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The Design Principles of Man-machine Interaction in a Digital Environment

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Modern society life is inextricably linked with the digital environment. A consequence is the transformation of ergatic systems into digital ones. The result is the emergence of new types of man-machine interaction. The essential feature of such interaction is to minimise human involvement in the ergatic system functioning. According to this, the issues of organising the safe and effective functioning of digital ergatic systems have priority importance. In this regard, the aim was to study the features of man-machine interaction in an actual digital ergatic system. We chose an ergatic system for research. The main elements of the system were students (70 people of the first-year study) and teachers (5 people) of the Simon Kuznets Kharkiv National University of Economics, as well as the digital system "Personal training systems the Simon Kuznets Kharkiv National University of Economics" (PTS). This digital system is an adapted model of the Moodle digital system. The study found out that the key components that determine the safety and efficiency of the digital ergatic system are the operator's digital mindset, digital tools and digital devices. The study of these components in the system made it possible to establish that it had a balanced state. It is substantiated the optimal form of man-machine interaction in the system. It is mixed learning. It is shown that the tendency to minimise the human role in a digital ergatic system does not always have the expected positive result, which determines the need for further research on this issue. In addition, we analysed the difficulties arising in the design of digital systems. The main reason for this is a lack of developers awareness of the ergonomic and cognitive aspects of man-machine interaction. It is shown that the development of critical thinking and intuition in students is closely related to the individual trajectory of learning. For this, it is essential to update interdisciplinary knowledge. In this case, it is necessary to familiarise students with current concepts and system-forming principles, which are the basis of human factors engineering. It was substantiated that the application of current concepts and system-forming principles in training will allow optimising man-machine interaction. The positive results will be evidence even at the stage of designing digital systems.

Keywords: digital environment, operator, ergatic system, safety, design, learning.

Introduction

The digital environment is an integral part of modern life. Moreover, today it is impossible to imagine both labour and daily activities without it. The digital environment makes it possible to perform a huge range of actions from simple (send or receive an e-mail, check the status of a bank account, find out the weather forecast, etc.) to complex (develop a training course, create an online shop, make an order, receive the services, etc.). Thus, the usage of the digital environment has many positive results for society. However, there are also many problems. The most difficult problem is that the work of humans in a digital environment generates new types of man-machine interaction, which are poorly studied today. Hence, the mechanisms and consequences of their influence on humans, the level of their safety and efficiency are not clear. An example is e-learning systems. On the one hand, there is an individual approach to the organisation of the learning process (free choice of disciplines, training schedule, etc.). On the other hand, there is no or insufficient contact with the teacher, a lack of knowledge about the rational organisation of working time and place in conditions of free planning, etc. As a result, there are situations of overstrain, poor-quality learning of knowledge, deterioration of physical and mental well-being due to prolonged work at the computer, etc.

Thus, it can be stated that today a new environment of human activity has been formed – the digital environment. But the issues of safety and efficiency of interaction between man and technics in the digitalization conditions are poorly studied today.

1. Literature review

Study the problem of man-machine interaction in the digital environment should start with an analysis of the concept of "digital environment", its components and their place in it. The most common is the following definition: a digital environment is an integrated communications environment where digital devices communicate and manage the content and activities within it [1]. The definition shows that the concept is broad and includes both devices that transmit and receive information and various types of software for working with it. That is why the digital environment is the basis for Industry 4.0 and digital ecosystems (Fig. 1).

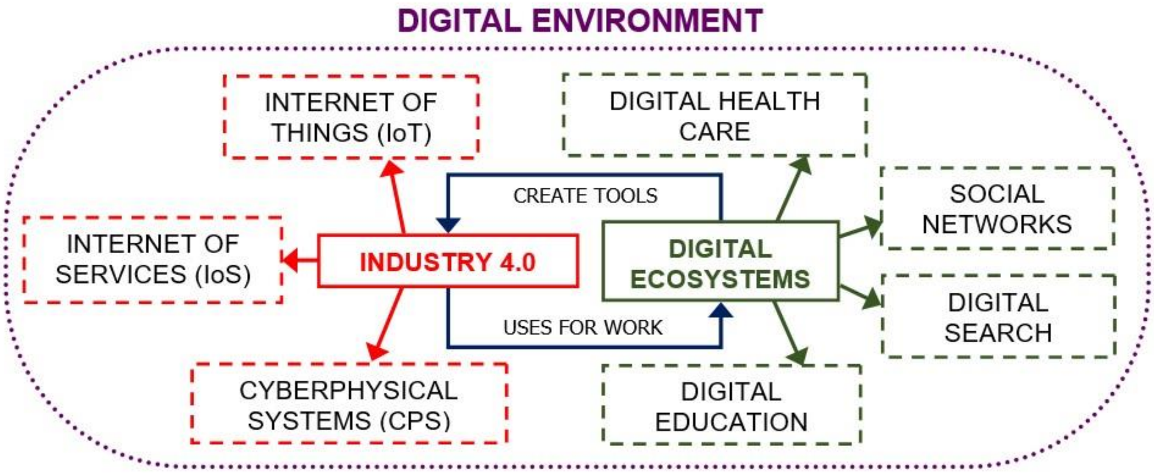

Fig. 1. The digital environment components

Key components of the digital environment are Industry 4.0 and digital ecosystems. But what are they? Industry 4.0 is the massive introduction of cyber-physical systems into the production and service of human needs, including everyday life, work and leisure. A digital ecosystem is a distributed, adaptive, open socio-technical system with properties of self-organisation, scalability and sustainability inspired by natural ecosystems. Both Industry 4.0 and digital ecosystems are the next stage in the development of ergatic systems, the main feature of which is to minimize the role of humans in their functioning. As a result of the transformation of ergatic systems into digital ergatic systems, human participation in their work has decreased. However, making essential decisions to ensure the safety of ergatic system functioning remains with a human [2-10].

New types of man-machine interaction are a logical consequence of the transformation of the ergatic system into digital ones. But they are insufficiently explored today. A detailed study of the features of the digital ergatic systems functioning will improve the safety and efficiency of man-machine interaction. Analysis of the literature on this issue made it possible to establish that the transformation processes of ergatic systems are directly related to the level of Industry 4.0 maturity [11-14]. There are five Industry 4.0 maturity models. In fig. 2 shows adapted versions of these models.

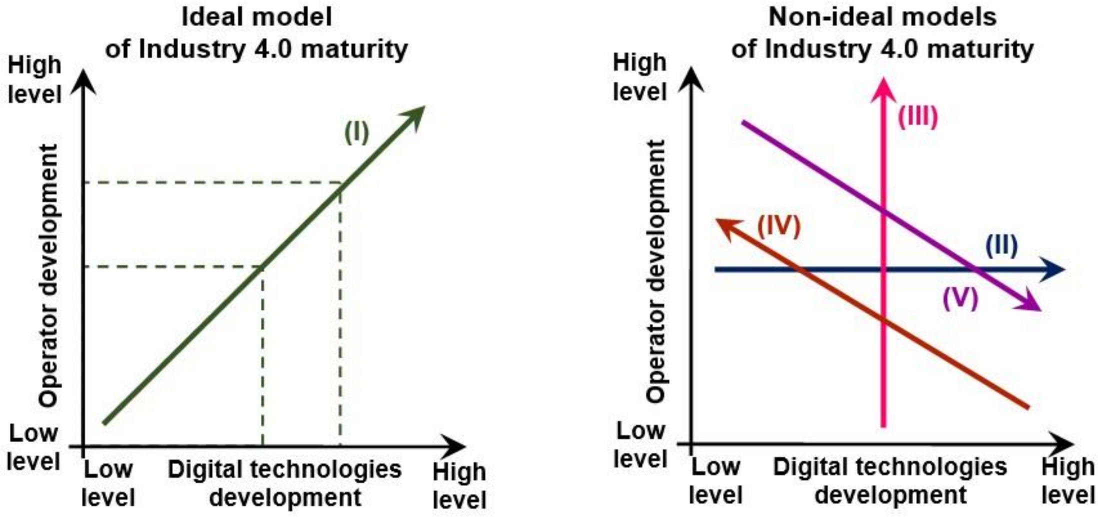

Fig. 2. Models of Industry 4.0 Maturity According to [11] (Adapted Version)

The model I demonstrates **a mature Industry 4.0**, in which the operator and digital technologies development go synchronously. It means that the professional knowledge, skills and abilities of the operator and level of his digital mindset correspond to the level of digital technologies development, which ensures the efficiency and safety of man-machine interaction. Models II – V show different variants of **the immature Industry 4.0**, in which the development of the operator and digital technologies occurs asynchronously. It means that either the operator's professional qualities do not correspond to the level of digital technologies used, or, vice versa, the technologies are outdated in comparison with the level of knowledge and training of the operator. In any case, it makes man-machine interaction ineffective and unsafe.

Model I is an ideal variant of digital ergatic system development, to the practical implementation of which should be strived. But in most cases, models II - V can be observed. Thus, a condition for effective and safe man-machine interaction in a digital environment is a balance between operator's development and digital technologies.

In addition, the safety and efficiency of man-machine interaction in the digital environment also determine the level usage of digital technologies for performing by the ergatic system of the assigned task. In this case, it is necessary to pay attention to the advisability of minimizing human participation in the digital ergatic system functioning, which is a priority task today. As mentioned earlier, human participation in such systems functioning has significantly decreased, but it does not always have the expected positive results [15-18].

Thus, **the scientific problem** is that the transformation of ergatic systems into digital ones is inevitable, which leads to the emergence of new forms of man-machine interaction, which are currently insufficiently explored on their safety and efficiency. The design of such interaction is **an actual problem**. The existence of the human factor phenomenon in man-machine systems confirms this fact. As shown in [19-21], the elimination or significant reduction of risks in ergatic systems is possible only if the principles of human factors engineering are applied at the design stage.

2. Aims

Based on this, the task is to study the degree of human immersion in the digital environment to optimize man-machine interaction using the example of the digital ergatic training system.

The aim is to apply the principles and concepts of human factors engineering and ergonomics to identify the most effective model for the functioning of digital ergatic systems.

3. Methods and Results

Preconditions for the study of man-machine interaction in the digital environment. We began the study of the man-machine interaction with the investigating problems in the work of humans and technics in a digital environment. It allowed us to identify the components that ensure the effective and safe functioning of an ergatic system in a digital environment. Consider the reasons for the decrease in the effective functioning of the ergatic system in the digital environment, associated with both the operator (Fig. 3) and technics (Fig. 4).

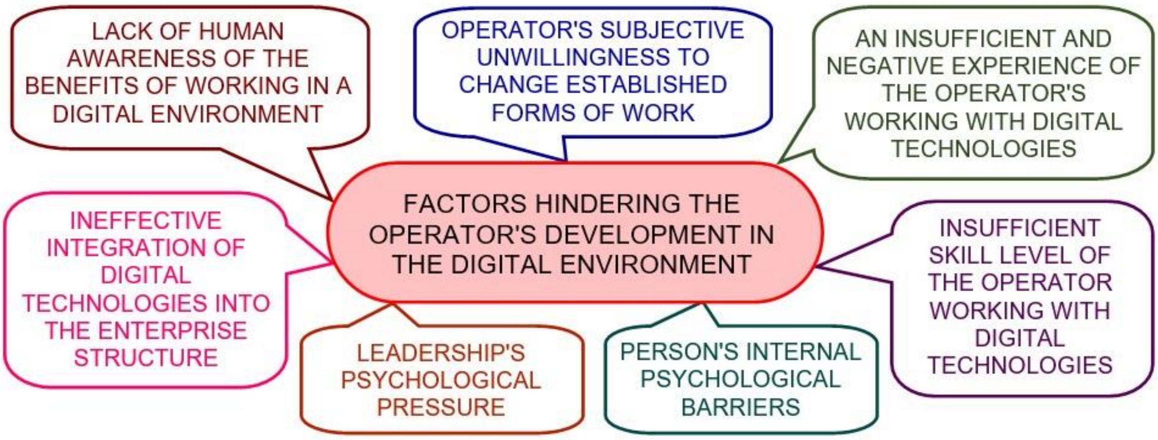

Fig. 3. Problems of an operator development in the digital environment

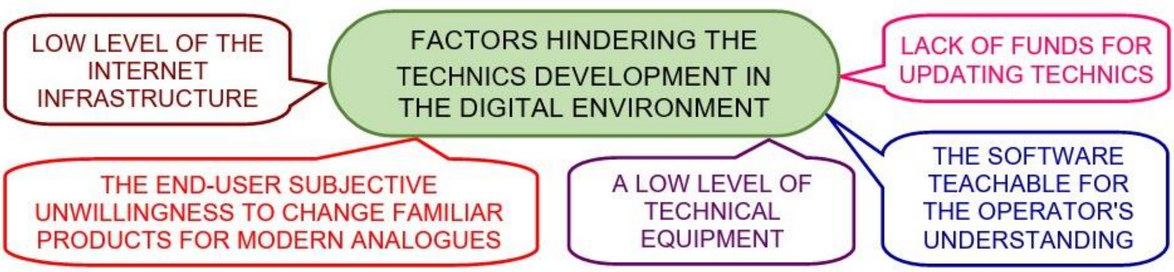

Fig. 4. Problems of Technics Development in the Digital Environment

The problems of an operator and technics development in the digital environment have to be solved not separately but as a whole. For this, it is necessary to identify the crucial components of a digital ergatic system that ensure its safe and efficient functioning. Based on the literary search [3, 5, 7, 9, 11-14], three components were identified – operator's digital mindset, digital tools and digital devices.

Operator's digital mindset is a set of attitudes, behaviours, and beliefs held by people or a group of people that influence curiosity about disruptive digital technology in an organization. In other words, a digital mindset is the operator's readiness to master and apply new technologies to accomplish the assigned tasks, the absence of internal psychological barriers during working in a digital environment.

Digital tools are programs, websites or online resources that can make tasks easier to complete.

Digital device is an electronic device that can create, generate, send, share, communicate, receive, store, display, or process information (e.g. computers, laptops, tablets, smartphones, etc.).

The components cannot exist in isolation from each other. A connecting element is needed to bring them together and ensure harmonious operation to ensure the safe and effective functioning of a digital ergatic system. Ergonomics acts as such a connecting element. The broad toolbox of ergonomics as a complex science combining engineering, psychological, social and environmental approaches makes it possible to solve the problem (Fig. 5).

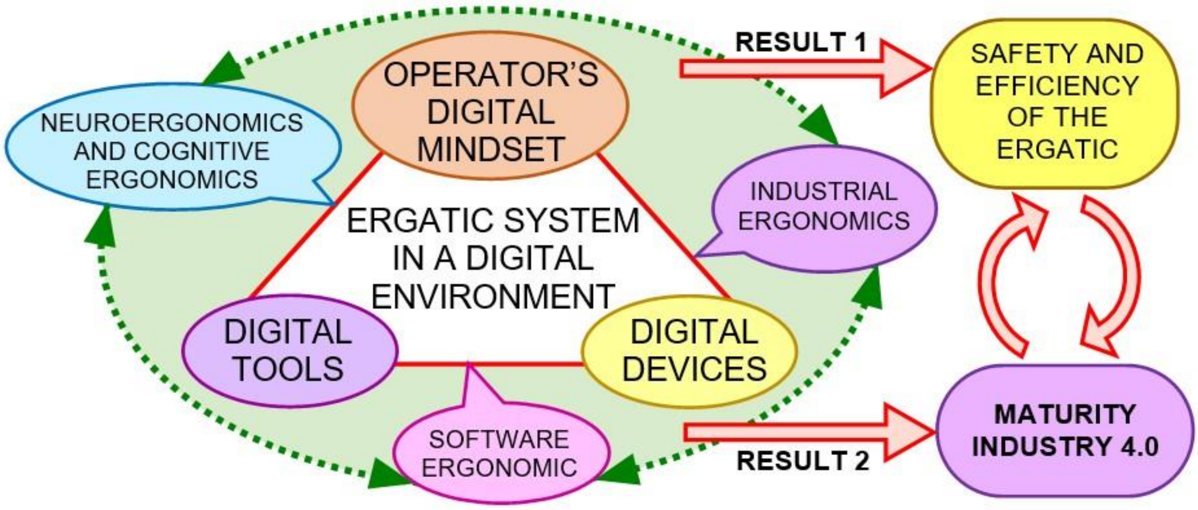

Fig. 5. The model of safe and effective functioning of a digital ergatic system

Thus, ergonomics ensures a balanced development of humans and technics in a digital environment, which is a precondition for the safe and effective functioning of the ergatic system, as well as the formation of a mature Industry 4.0.

Problems of man-machine interaction in the digital environment. The features of the current stage of development are a paradigm shift (from analysis to synthesis), the convergence of inorganics and the organic of wildlife. It is based on the idea of convergence of info-, nano- and biotechnologies to create dynamic systems and technologies of the new generation [22]. This idea is already the basis of ergonomics and human factors engineering as scientific and practical disciplines. It is important to take into account the influence of environmental stressors on: a) the features of man-machine interaction; b) the psychophysiological factors and risks (transient condition, functional disorders and others); c) the sources of information in the design of digital systems. To do this, you need to know: a) methods of research of those cognitive abilities that affect the effectiveness of student learning; b) methods of risks control and readiness for scenarios of their realisation. Accounting for the diversity of human factors requires the formalization of procedural knowledge and modelling of interaction in the system "man – digital tools – digital device". These interdisciplinary issues need to be covered systematically and teach the principles of digital systems developers. For this, it is necessary to train the disciplines "Ergonomics" and "Human factor engineering" [23].

Features of man-machine interaction in the digital learning environments. Traditional education has many destabilizing factors. In particular, these are a diversity of educational information and information perturbations. They affect the student and teacher functional state. Besides, they determine the existence of the human factor phenomenon, the study of which is necessary for solving current safety problems. Accounting for possible changes in human's physical, psychological, physiological and cognitive capabilities will contribute to the design of more perfect digital systems and more effective man-machine interaction.

In addition, it is essential to find new approaches to building an individual learning trajectory. Students training in the elements of cognitive ergonomics and engineering psychology will also increase the effectiveness of training. It is necessary to accounting individuality, i.e. learning style, features of cognitive and motivational areas, functional state, etc. All this requires a broader use of recent information, switching and educational technologies in the learning environment. So far as the success of the student's self-education determines the reliability of his activity in the future and the safety of the ergatic system managed by him.

Modern digital technologies already widely use the achievements of neuroscience (neuroergonomics, neurobiology and others) and cognitive sciences (cognitive ergonomics, cognitive computing and others). While learning in engineering areas (industrial, military, bio, software) takes place in a breakaway from the account the peculiarities of the organisation of man-machine interaction in the systems "man – machine" and "man – machine – environment" determining their ergonomic quality.

The conservative form of education contributes to the formation of mainly divergent thinking. At the same time, in a row with a deep immersion in the theoretical and specialised disciplines for future engineers, little attention is paid to interdisciplinary links and systemic problems. Such an approach limits the possibilities of information technology in the formation of the students creative potential. In particular, the further development of their cognitive abilities and intuition requires individualisation of learning, as well as achieving a balance of creative (divergent) and critical (convergent) thinking, which contributes to the development of nonlinear thinking in students. That is why a personal choice of information, its processing means, display and analysis play a significant role in knowledge formation.

Research of man-machine interaction in the digital environment. The practical testing of the presented model gave interesting and some predictable results. We chose an ergatic system for research. The main elements of the system were students (70 people of the first-year study) and teachers (5 people) of the Simon Kuznets Kharkiv National University of Economics, as well as the digital system "Personal training systems the Simon Kuznets Kharkiv National University of Economics" (PTS). This digital system is an adapted model of the Moodle system (Modular Object-Oriented Dynamic Learning Environment). It is a free web application that implements the ability to create sites for online learning.

The research included three stages. The first stage is to assess the balance of the ergatic system development. The stage included:

1) assessment of proficiency level of the digital technologies by students and teachers;

2) training teachers and students to work in the PTS system;

3) verification of participants provision with digital devices to participate in the study.

At the first stage of the study, the following results were obtained (Table 1).

Table 1

Ergatic System Components

№	Component Name	Component Realisation	
		Students	Teachers
1	Digital mindset	100%*	100%**
2	Digital tools	PTS	PTS
3	Digital devices	100%***	100%***

* – the percentage of students who have the required level of proficiency in digital technologies, and passed the train to work in the PTS system;

** – the percentage of teachers who have the required level of proficiency in digital technologies, passed the train to work in the PTS system and received a certificate;

*** – the percentage of students and teachers who have the necessary digital devices to work in the PTS system (computers, laptops, tablets, smartphones), as well as constant access to the Internet.

According to the results, the ergatic system had a balanced state since all components develop synchronously and the level of their development had high indicators, which is a precondition for the safe and effective functioning of the system.

At the second and third stages of work, we investigated the ergatic system functioning in two modes, which differed by using digital tools and digital devices to perform the assigned tasks. At the second stage, we used a combined form of training: 50% of the material are tasks for consideration in the classroom accompanied by a teacher, and 50% are tasks for independent study. Students performed classroom tasks and independent ones using the PTS system. Students sent reports with completed tasks for verification through the PTS system. To analyse the students' progress, we created in the PTS system a grade book in which we recorded grades for completed tasks. At the third stage, we used distance learning: students studied the material by themselves in a mode suitable for them. They had to send reports on the completed tasks in a set time. As in the second stage, to analyse the students' progress, grades for completed tasks were recorded in a grade book.

At the end of the second and third stages, students and teachers passed the sociological surveys to determine the degree of their satisfaction with each form of learning and identify negative aspects of their work.

Based on the results of the second and third stages of the research, we built graphs of students' progress for mixed and distance learning (Fig. 6).

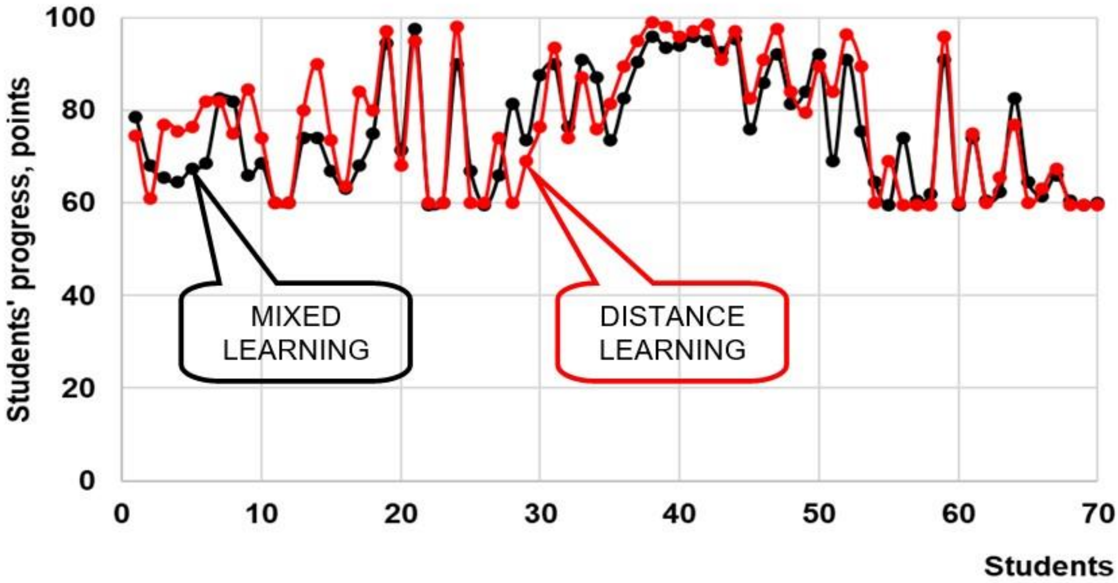

Fig. 6. Students' progress in cases of mixed and distance learning

Thus, we concluded that there were no significant differences in students' progress under mixed and distance learning. However, the analysis of subjective assessments of students and teachers satisfaction with different learning forms showed that mixed one was better perceived than distance one (Fig. 7).

Fig. 7. Histogram of student and teacher satisfaction with mixed and distance learning

According to the opinion of students and teachers, the reasons that led to low satisfaction with distance learning were following:

1) insufficient level of direct contact between student and teacher, due to which, on the one hand, students spent much more time studying new material, and, on the other hand, teachers more often returned work to students for revision;

2) insufficient level of intragroup interaction, which determines mutual aid of students in the study of material;

3) insufficient level of student's knowledge about the rational organisation of working place and time management, due to which there were cases of overwork, sleep deprivation, poor-quality learning of the material, etc.;

4) the PTS system faults;

5) insufficient level of technical equipment.

The significance of these factors is in Fig. 8.

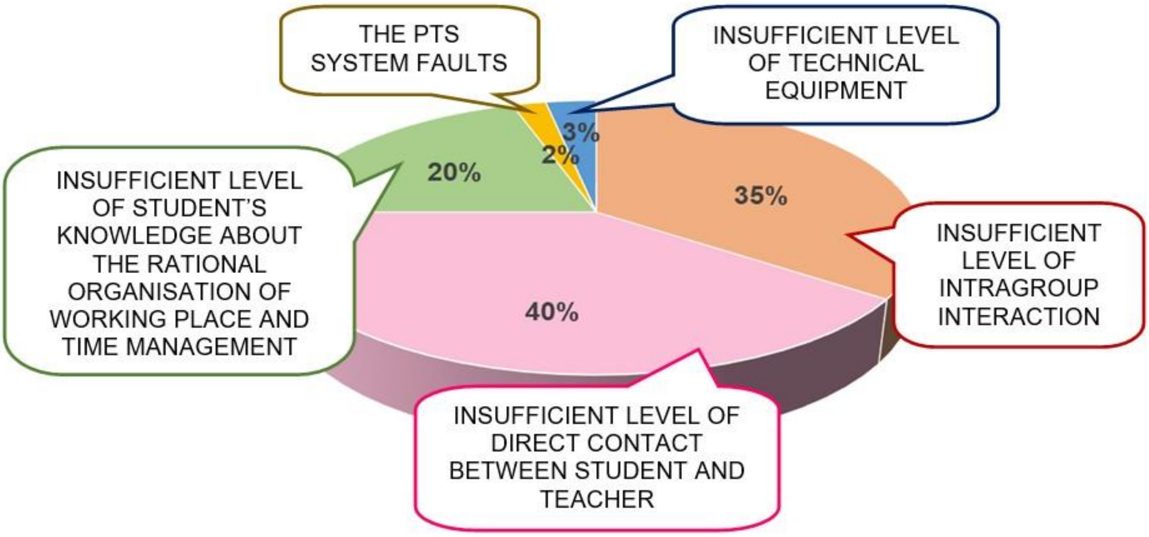

Fig. 8. Diagram of the significance of the factors that caused low satisfaction with distance learning

Thus, the main reason for the dissatisfaction of students and teachers with distance learning is the insufficient level of direct contact between students and teachers. Consequently, the level of safe and effective functioning of an ergatic system in a digital environment sets in with mixed learning.

The research of man-machine interaction in the PTS system, operating based on the Moodle digital platform, showed the following results:

1) the essential components of the digital ergatic system, which determine the safety and efficiency of its functioning, are identified. These are digital mindset, digital tools and digital devices;

2) the ergatic system had a balanced state since essential components developed synchronously and had high indicators;

3) empirically established that mixed learning is better in comparison to distance one because it provides the safety and efficiency of the ergatic system in a digital environment;

4) to optimize the ergatic system functioning in a digital environment, it is necessary to assess the balance of operator and technics participation in it; since the tendency to minimize human involvement in the digital ergatic system does not always have positive results.

Conclusions

Modern life is inseparably linked with the digital environment. The result is the transformation of ergatic systems into digital ones and the emergence of new types of man-machine interaction. According to this, the issues of organising the safe and effective ergatic systems functioning in the digital environment have gotten priority importance.

There are also difficulties in designing effective, reliable and resistant digital systems, due to the lack of awareness of developers with ergonomic and cognitive aspects of man-machine interaction. The development of critical thinking and intuition is closely linked to the individual trajectory of learning. It is essential to update interdisciplinary knowledge for its construction, which necessitates the acquaintance with current concepts and system-forming principles used in human factors engineering. Thus, the application of advanced concepts and system-forming principles allows optimising man-machine interaction at the design stage of digital systems.

In this regard, the aim was to study the features of the functioning of an actual digital ergatic system. It was found out that the essential components that determine the safety and efficiency of the digital ergatic system are digital mindset, digital tools and digital devices. The research of the actual digital ergatic system by these components revealed that it had a balanced state because its components developed synchronously and corresponded to the model of mature Industry 4.0. In addition, we substantiated the optimal form of man-machine interaction, in which the safety and efficiency of the ergatic system are ensured. This form of interaction is a mixed form of learning. It is also shown that the tendency to minimise the role of an operator in the digital ergatic system does not always have the expected positive result, which determines the need for further research on this issue.

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Принципы проектирования человеко-машинного взаимодействия в цифровой среде

Жизнь современного общества неразрывно связана с цифровой средой. Закономерным следствием этого является трансформация эргатических систем в цифровые эргатические системы. Результат – появление новых типов человеко-машинного взаимодействия, ключевой особенностью которых является минимизация роли человека в работе системы. В свете этого, вопросы организации безопасного и эффективного функционирования цифровых эргатических систем имеют сегодня приоритетное значение.

В связи с этим целью исследования стало изучить особенности человека-машинного взаимодействия в реальной цифровой эргатической системе. В качестве таковой выбрана эргатическая система, ключевые элементы которой – студенты и преподаватели Харьковского национального экономического университета имени Семена Кузнеца, а также цифровая система “Персональные обучающие системы Харьковского национального экономического университета имени Семена Кузнеца” (ПОС). Данная цифровая система – это адаптированная модель цифровой системы Moodle.

В ходе исследования установлено, что ключевыми компонентами, определяющими безопасность и эффективность функционирования цифровой эргатической системы, являются цифровое мышление оператора, цифровой инструментарий и цифровые устройства. Исследование системы ПОС по этим компонентам позволило установить, что она имеет сбалансированное состояние. В работе обоснована оптимальная форма человеко-машинного взаимодействия в исследуемой системе – комбинированная форма обучения. Показано, что тенденция к минимизации роли человека в цифровой эргатической системе не всегда имеет ожидаемый положительный результат, что определяет необходимость проведения дальнейших исследований по данному вопросу.

Также в работе проанализированы трудности, возникающие при проектировании цифровых систем, обусловленные недостаточной осведомленностью разработчиков с эргономическими и когнитивными аспектами человеко-машинного взаимодействия. Показано, что развитие критического мышления и интуиции у студентов тесно связано с индивидуальной траекторией обучения. Для ее построения важна актуализация междисциплинарных знаний, что обусловливает необходимость ознакомления студентов с современными концепциями и системообразующими принципами, которые применяются в инженерии человеческих факторов. Обосновано, что применение современных концепций и системообразующих принципов в обучении позволит в дальнейшем оптимизировать человеко-машинное взаимодействие еще на стадии проектирования цифровых систем.

Ключевые слова: цифровая среда, оператор, эргатическая система, безопасность, проектирование, обучение.

Принципи проектування людино-машинної взаємодії у цифровому середовищі

Життя сучасного суспільства нерозривно пов’язане з цифровим середовищем. Закономірним наслідком цього є трансформація ергатичних систем у цифрові ергатичні системи. Результат – поява нових типів людино-машинної взаємодії, ключовою особливістю яких є мінімізація ролі людини в роботі цифрової ергатичної системи. У світлі цього, питання організації безпечного та ефективного функціонування цифрових ергатичних систем мають сьогодні пріоритетне значення.

У зв’язку з цим метою дослідження стало вивчити особливості людини-машинної взаємодії у реальній цифровій ергатичній системі. В якості такої обрана ергатична система, ключові елементи якої – студенти і викладачі Харківського національного економічного університету імені Семена Кузнеця, а також цифрова система "Персональні навчальні системи Харківського національного економічного університету імені Семена Кузнеця" (ПНС). Вибрана цифрова система – це адаптована модель цифрової сисмети Moodle, яка є вільним веб-додатком, що реалізує можливість створювати сайти для онлайн-навчання.

У ході дослідження встановлено, що ключовими компонентами, що визначають безпеку і ефективність функціонування цифрової ергатичної системи, є цифрове мислення оператора, цифровий інструментарій і цифрові пристрої. Дослідження системи ПНС за цими компонентам дозволило встановити, що вона має збалансований стан. У роботі обґрунтована оптимальна форма людино-машинної взаємодії у досліджуваній системі –

комбінована форма навчання. Показано, що тенденція до мінімізації ролі людини в цифровий ергатичній системі не завжди має очікуваний позитивний результат, що визначає необхідність проведення подальших досліджень з даного питання.

Також у роботі проаналізовані труднощі, що виникають під час проектування цифрових систем, що обумовлені недостатньою поінформованістю розробників з ергономічними і когнітивними аспектами людино-машинної взаємодії. Показано, що розвиток критичного мислення та інтуїції у студентів тісно пов'язаний з індивідуальною траєкторією навчання. Для її побудови важлива актуалізація міждисциплінарних знань, що обумовлює необхідність ознайомлення студентів з сучасними концепціями і системоутворючими принципами, які застосовуються в інженерії людських чинників. Обгрунтовано, що застосування сучасних концепцій і системоутворюючих принципів у навчанні дозволить у подальшому оптимізувати людино-машинну взаємодію ще на стадії проектування цифрових систем.

Ключові слова: цифрове середовище, оператор, ергатична система, безпека, проектування, навчання.

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