespread total closure of educational institutions, UNESCO has taken various international initiatives to monitor the education system in order to minimize educational disruptions and ensure the continuity of learning [2].

Understanding the impact of the pandemic on young people and the response of educators and government agencies, as well as gathering knowledge, ideas, experiences, and practices in the new environment became the central theme of the UNESCO-UNEVOC TVET 2020 conference, which was attended by about seven thousand people. The conference discussed skills for resilient youth in the face of new challenges, highlighted the importance of training young people in employability, decent work, and entrepreneurship skills to work in post-COVID-19 societies when young people are looking for work, and called for support for the recovery efforts they need, will have the appropriate skills as well as competencies to solve emerging problems and adapt to future disruptions successfully [3].

The International Institute for Educational Planning is concerned in this regard both with the unpreparedness of the teaching staff and administration and, in particular, with students, many of whom did not have access to digital learning tools [4]. At the same time, the Inter-agency Network for Education in Emergencies, under the auspices of UNESCO to mitigate the challenges of the pandemic COVID-19 is releasing a guide to support education during periods, which, based on educational standards, highlights different steps in the work of educators in the acute phase of the pandemic [5].

Quite a large number of scientific works are devoted to the study of such a large-scale and significant phenomenon. A very detailed development of events and a description of the measures taken in various countries are presented in the work "COVID-19: 20 countries' higher education intra-period digital pedagogy responses" by an international team of authors, calling for the aggravation of integration response measures to the pandemic [6]. Analyzing publications on the topic of the emergency distance learning experience caused by the COVID-19 pandemic, several key aspects can be identified.

*The main difficulties and difficulties in the transition to a remote format.* A survey conducted by the Bay View Analytics collaboration and the academic community of several leading universities and colleges in the United States and Canada showed that the majority of teachers did not have experience working in a distance format and the challenge of the impersonal nature of virtual learning becomes a problem for them [7]. In addition, attention is drawn to the lack of a "modern" teaching methodology adequate to the situation. From the point of view of the education system: issues of mobility, technical resources of digital learning, differentiated access to education, and the need for additional financial support for students [8–10]. Universities had to take colossal measures to provide uninterrupted educational services [11]. From the point of view of the teaching staff: the required high level of computer literacy, special communication skills for working online, and the readiness of the teaching staff and students for online learning [12–14]. From the point of view of students: technical problems, difficulties with self-organization, and concentration of attention [12,15].

These problems can be traced despite the fact that over the past decades, humanity has shown cardinal breakthroughs in technological progress, breaking into the temporality of the development of digital technologies in a new era [16]. The world within one human life has gone through several stages of development, having found itself, almost instantly, in Industry 4.0 [17,18], which, of course, manifested itself in many ways in education [19], transforming it in a significant way. At the same time, the term Industry 5.0 [20] and Education 5.0 are increasingly being used in the scientific and business community [21–23].

However, education, having moved partially in the form of courses to the online environment, mainly remained in the previous format of real lectures and seminars [24]. At the same time, there were opinions both suggesting transferring education to a distance format [25] and those who believed that this was hindered both by the unpreparedness of the environment [26] and, most importantly, that the digital reality lacks the most important component of university education, namely socialization [27].

The pandemic forced everyone to bend themselves and forced them to switch to distance education [28]. The surprising fact was that for the first time in the conditions of the global world, such a radical transformation took place [29], which affected not a single

group of the population, but humanity as a whole [30]. The experience gained has already left its mark [31].

*Advantages of distance learning format.* An opinion is expressed that due to the ultra-fast development of the digital world and the resulting radical transformation of all social institutions [32], as well as the use of some new technologies and approaches to learning in the pre-COVID-19 period, which was exclusively local and short-term in nature [33,34], the education system was, to some extent, ready for the coming transformation, despite all the warnings and fears, the so-called progressophobia, regarding digital transit [35]. In publications, the assessment of the advantages of distance education is usually formed on the basis of the respondent's answers, the most popular of the options: no need to attend general classes and, as a result, the opportunity to better organize one's own time, saving time [36–38].

*Prospects for further use.* In this direction, both the prospects for using the experience of emergency distance learning and the reasons that caused the problems described above, methods for their elimination, as well as limitations and obstacles in the further use of the system are noted [39]. Some new trends are shown, which made it possible to find and test new teaching methods [11]. The new accelerated communication format provided educators with the basis for the need to retrain and fill the current gap, as well as to rethink and change the future curriculum [40]. It is emphasized that despite the comparative success of this experiment, a whole range of problems were noticed, which should be eliminated with the further development of this direction [41]. Thus, a number of challenges are given: unpreparedness for a quick transition, problems with the quality of distance education, financial problems, and the process of transition to an alternative form of education. As a solution, some authors propose the concept of a sustainable digital environment, following which the university will not only actively use digital technologies but will also be prepared for similar challenges in the future [42]. Within the framework of the Russian Federation, a large-scale sociological study was also carried out, the results of which noted the main trends and problems faced by teachers [43]. It should be noted that despite the fact that the experience of emergency distance learning can be called useful, the prospects for further integration of distance learning into the higher education system, even if the existing problems in its organization are solved, are highly doubtful, due primarily to the lack of a practical component, which, for example, is a critical factor for engineering specialties [44,45].

However, the COVID-19 pandemic has significantly accelerated the process of digital transformation of the higher education system and served as a kind of catalyst for its further development [46]. At the same time, it should be noted that such a great interest in this topic [47] can lead to ineffective changes. Therefore, at the moment, the urgent task is to structure the phenomenon of digital transformation in higher education.

The structuring of this process should include the classification of digital solutions, the identification of the main factors that determine changes in the higher education system, as well as the formulation of the elements for the development of digital transformation.

The vast majority of research on this topic focuses on digital decisions and changes that are adopted or initiated by an educational organization. However, there are aspects of the digital transformation process that influence the educational process from the outside. We are talking about the process of independent search and elaboration of information by the student, which is an integral part of higher education. However, despite the importance of this aspect in the literature, insufficient attention has been paid to its change in the framework of digital transformation. Moreover, the importance of studying this aspect should be emphasized not only at the global level but also in individual countries since its changes will largely depend on the characteristics of the digital transformation of a particular country.

As part of the study, a hypothesis was put forward that the active development of digital technologies in recent decades, as well as the COVID-19 pandemic, has radically

changed the approach to independent information search and also require students to have new information search skills that are currently being acquired in the course of study.

Thus, a number of objectives of this work can be distinguished:

1. Ascertain the most preferred source of information for self-preparation.
2. Determination of the average time spent on preparing for a lesson, as well as an analysis of the influence of the current course of study, the level of motivation, and academic performance on the duration of training.
3. Analysis of the thoroughness of the study of the material under study, depending on the motivation and progress of the student.
4. Exploration of changes in the degree of use of basic tools for information search in the network, depending on the current course of study.
5. Structuring the process of digital transformation in the Russian Federation by proposing the authors a set of elements and factors that will allow focus on the key aspects of the process of digital transformation of a higher educational institution, which may be useful due to the catalytic effect that the COVID-19 pandemic played.

## 2. Materials and Methods

As part of this study, a survey was conducted among students at St. Petersburg Mining University. The survey was conducted in the 2021/2022 academic year using the Google Forms platform. It was attended by 352 respondents from among the students at St. Petersburg Mining University of various specialties and courses. Participation in the survey was completely voluntary and anonymous.

Before proceeding to a full-scale study, a focus group was assembled on a voluntary basis, which went through the questionnaire in the office in the presence of the authors and could make clarifications as they filled out the questionnaire if some questions or answers options were not clear. The results of this stage of preparation are absent in the materials presented in this work and were not used by the authors when describing the results of the study. Based on the work with the focus group, the final version of the study was adjusted to take into account all the questions that the group had and to make the necessary explanatory comments on the questions and answer options. You can read the full results of the survey in detail at the link provided in the materials of this work.

Respondents on the university intranet were asked to complete an anonymous survey that did not require email or any other form of registration. The survey contained 22 questions, but this publication does not present a complete analysis made on the basis of the questionnaire, but only an analysis of those questions that are directly related to the study described in this work.

The survey is structured in such a way that the questions posed in it can be divided into two broad categories.

1. Questions that make it possible to divide respondents into groups based on common characteristics or their combinations (course, gender, university and school performance, USE score, level of motivation, reason for obtaining higher education). This category includes the first seven questions.
2. Questions that allow you to assess the reaction of respondents to any aspect of digital transformation. Questions 8 to 22.

After a representative number of participants was received and the main flow of those wishing to take part in the study ended, access to the survey was closed.

After that, the function of unloading the survey results in the form of an xls-file was used. Then, to speed up the analysis of the obtained data, a program code was implemented in the Python programming language. The developed program reads data from the provided xls-file and then allows you to generate several types of reports also in the xls-file format:

"General statistics"—the simplest option without division into categories, questions are presented in order along with answer options. Next to each option, the number and percentage of respondents who chose this answer option are presented.

"Detailed statistics"—for each question, a separate sheet is created in the xls-file, in which the respondents are divided into separate columns, depending on which option they chose in this question. The columns show the distribution of answers in this category to all other questions.

"Combined groups"—for this type of statistics, two questions of interest are indicated, from the answers to which

"Multiple Answers" is a separate category that generates statistics similar to the "General Statistics" type but for questions in which more than one answer can be selected.

Thus, the developed program allows you to quickly present the distribution of respondents by category in a form convenient for understanding and further analysis.

To test the hypothesis, a block of questions was formed, which, according to the authors, reflect the most basic information retrieval tools, will be understandable to the target audience of the survey without additional comments, and do not depend on a particular specialty. This set of questions included the following:

1. What source do you most often use to find the information you need to study?
2. How many search engines do you use when looking for information you need to study? (Example: Yandex, Google)
3. Are you using search syntax? (Example: " ", -, *, allintext: etc. . . . )
4. How often do you use the key combination "Ctrl + F" when searching for information?
5. Do you use the Search by Image tool?

The second block is designed to analyze the process of student self-training and consists of the following questions:

1. How much time do you spend on average searching for information while preparing for classes in one subject?
2. How do you remember the information found on the Internet?

The greatest interest within the framework of the research hypothesis was the division of respondents into groups in accordance with the current course of study. However, a division into groups was also carried out depending on the motivation for further education and current academic performance in order to analyze the impact of the student's interest in learning on the process of independent work.

## 3. Results

### *3.1. Results of Sociological Research*

In the modern world, this issue is becoming increasingly relevant since the methods of searching for information and the problems faced by students have changed dramatically over several decades. So, if earlier information had a fairly high quality, but due to its physical nature, the search and development of knowledge were very labor-intensive processes, now there is an opposite picture: the transformation of information into a digital environment and its easy accessibility has led to the formation of information chaos in which repeatedly processed information no longer reflects reality or even is fundamentally wrong. This point is incredibly important when it comes to a student who is just studying the specifics of his profession and can be misled by unreliable sources. At the early stages of learning, it is impossible to provide a holistic understanding of the subject, so it is necessary to solve the problem of information chaos by developing the appropriate skills to search for and use useful functions.

#### 3.1.1. Groups of Respondents

This section describes the distribution of students into groups depending on the parameters of the studied parameters (course of study, current performance, motivation for further education). The main objective is to give the reader a better understanding of the

structure of the resulting sample and to provide quantitative data about each group, which will be used in subsequent blocks. Information about groups of students is formed in the form of a table (Table 1).

**Table 1.** Data on groups of respondents.

| Please indicate which year student you are | | |
|---|---|---|
| **Answer options** | **Number of respondents** | **Percentage of the total number of respondents** |
| First-year student | 188 | 53.41 |
| Second-year student. | 74 | 21.02 |
| Third-year student | 26 | 7.39 |
| Fourth(fifth)-year student | 35 | 9.94 |
| Master student | 29 | 8.24 |
| **What grades do you usually get now? (Differentiated tests, exams, term papers, etc.)** | | |
| **Answer options** | **Number of respondents** | **Percentage of the total number of respondents** |
| Excellent student | 45 | 12.78 |
| Good student | 231 | 65.63 |
| Average student | 76 | 21.59 |
| **How would you rate your level of motivation to learn?** | | |
| **Answer options** | **Number of respondents** | **Percentage of the total number of respondents** |
| Very high | 43 | 12.22 |
| High | 138 | 39.21 |
| Average | 122 | 34.66 |
| Low | 29 | 8.23 |
| Very low | 20 | 5.68 |

#### 3.1.2. Information Search Skills

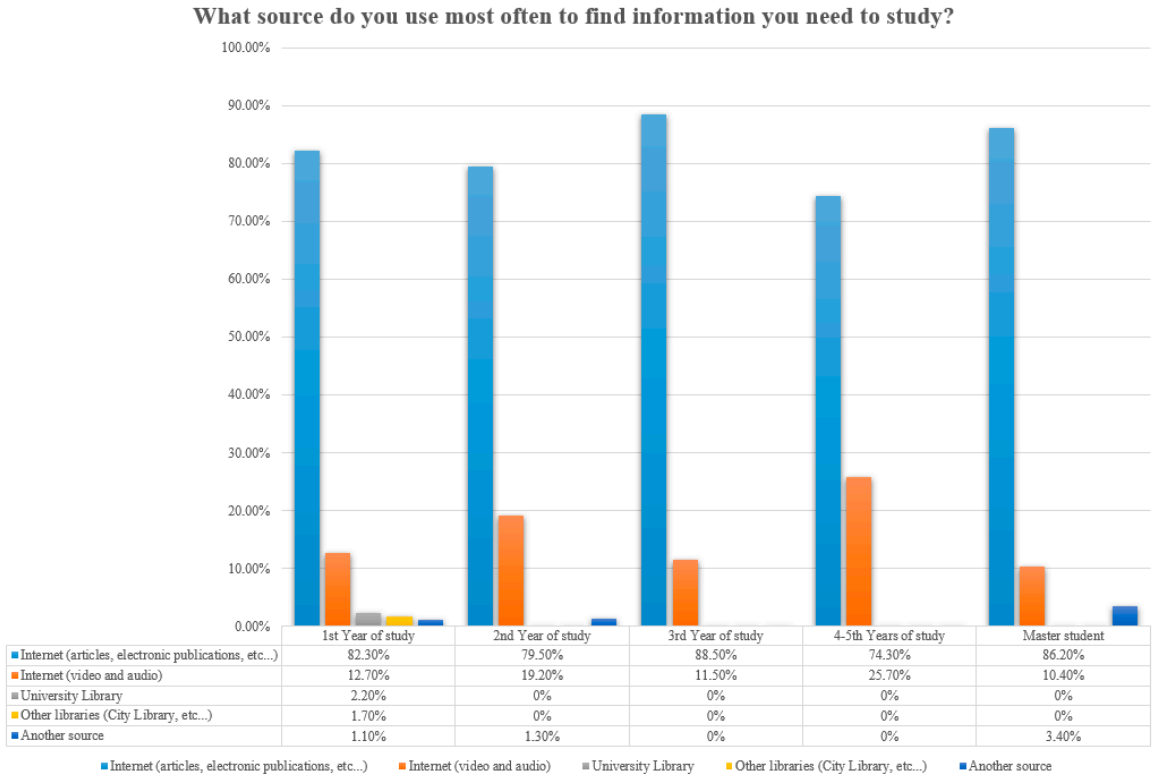
This section presents the results of the analysis of a block of questions devoted to the skills of searching for information on the network. In this case, in order to test the hypothesis, the respondents were divided into groups depending on the course of the study.

Thus, the diagram (Figure 1) shows the distribution of respondents' answers to the question, "What source of information do you most often use to find the information necessary for study?". As can be seen from the diagram presented, the vast majority of students use the Internet as the main source of information, regardless of the course of study. Thus, 82.1% of respondents are looking for information for classes on the Internet and give priority to textual information, 14.79% of respondents are looking for information for classes on the Internet and give priority to video information, and only 3.11% of answers come from all other sources.

The diagram (Figure 2) shows the distribution of respondents' answers to the question, "How many search engines do you use when searching for information necessary for the study?". As can be seen from the presented diagram, this indicator practically does not depend on the course of study. At the same time, 38.07% of respondents use one search engine, 44.6%—two, 8.24%—three, and 9.09%—use more than three search engines.

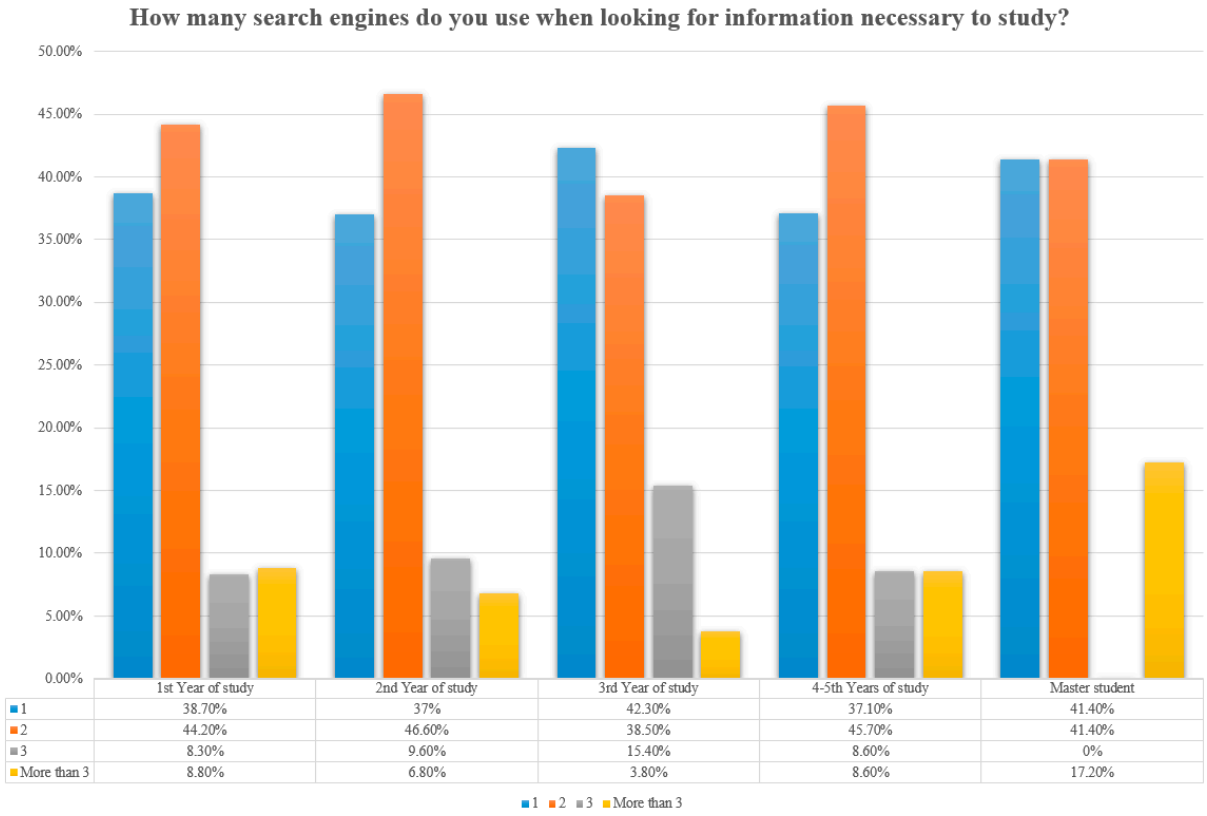
In addition, from a chart visualizing respondents' answers to the question "Do you use the Image Search tool?" (Figure 3) it can be concluded that the use of this tool does not practically depend on the course of study. Among all respondents, the number of those who actively use the tool "search by image" reaches 65.9%.

On the basis of the survey, it is impossible to judge the effectiveness of these approaches. However, it can be concluded that solving the problems of searching for information on the Web as part of the educational process does not contribute to their acquisition.




| | 1st Year of study | 2nd Year of study | 3rd Year of study | 4-5th Years of study | Master student |
|---|---|---|---|---|---|
| Internet (articles, electronic publications, etc...) | 82.30% | 79.50% | 88.50% | 74.30% | 86.20% |
| Internet (video and audio) | 12.70% | 19.20% | 11.50% | 25.70% | 10.40% |
| University Library | 2.20% | 0% | 0% | 0% | 0% |
| Other libraries (City Library, etc...) | 1.70% | 0% | 0% | 0% | 0% |
| Another source | 1.10% | 1.30% | 0% | 0% | 3.40% |

**Figure 1.** "What source do you most often use to search for information necessary to study?". Question answer statistics.




| | 1st Year of study | 2nd Year of study | 3rd Year of study | 4-5th Years of study | Master student |
|---|---|---|---|---|---|
| 1 | 38.70% | 37% | 42.30% | 37.10% | 41.40% |
| 2 | 44.20% | 46.60% | 38.50% | 45.70% | 41.40% |
| 3 | 8.30% | 9.60% | 15.40% | 8.60% | 0% |
| More than 3 | 8.80% | 6.80% | 3.80% | 8.60% | 17.20% |

**Figure 2.** "How many search engines do you use when looking for information necessary to study?" Question answer statistics.

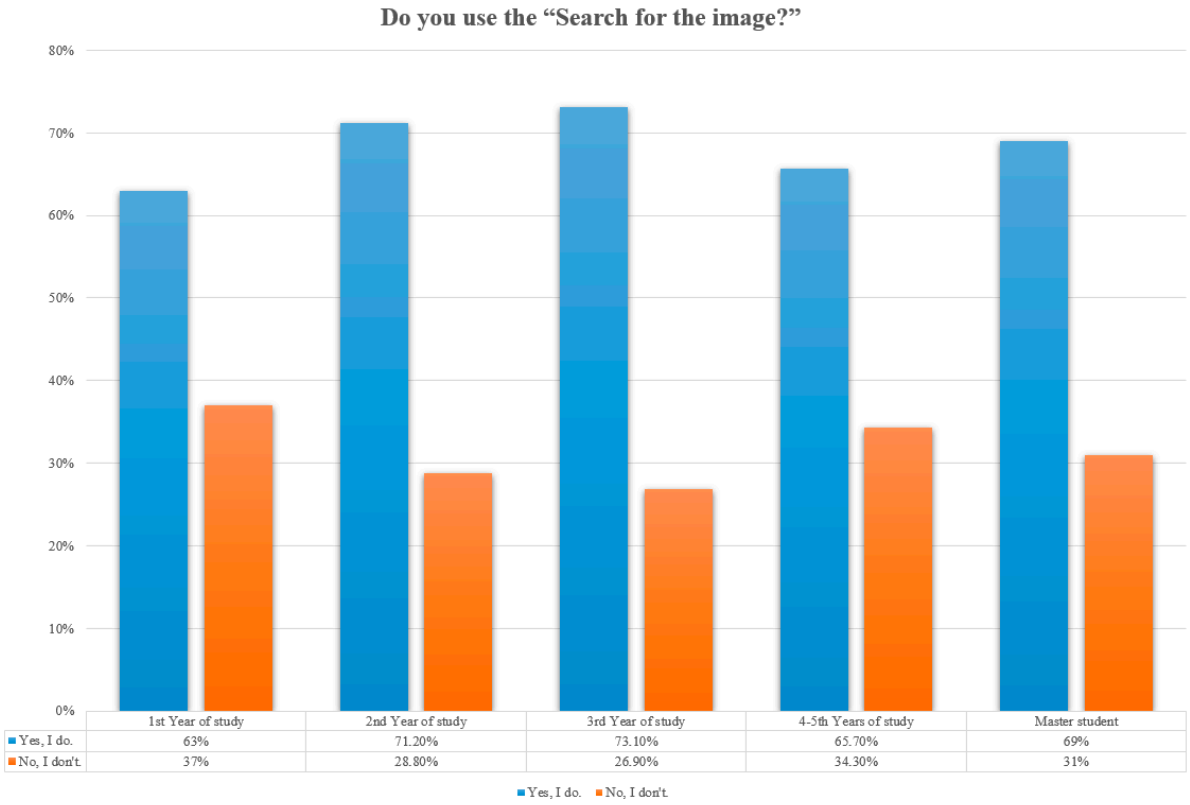



**Figure 3.** "Do you use the 'Search for the image?" Question answer statistics.

However, if you pay attention to the other two search tools considered in this block of questions, then you can quite clearly see the dependence of the activity of their use on the student's current course of study.

So, the diagram (Figure 4) shows the distribution of respondents' answers to the question "Do you use search syntax? (Example: " ", -, *, allintext: etc.", according to which one can clearly observe an increase in the number of affirmative answers from one to five courses in undergraduate and specialist programs. So, in the first year, the number of answers "Yes, use" reaches only 18.20%, while in the 4th–5th year, it is already 40%. At the same time, there is a decrease to 31.10% in the group of masters.

The distribution of respondents' answers to the last question in this block is shown in the diagram (Figure 5). So, analyzing the statistics of answers to the question "How often do you use the key combination "Ctrl + F" when searching?" trends similar to the previous diagram can be noted. So, in the first year, the percentage of students who constantly use the "Ctrl + F" key combination when searching for information reaches only 17.2%, while in all subsequent courses, this percentage grows and reaches 74.3% in 4–5 years of study. At the same time, for the group of masters, there is again a slight decrease to 72.4%.

Given the fact that the survey included the most common search tools, it is worth noting the fact that first-year students often do not have the necessary information search skills but gain some work experience only by their senior years. This circumstance indicates that the issue of obtaining information search skills at the early stages of education is relevant in view of their further active use in senior courses.

#### 3.1.3. Analysis of the Process of Self-Training of Students

This section presents the results of the analysis of a block of questions devoted to the process of self-training of students. The respondents were divided independently according to several parameters: course of study, current performance, and motivation for further education.

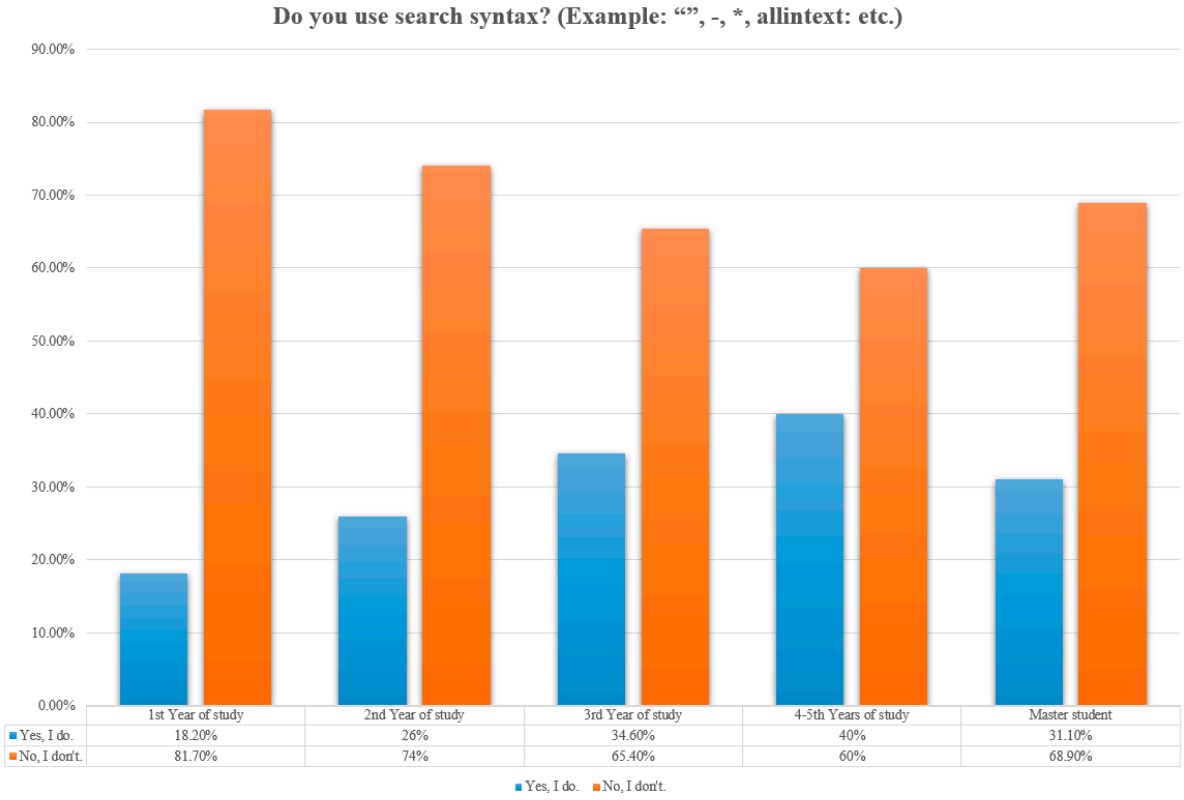



**Figure 4.** “Do you use search syntax? (Example: “”, -, *, allintext: etc.)” Question answer statistics.

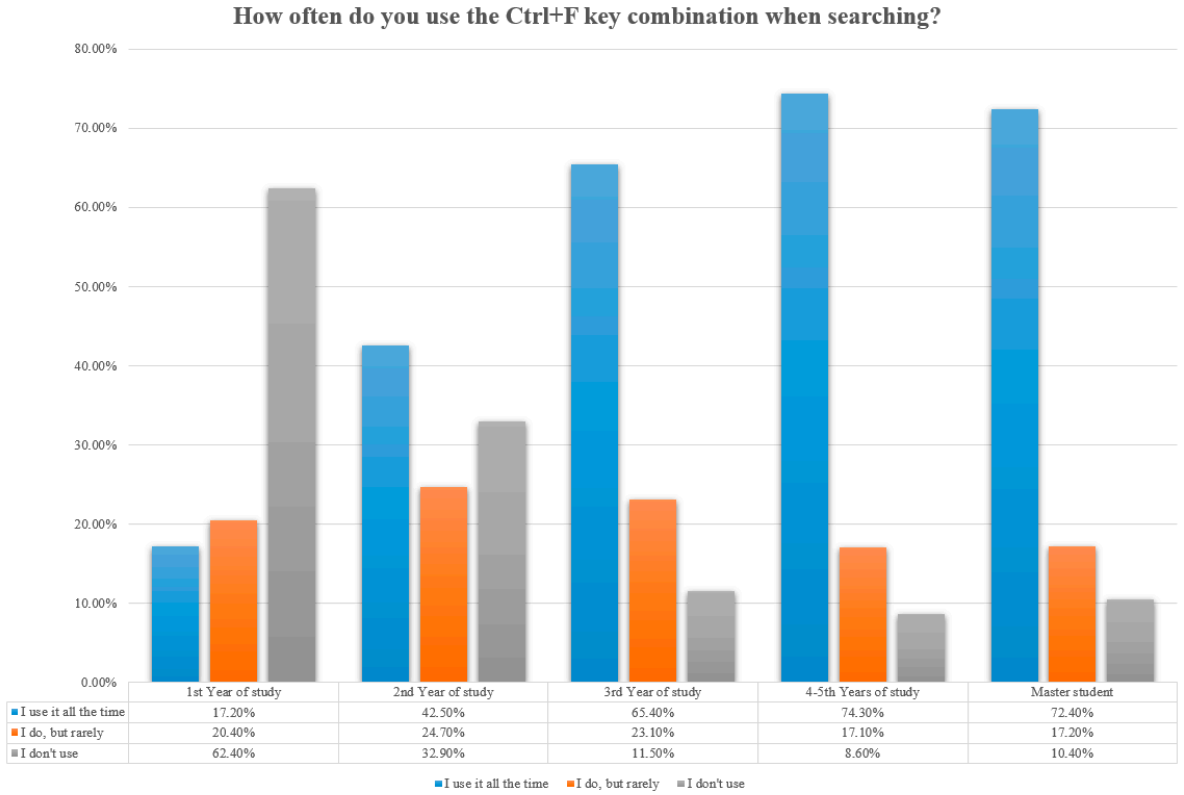
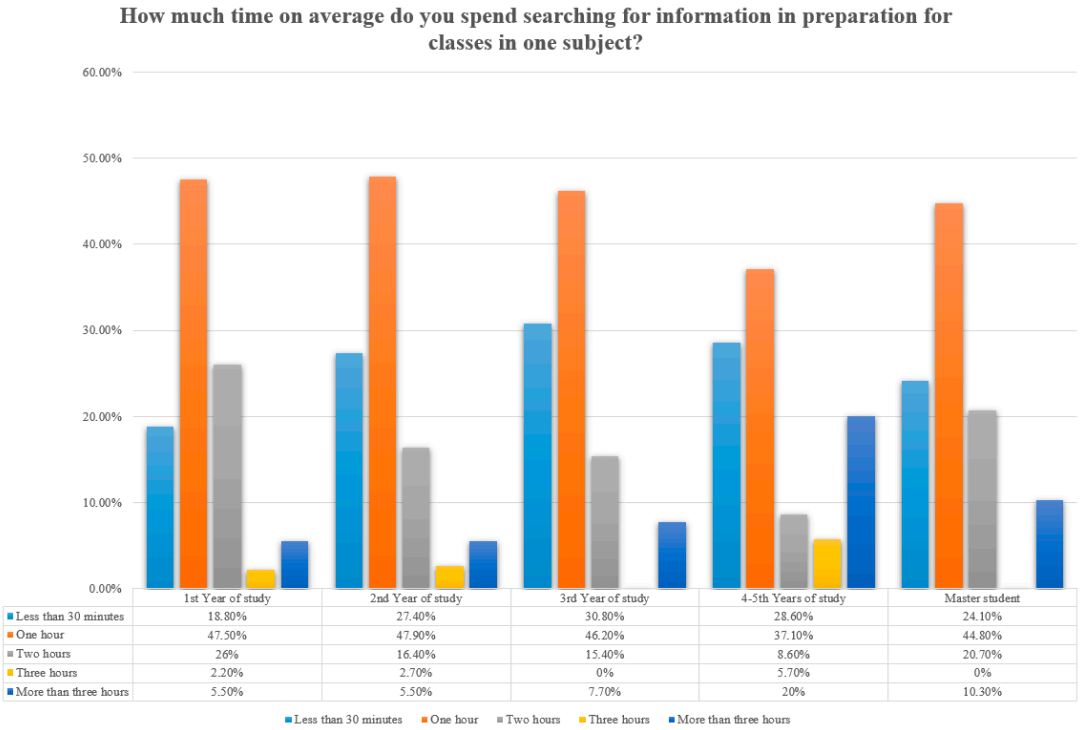


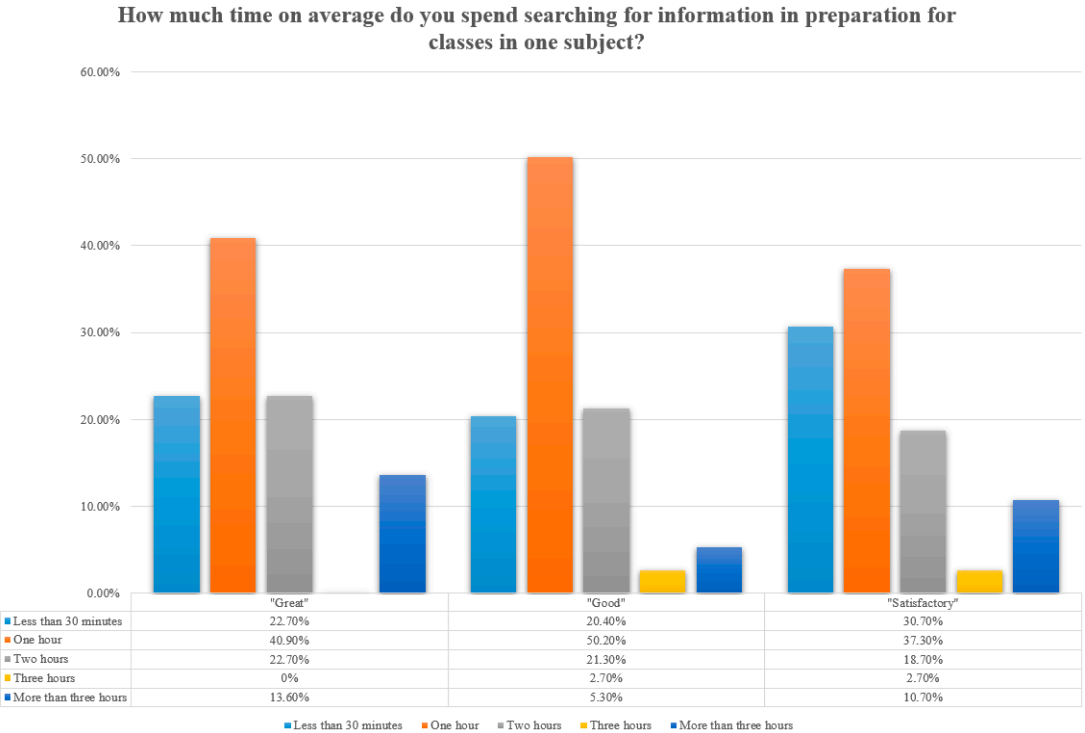

**Figure 5.** “How often do you use the Ctrl + F key combination when searching?” Question answer statistics.

The diagrams (Figures 6–8, respectively) show the distribution of respondents' answers to the question "How much time do you spend on average searching for information while preparing for classes in one subject?" depending on the course of study, university performance and motivation for further education.



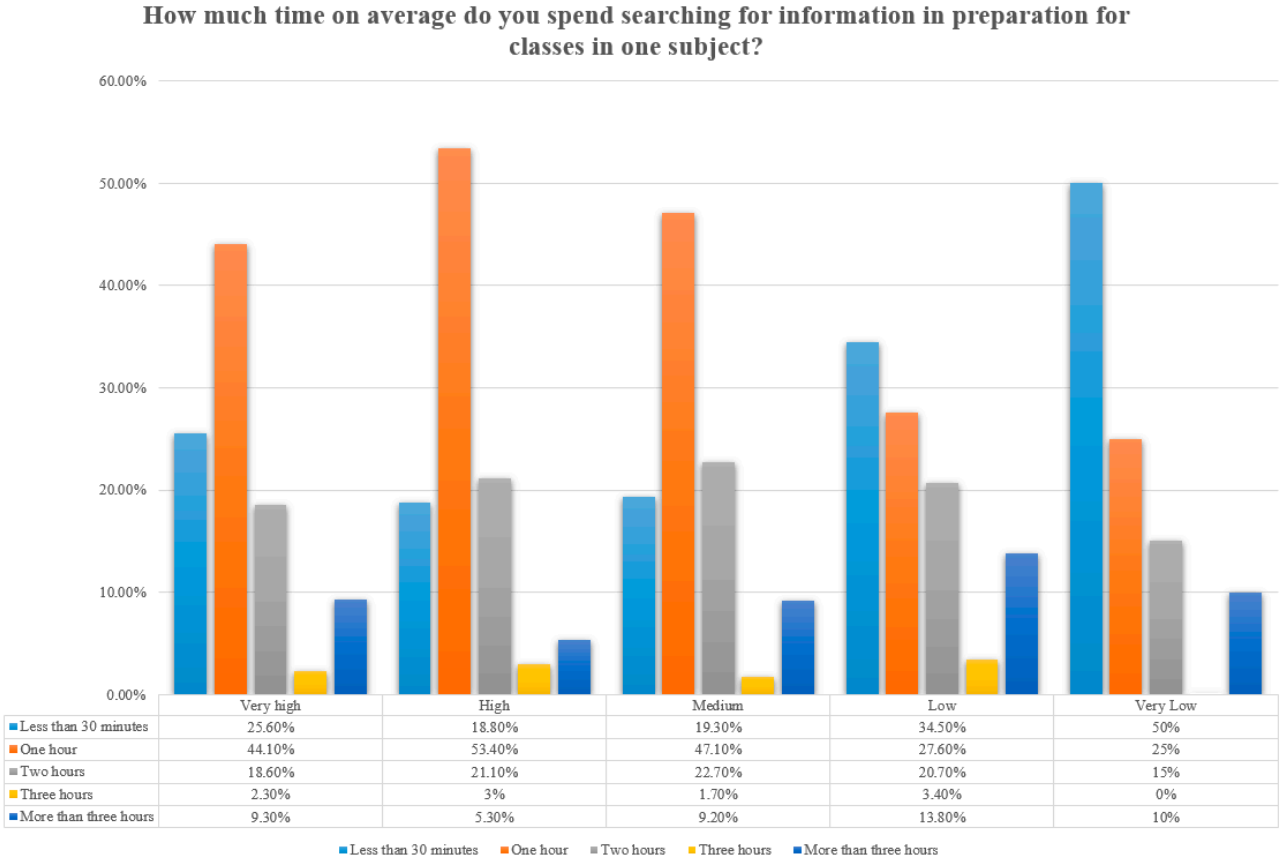

| | 1st Year of study | 2nd Year of study | 3rd Year of study | 4-5th Years of study | Master student |
|---|---|---|---|---|---|
| Less than 30 minutes | 18.80% | 27.40% | 30.80% | 28.60% | 24.10% |
| One hour | 47.50% | 47.90% | 46.20% | 37.10% | 44.80% |
| Two hours | 26% | 16.40% | 15.40% | 8.60% | 20.70% |
| Three hours | 2.20% | 2.70% | 0% | 5.70% | 0% |
| More than three hours | 5.50% | 5.50% | 7.70% | 20% | 10.30% |

**Figure 6.** "How much time, on average, do you spend searching for information when preparing for class in one subject?" Statistics of answers to the questions by year of study.




| | "Great" | "Good" | "Satisfactory" |
|---|---|---|---|
| Less than 30 minutes | 22.70% | 20.40% | 30.70% |
| One hour | 40.90% | 50.20% | 37.30% |
| Two hours | 22.70% | 21.30% | 18.70% |
| Three hours | 0% | 2.70% | 2.70% |
| More than three hours | 13.60% | 5.30% | 10.70% |

**Figure 7.** "How much time, on average, do you spend searching for information when preparing for class in one subject?" Statistics of answers to the questions on academic achievement.




| | Very high | High | Medium | Low | Very Low |
|---|---|---|---|---|---|
| Less than 30 minutes | 25.60% | 18.80% | 19.30% | 34.50% | 50% |
| One hour | 44.10% | 53.40% | 47.10% | 27.60% | 25% |
| Two hours | 18.60% | 21.10% | 22.70% | 20.70% | 15% |
| Three hours | 2.30% | 3% | 1.70% | 3.40% | 0% |
| More than three hours | 9.30% | 5.30% | 9.20% | 13.80% | 10% |

**Figure 8.** "How much time, on average, do you spend searching for information in preparation for classes in one subject?" Question answer statistics.

Thus, according to Figure 6, it can be noted that the time spent by students on preparation increases depending on the current course of study. Again, this dependence is typical from the first to the fourth-fifth course.

In Figure 7, it can be noted that students receiving "Satisfactory" grades are 10% more likely than other groups to choose the answer "Less than 30 minutes". Thus, this answer was chosen by 30.7% of the respondents in this group, while among the "Excellent" and "Good" groups, only 22.7% and 20.4%, respectively.

In Figure 8, it should be noted that students with very low motivation show the least amount of time for preparation, among which the option "Less than 30 minutes" was chosen by 50% of the respondents.

From the general statistics without distribution by groups, we can say that 22.44% of respondents spend on the preparation of "Less than 30 minutes", "One hour"—46.59%, "Two hours"—20.74%, "Three hours"—2.84%, "More than three hours"—7.39%.

Figure 9 shows the distribution of respondents' answers to the question "How do you remember the information you find on the Internet?" depending on the motivation for learning and current academic performance. With the help of the orange arrow in the diagram, there is a very noticeable tendency to simplify the methods of information analysis as academic performance and motivation decrease. So, with "Very high" motivation, each of the presented options accounts for about a little more than 30% (34.8%; 32.6%, 32.6%), while as the level of motivation decreases, more labor-intensive ways of analyzing information, such as its structuring or note-taking become less popular among those surveyed. As a result, for students with a level of motivation for learning "Very low," the option with the simplest method of analyzing information is 65%, while its structuring and note-taking account for only 20% and 15%, respectively.

| Answer | Very High | High | Medium | Low | Very Low |
|---|---|---|---|---|---|
| How do you remember the information you find on the Internet? | | | | | |
| Structuring information on the topic in a document | 34.8% | 30.8% | 38.7% | 31% | 20% |
| All I need to do is read/watch the video | 32.6% | 45.1% | 44.5% | 58.6% | 65% |
| Taking notes in a notebook | 32.6% | 24.1% | 16.8% | 10.3% | 15% |

Simplification of information analysis methods

| Answer | "Great" | "Good" | "Satisfactory" |
|---|---|---|---|
| How do you remember the information you find on the Internet? | | | |
| Structuring information on the topic in a document | 36.4% | 28.4% | 24% |
| All I need to do is read/watch the video | 31.8% | 39.6% | 64% |
| Taking notes in a notebook | 31.8% | 32% | 12% |

**Figure 9.** "How do you remember the information you find on the Internet?". Question answer statistics.

An absolutely similar situation can be observed in the distribution by performance. Almost equal shares of answers among respondents from the "Excellent" group and the prevalence of the least time-consuming way of analyzing information in the "Satisfactory" category.

### *3.2. Structure of the Digital Transformation Process*

#### 3.2.1. General Structure and Brief Explanation

In this section, the authors propose a structure for the digital transformation process, the main task of which is to give a clearer idea of the process and emphasize the most important aspects of this process from the point of view of an educational organization.

Thus, the authors identified three main aspects (Figure 10): factors, elements, and digital solutions.

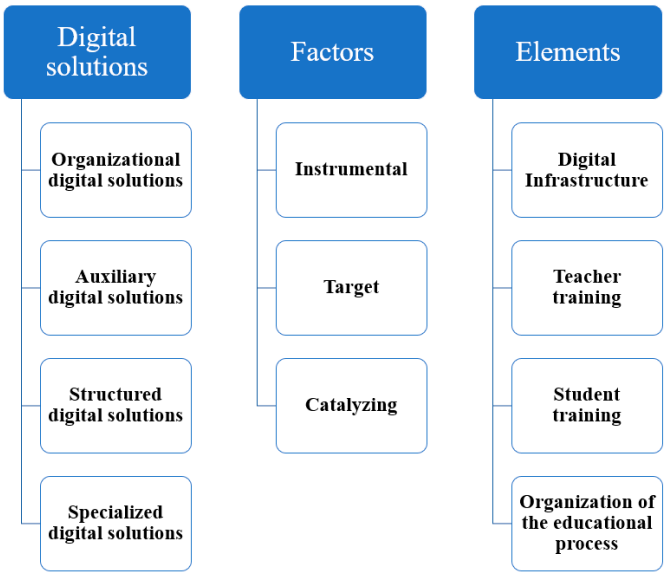



**Figure 10.** Structure of the digital transformation process.

Digital solutions are a kind of software and hardware tools that are actively used in universities.

Elements of digital transformation—a minimum set of elements that should be properly developed when integrating digital solutions into the educational process.

Factors of digital transformation are the most significant aspects that affect the intensity of the process of digital transformation in education.

3.2.2. Digital Solutions

*Organizational digital solutions.* This category must be singled out since it does not directly relate to teaching methods and includes organizational solutions implemented at the university level, while this category can include tasks of varying complexity in terms of required skills and practical implementation. Thus, the following solutions can be distinguished as examples:

- creating your own web portals with integrated instant messengers and file-sharing capabilities;
- the use of artificial intelligence to reduce the number of routine tasks (for example: using chatbots to work with the library);
- implementation of projects of various scales for the digitalization of various aspects of the educational space of the university;
- development of own LMS (Learning Management Systems) and DLS (Distance Learning Systems);
- using a flexible class schedule;
- Establishment of electronic document management within the organization;
- creation of structural divisions that ensure the proper operation of digital devices;
- creation of structural divisions, the purpose of which is the active introduction of high-level digital technologies and specialized software in the educational process;
- other structural transformations aimed at increasing the success of the digital transformation of an educational institution.

*Auxiliary digital solutions.* This category should include digital technologies that allow improvement of the educational process, requiring basic skills in working with software products and digital technologies but not contributing to serious structural changes. Here are some examples of solutions:

- use of projectors and touch screens to create photo and video accompaniment or other similar content;
- the use of the PowerPoint software product or its analogs for the preparation of educational materials;
- the use of mail and cloud services for sending messages and files as part of the educational process;
- the use of instant messengers or software platforms of the university as a means of prompt exchange of information within the framework of the educational process;
- use of office programs by teachers and students.

*Specialized digital solutions*. This category should include the practice of using specialized software products and digital technologies that require a sufficiently high level of technological equipment and in-depth skills in working with digital technologies used in a particular solution. The use of technologies from this category presents unique and qualitatively new opportunities for higher education.

- use of VR and AR technologies;
- use of specialized software modeling products;
- application of neural networks technology.

3.2.3. Factors Determining Changes in the System of Higher Education

Every year the pace of development in modern society is increasing, increasing the requirements for the skills and level of training of specialists [35,48]. To meet the new standards and needs of society, a necessary process is the improvement of higher education as the main social institution for the education and training of highly qualified and sought-after specialists. Of course, a similar trend has been observed before, but the complex influence of external factors on the education system makes the current situation unprecedented and relevant in the context of the development of society.

So, if we talk about the factors that determine changes in the system of higher education, then three large categories should be distinguished: instrumental, target, and catalytic factors.

*Instrumental factors.* First of all, the widespread introduction of digital technologies should be attributed to instrumental ones. Thus, the availability of digital devices, easy access to the Internet, and the development of artificial intelligence provides a person with fundamentally new opportunities that can be used in higher education. The influence of this factor is to provide the education system with a certain set of tools, but a significant problem in their use is the relatively small experience of their use in this area and, as a result, the lack of a clear understanding of the mechanism and results of using these tools.

*Target factors.* The group of target factors includes modern challenges facing society, new unique global challenges, the implementation of old theoretical developments that can be implemented at the current level of technological development, compliance with international standards, and much more. In other words, goals that require the development of higher education and its adaptation to new challenges can be included in this category. However, it should be noted that these factors either do not require significant changes at the level of the entire education system or require a long period of implementation of innovations associated with their study and monitoring of results.

*Catalyzing factors*. Catalyzing factors are driving rapid and massive change in the education system. A striking example is the COVID-19 pandemic, which forced us to urgently change the entire educational process, adjusting it to the new conditions of distance education. The temporary transition to distance education, of course, had a somewhat negative impact on the educational process, but on a global scale, a one-time, short-term transition to distance learning cannot be called a significant problem. Much more important is the fact that such a sudden transition from full-time education to full-time education across the country has shown the high potential of using digital technologies in the educational process, not only for people involved in this topic but also for those teachers who, before the transition, were little is known about the possibility of using digital technologies in education. Therefore, after the end of the period of distance learning, the issue of digitalization of education has become much more relevant. Moreover, if earlier it was of a more theoretical nature, now various practical implementations of this process are being discussed.

The uniqueness of the current situation is due to the presence and exacerbation of all three categories of factors described earlier. Currently, there is a rich set of digital tools for modernization and a large number of global tasks, the solution of which is complicated by the political situation. The problem is that the presence of a catalytic factor, combined with the other two categories, makes the education system develop too quickly, introducing new, untested technologies in this area without proper control and monitoring of results. Moreover, the local use of various approaches based on digital technologies does not allow centralized control of this area and manage the pace of its development, which as a result, can lead to a decrease in the quality of education. Therefore, the issue of digitalization, especially when it comes to training specialists in engineering specialties, is now relevant and requires a thorough and comprehensive study.

#### 3.2.4. Fundamental Elements of the Digitalization of Education

To analyze the process of digitalization of education, it is necessary to single out the four main elements that are fundamental, and without the successful implementation of which, it is impossible to build an effective educational process using digital technologies.

*Digital infrastructure*. The first fundamental element is the digital infrastructure. For the full development of modern approaches based on the use of digital technologies, it is necessary to create conditions under which high technological equipment of universities will be maintained. Moreover, it should be noted separately that it is not a one-time provision of an educational institution with equipment but a full-fledged system designed for long-term interaction with the university, which includes the supply of equipment and components, as well as timely maintenance.

*Preparation of teaching staff*. The second element is the preparation of teaching staff for the use of digital technologies. The training system for employees should be built in

such a way as to not only teach the skills to work with the equipment but also give a clear understanding of the benefits of using it in the context of the subjects taught. It should be illustrated with a simple example. So, an object that has already become commonplace in some way—a sensory board, can be used in completely different ways during a lesson. If the teacher understands the advantages that this technology gives him, then he begins to build the entire structure of the lesson in such a way as to use these opportunities successfully. He begins to prepare presentations and media accompaniment, which will allow him to focus the attention of the audience on his speech throughout the lesson, emphasize important points, emphasize the main ideas in the thesis, simplify taking notes, and influence not only the sound channel of perception but also the visual one. If the teacher does not seek to realize these advantages but uses the technology only because of the need to use it, then in this case, the structure of the lesson will not change, and the full text of the lectures can be displayed on the screen in an inconvenient format for reading. Such an approach not only does not bring any benefit but, on the contrary, has a negative impact since such a presentation of the material can repel the student with the appearance of a huge hard-to-read text.

*Student preparation.* The third element is student preparation. Among all the elements, perhaps this one may seem less significant, but for a number of reasons, this is an incorrect statement. One of the key features of digitalization is the critical importance of information and the changing ways of finding it. It seems that now, in the age of digital technologies, it is incredibly easy to find information. However, unstructured data on the network creates a kind of information chaos, especially when it comes to rather subtle and ambiguous moments or, on the contrary, compiling a holistic and structured understanding of the subject of study. Moreover, it should be noted that this feature of the modern world is of great importance precisely for students since, at the time of their studies, they still form a holistic view of the issue under study. Therefore, without outside help, they may encounter problems in the search and analysis of new material.

*Organization of the educational process.* The last element is the organization of the educational process. This group can combine changes in the structure of the organization of the educational process with the use of digital technologies and decisions on the development of large-scale projects at the faculty or university level. A prerequisite for the effective implementation of this element is a clear understanding of the mechanism of the impact of digital technologies on the educational process and the formulation of the desired result, which should be achieved with the introduction of appropriate changes in the educational process. In other words, before introducing innovations, it is necessary to study and develop the method in order to evaluate it in terms of effectiveness within the educational process and economic feasibility. It is also necessary to return to the idea that digitalization is just a tool to achieve a goal, which, if misused, can suffer the quality of education.

Thus, today the most important task is to control the process of digitalization of higher education, which should ensure the effective use of digital technologies in the educational process and prevent the use of practices that can reduce the quality of education on a regular basis. To achieve this task, centralized management is necessary, which will require structural changes in the education system itself [49], as well as significant changes in the mechanism for financing universities since the needs associated with the process of digitalization of education will differ significantly from the current ones.

However, there are already examples of universities in the Russian Federation actively implementing digital technologies in the educational process. Using the example of such educational institutions, one can imagine the opportunities that the digitalization of education provides when it is used in the learning process. One of these universities is St. Petersburg Mining University. On the basis of this institution, a large number of full-scale programs have already been implemented—both additional training and projects integrated into the educational process.

## 4. Discussion

Modern society is facing a large number of new challenges; however, of particular interest are complex tasks, the work which is associated with political factors. At the moment, such a task is the development of the energy sector of the Russian Federation [50]. However, it should be noted that the material presented in this work is conceptual, the main purpose of which is to show the prospect of digitalization of education, as well as to illustrate the idea of using four elements as an effective approach to monitoring the implementation of this process.

Thus, the first of the considered elements is the availability of digital infrastructure.

From the very beginning of the era of computers and the Internet, this topic has been a stumbling block in understanding the challenges of the new reality [51] since the absence of such, no doubt, led to a lag and an ever-increasing gap [4,52,53]. In this regard, Mining University has at its disposal 2923 computers with Internet access, which students can use. This means that the number of PCs per thousand students will be 322 computers, which is 30% more than the national average, according to Rosstat data for 2020 [54]. In addition, touch screens or projectors are used in the classrooms, and separate departments are allocated in the structure of the organization, the task of which is to maintain digital devices in working order. Moreover, Mining University also has more advanced digital technologies. For example, a digital modeling software package based on a high-performance computing cluster has been implemented within the walls of the university.

At the same time, it is known that in the global space, access to the Internet and modern devices is still a privilege for many [55]. The study [56] revealed that, in general, in universities, one of the difficulties that students encountered in distance learning was a technical problem (Internet speed and communication quality) and the lack of the necessary headset (headphones, microphones, good resolution cameras), despite the fact that in the educational process, the presence of new equipment promotes motivation, and is also a driver of progress [57,58]. As another confirmation of the possibility of implementing large-scale digital programs at the university, we can cite the results of a student survey. Thus, 80% of respondents reported that the provided equipment is sufficient for comfortable and efficient work within the framework of the program. As mentioned earlier, a necessary condition for full-fledged work is the constant access of a student to digital devices outside the university, so this question was also included in the questionnaire. In total, 95.6% of students reported having a PC, laptop, or similar device at their disposal.

The next element that requires attention is the organizational component. This task is incredibly important and kind of unique, requiring the coordinated work of a large number of leading scientists in various fields of science. The use of digital technologies can provide a unique opportunity for promising students of relevant master's programs to participate in research and development of solutions. Of course, the vast majority of students do not have the necessary experience to solve such complex and important problems [59,60]. Therefore, in the context of this project, their main task would be to learn from a real comprehensive study. The need for a more science-centric approach to the preparation of students is emphasized, in particular, in the studies [53,61].

In our paper, we conclude that such an experience can be considered unique, as it includes collaboration with leading scientists, organizing research on the scale of large scientific projects, gaining practical skills in a specialized specialty, as well as developing a deeper understanding of global trends. Participation in such a project for a student will be an excellent starting point both for starting work in leading specialized companies and for development in the scientific field.

The third and fourth elements in relation to this study in the context of the Mining University can be considered successfully implemented. This concept implies the involvement of only masters who have proven themselves as promising students aimed at development within the specialty or scientific activity. In this case, students who meet the stated conditions already have the skills to search and work with information and

also clearly understand their role in the educational process in the context of the use of digital technologies.

In addition, young people generally have such skills, which is shown by various studies [7,12–14], and our study confirmed this trend in the conditions of an engineering university. In addition, we managed to clarify the distinction in the level of quality and ease of obtaining information depending on academic performance. On the other hand, the sad fact remains that the older generation, and these are those who teach, are far from fully adapted to ultra-rapid changes. Therefore, the situation with teachers who could be involved in a project of this kind can be described in a similar way.

It is the use of digital technologies that will effectively introduce students to work on large-scale and complex tasks, allowing them to gain a unique experience. Of course, the description presented is only a concept, but even the very possibility of such a practice already speaks of the great prospects of digital tools in the field of education. Moreover, this example illustrates that digital technologies make it possible not only to change the learning process depending on the initial skills and personal characteristics but also to provide capable students with the opportunity to acquire truly unique work skills, thereby creating conditions for the training of future scientific and pedagogical personnel.

## 5. Conclusions

Thus, in this work, we come to the following conclusions:

1. The explosive growth in the speed of transformation of the educational infrastructure causes the onset of a turning point, which will largely determine the further development of the education system in general and engineering education in particular.
2. The combination of target, instrumental and catalytic factors that provoke a radical acceleration of the process of digitalization of education allows us to conclude that the current situation is unique. At the same time, the consequence of the new temporality of socio-technological changes is the almost complete absence of a single generally accepted methodology for analyzing the effectiveness of innovations and centralized management of the digital transformation process.
3. In this paper, the authors propose a concept of the structure of the process of digitalization of higher education in the Russian Federation, which is designed to emphasize the main aspects of this process and can be used in the process of further integration of digital solutions into the learning process.
4. The process of self-training of students can be called an independent aspect of the digital transformation of higher education, which is confirmed by the results of the survey, according to which 96.89% of respondents use the Internet as the main source of information when preparing for classes.
5. Information search skills such as search syntax and the use of hotkeys (in this case, Ctrl + F) develop as you study at the university.
6. The average time for a student to prepare for a lesson is from 30 minutes to two hours. The largest number of respondents who spend more than three hours on preparation is noted in the final courses of undergraduate and specialist degrees. The least amount of time for preparation is spent by students with low motivation for further education.
7. The thoroughness of the study of the material and the use of more time-consuming methods of processing information, such as its structuring or taking notes, are associated with student performance and motivation. So, with a decrease in the level of motivation and academic performance, preference is given to simpler ways of remembering information, such as simple reading.
8. All respondents who participated in the survey are students at an engineering university with full-time education, so these results should be considered only in the context of this category.
9. The issue of self-training of students requires further in-depth consideration. In particular, the question of searching for basic subject knowledge to prepare for ordinary classes and new scientific achievements (publications, patents) is very interesting.

Therefore, in the future, this aspect should be studied in more detail, especially among students enrolled in master's programs.

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