Metrological Skills Development of Technical University Students in a Digital Educational Resource with a Smart Laboratory

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Abstract

The relevance of the current problem study is due to the intensive development of digital education using online access. It is becoming more and more in demand, especially in the situation of the world quarantine, when obtaining an educational result is formed in conditions of remote access. Metrological skills of technical university students are structure-forming in the professional competencies of a future engineer. Thus, their development in the conditions of the modern university educational environment should be organized taking into account the constantly changing tasks of engineering activity and the conditions for its implementation. The purpose of this article is to present approaches to the development of a digital educational resource with a built-in smart laboratory for remote access. This digital resource is focused on the development of the metrological skills of students. The authors present the results of its approbation in the course of teaching students at the Kazan National Research Technical University named after A.N. Tupolev while training them as engineering and technical personnel. The basic method in the work was the design of an online training course "Metrology and radio measurements" based on a virtual laboratory platform, including testing and assessment of the level of students' metrological skills (with a diagnostic map). As a result of the research, a virtual laboratory site was created, based on logical and object-oriented approaches. When using a virtual laboratory platform, a monitoring system for assessing the development of metrological skills was applied, which showed the effectiveness of using a smart laboratory in a digital course aimed at the development of students' metrological skills. This allowed me to start work on the development of theoretical and methodological support for the virtual laboratory site, taking into account its flexibility and ability to integrate it with other measuring sites.

Keywords 1

metrological skills, digital educational resource, smart laboratory, remote access laboratory, virtual laboratory platform.

1. Introduction

During the 2020 pandemic, the world community was forced to switch to remote forms of functioning in all possible areas of activity, and first and foremost in education. In Russia, there were used all the best practices in education digitalization programs (Bazarov K.A., 2020), however, with a massive and almost simultaneous transition to distance learning, this was not enough. Thus, the

Proceedings of VI International Scientific and Practical Conference Distance Learning Technologies (DLT–2021), September 20-22, 2021, Yalta, Crimea
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undoubted advantages of these methods have led to their integration into life and rapid development, which continues every day.

Metrological skills of technical university students are important in the structure of the professional competencies of a future engineer (Piganov, M.N., & Podlipnov, G.A., 2004). A modern specialist must know the basics, be able to carry out activities for standardization, regulation of accuracy, and metrological support of production. As part of the professional competencies of future engineers, one of the leading is the one in the field of metrology and radio measurements that provide the effective functioning of production (Molotkova, N.V., & Sviryaeva, M.A., 2009). The work (Mercader-Trejo et al, 2016) examines the importance of practical work in the development of students' metrological skills and emphasizes the significance of teaching work in research centers, testing, or calibration laboratories. High technology, speed of evolution, the complexity of mastering, and high costs of modern measuring instruments make the process of education at a university difficult to implement and not effective enough. In the context of a pandemic, the world educational community is faced with the need to develop practical skills among students using remote access to equipment. Virtual laboratory sites with remote access can provide the opportunity to develop the necessary metrological skills both full-time and remotely. At the moment, most Russian universities have chosen the Moodle platform to create digital educational resources. The convenient interface and wide functionality of the platform allow solving most of the educational tasks, but problems also arise when integrating Moodle with remote access laboratories, for example, described in the work of Fabini et al. (Fabini, J., at al., 2021). Lecturers also highlight the need to improve teaching materials of laboratory works implemented in a digital educational environment with remote access to equipment (Lal, S., et al., 2020).

Analyzing the theoretical studies of domestic and foreign scientists, as well as taking into account the experience of practical work, it can be noted that the problem of formation of basic engineer professional competencies requires the search for means, methods, and conditions for the implementation of professional training, which ensure high efficiency of the educational process in modern socio-economic conditions. Currently, there is a search for approaches to creating digital resources, which ensure they're most useful for solving specific educational problems. For example, in the study of Hoegen et al, problem-oriented learning in the field of automation is presented, which allows students to gain an understanding of theory through practical work (Hoegen, AV, et al, 2021). When training engineers of different specializations, there are already functioning digital laboratories for remote access (Villar-Martínez, A. et al, 2021; Rodriguez-Calderón, R., 2021). That experience is undoubtedly important in the development of similar platforms and software for monitoring the reliability of their functioning. There are still many doubts about the effectiveness of using distance technologies in engineering education due to the emerging difficulties in their development and application, doubts in the development of practical skills, which is also noted in research conducted in engineering education (Ferreira, P., Fidalgo, A., & Gericota, M., 2020).

The development of telecommunication systems and technologies is relevant all over the world and becomes a priority in the Russian Federation due to the large-scale territories of our country. Wireless technologies are most in-demand, in particular, development of standards, equipment, and deployment of 5G networks. This increases the requirements for the competencies of radio engineers in general, and their metrological skills as one of the basic and structure-forming competencies, which make up the profile of a high-class specialist. Thus, the development of the metrological competence of radio engineers using virtual laboratory sites becomes a relevant goal.

2. Purpose and Objectives of the Study

The purpose of this article is to describe the approaches that the authors used when developing a digital educational resource with a built-in smart laboratory aimed at the development of students' metrological skills. The article also presents the results of approbation of the digital resource implemented during the teaching students at the Kazan National Research Technical University named after A.N. Tupolev while training them as engineering and technical personnel.

3. Methodology

The presented study was carried out at the Institute of Radio Electronics and Telecommunications (Kazan National Technical University named after A.N. Tupolev) and the Institute of Psychology and Education (Kazan Federal University).

When designing a digital educational resource, both theoretical and design and diagnostic research methods were used. The first included study and analysis of psychological, pedagogical, methodological, and engineering-technical literature on the implementation of a competency-based approach in the development of metrological skills. Design and diagnostic methods included: the creation of an online training course "Metrology and radio" in a virtual laboratory platform based on logical and object-oriented approaches, the design of assessment tools, the development of a diagnostic card for assessing the level of metrological skills development and testing students' metrological skills. The course was developed with pedagogical supervision and methodological support of the Department of Higher School Pedagogy of the Kazan Federal University.

A formative experiment to test the effectiveness of the created virtual laboratory site was carried out at the "Center of Electrophysical Diagnostics" of the Kazan National Technical University named after A.N. Tupolev.

At the final stage of the work, statistical processing of the formative experiment data was carried out.

The experiment involved 41 students of the 4^{th} and 5^{th} years of study at the Department of Radio Engineering, training program 25.05.03 "Technical operation of transport radio equipment".

4. Results

A digital educational resource with a built-in virtual laboratory was developed by an object-oriented approach as an innovative direction in distance learning. The key factor of this approach is a new paradigm of object perception when it is included in interaction with other course structures. In this case, we consider objects as measuring devices and their functionality. The object interacts with other structures of the environment:

- other objects;
- theoretical and methodological support for the development of metrological skills,
- diagnostic and assessment structures of the level of metrological skills development (tests, cases),
- special software for processing data obtained in the course of laboratory work.

This approach posits that a student percepts the dynamics of the environment while interacting with an object. This happens as a result of the student's actions to change this environment and his interpretations of the observed phenomena.

The logical approach to building the course is based on modeling reasoning and creates flexibility in solving practical problems by students, depending on their level of metrological competencies development.

The content of the developed resource was designed supported by the educational results defined in the Federal State Educational Standard for the training program 25.05.03 "Technical operation of transport radio equipment". The digital resource was created taking into consideration the needed minimum of topics for students: "Fundamentals of circuit theory", "Basics of standardization", "Circuitry engineering of analog electronic devices", "Digital devices and microprocessors", "Radio circuits and signals". Laboratory tasks also contain theoretical material. To organize feedback, LMS MOODLE structures such as "chats" and "thematic forums" were used, where the teacher formulated coaching questions, for example, "Why do we see a straight line on the graph screen?", "How will you use what you see on the screen graph?" and "Explain why this happens".

The technology of the created virtual platform is as follows. Modern measuring equipment, as a rule, has a computer onboard that controls all measuring systems and devices. This allows one to remotely connect, measure, and control the device. Normally, all physical control elements and information displays are visualized on a virtual display in the same way as physical control elements. That is, if we worked with the device virtually, then it is enough for us to simply switch to working with the real (physical) control elements of the device. In addition, it is possible to display a limited set of

measurement functions for a specific user for individual measurements, which can be convenient for making a gradation of users depending on their level: from beginners to advanced. At the initial level, the functionality is limited so that an inexperienced user does not harm the device by incorrect actions. If an experienced specialist is connected, then the functionality is expanded.

If we need to use devices of the previous generation that do not have remote access systems, then there are a large number of universal auxiliary devices (for example, video cameras with network access, simple manipulators for pressing buttons) that help to obtain visual access and physical control of devices via remote access. In addition, we used ready-made software products, which allow us to combine all available instruments into one measuring installation or stand.

This made it possible to combine various instruments into a single virtual laboratory site, even if the instruments may physically be located in different universities or even in different countries, but for the user, they will be perceived as a single measuring system. Certainly, for measuring specific physical samples or any physical quantities, we will need firstly, to deliver the measured samples to the device, and secondly, to engage a laboratory assistant. However, nowadays quick and reliable logistics can be provided, which increases the functionality of such systems.

This allowed us to solve two tasks. First, we could teach students using high-tech equipment, initially in a virtual environment, and then directly on physical devices. Because it is not possible to give access to a high-tech expensive device to students of 3rd, 4th, even 5th years of study without appropriate training. This training will be provided by performing laboratory tasks in a virtual laboratory environment. The second task was to improve the qualifications of working engineers. It is connected with the complex and wide functionality of modern measuring instruments, so even experienced engineers cannot use all the functions. From the experience of operating such measuring stands, it can be concluded that a working engineer, as a rule, uses just limited functionality and, when solving new tasks, he needs to gain knowledge within a short time, to develop skills for mastering new functionality of devices, which is sufficient costly. Often there is not enough time and money to complete training courses for professional development in person and in full.

When organizing methodological support for the metrological skills development of technical universities students in distance learning, the course “Metrology and radio measurements” was taken as a basis. When developing a diagnostic card, we relied on the identified nine professional structure-forming competencies of a radio engineer:

- ability to use measuring instruments for solving radio engineering problems;
- ability to choose a measuring instrument with appropriate metrological characteristics;
- ability to analyze and select measuring instruments with a permissible error;
- ability to use control and measuring equipment;
- interest in radio engineering, including instrumentation;
- desire to introduce the achievements of measuring technology into production;
- tracking achievements in the field of measuring radio equipment;
- understanding a category of standards and in other normative and technical documentation in the radio engineering field;
- understanding the basic concepts of certification in the radio engineering field.

The experimental search work was carried out with two student groups of the KNRTU-KAI - the 4th (22 people) and 5th (19 people) years of study at the Department of Radio Engineering. To organize the experimental-search work in each of the student groups, an experimental (EG) and control (CG) subgroup was set. In the experimental subgroup, laboratory tasks were organized only using remote access to measuring instruments. In the control subgroup, laboratory tasks were carried out in a traditional way (offline). At the end of the semester, all students traditionally completed two unknown laboratory tasks. We obtained the following results: during the first laboratory task, the decrease in results in the experimental subgroup was 13% and 27%. However, during the second laboratory task, the indicators of the EG surpassed the CG by 14% and 16%.

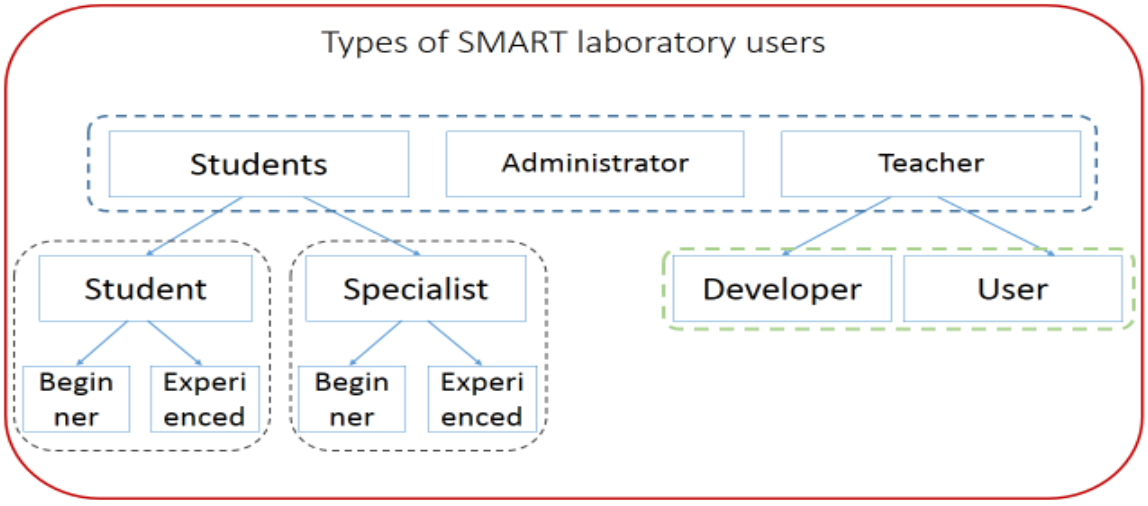

Figure 1: Structure of a SMART laboratory

That, in the authors' opinion, is because students quickly developed the skill of working with equipment "live".

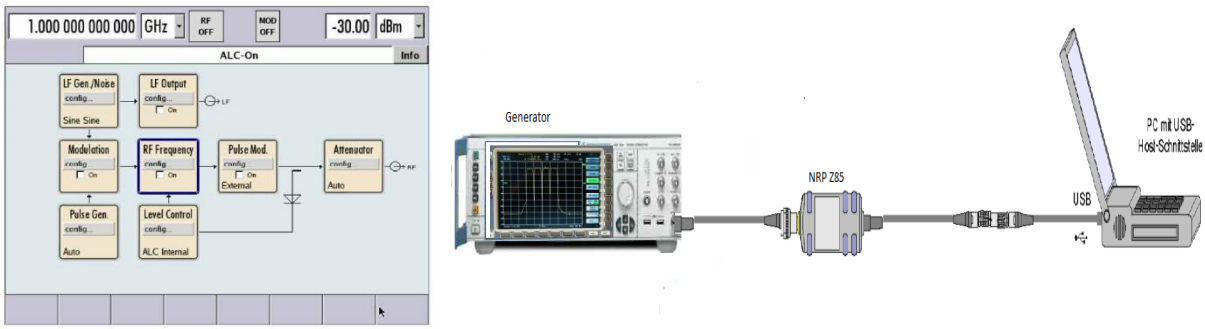

Figure 2: Example of a laboratory task on measuring the power of a microwave signal

5. Conclusions

The developed digital educational resource (CER) based on a virtual laboratory platform uses logical and object-oriented approaches. Theoretical and methodological support of a virtual laboratory site takes into account its flexibility and possibility to integrate it with other measuring sites. The CER with a built-in virtual laboratory was developed based on an object-oriented approach as an innovative direction in distance learning. The key factor of this approach is a new paradigm of object perception, from the point of view of its inclusion in interaction with other course structures. The applied approach entails interacting with an object, and, as a result, a student percepts the dynamics of the environment. This happens because the student is taking action to change this environment and interpreting the observed phenomena.

The logical approach to building the course is based on modeling reasoning and creates flexibility in solving practical problems by students, depending on their level of metrological competencies development. To implement the logical approach, it is proposed to use neural computer systems to help a student choose educational content. To work with a device, a student needs to study material consisting of several topics. Laboratory tasks contain theoretical and practical material. To organize feedback, LMS MOODLE structures were used, such as "chats" and "thematic forums", where a lecturer formulated formative or coaching questions.

Active digitalization of education is an important factor in creating a system of education that meets the requirements of the information society and follows the reforming process of the traditional education system due to scientific and technological progress. The most promising area for the development of students' metrological skills in the field of electronic measurements is the use of virtual laboratory sites in the educational process of a university.

As a result of the research, the hypothesis was confirmed that the development of metrological skills of technical university students in distance learning will be effective when creating a virtual laboratory platform basing on logical and object-oriented approaches. The main idea of the object-oriented approach is that at the beginning of training, students study not a general theory of metrology, but specifics of a high-tech measuring device. A logical-oriented approach assumes the independence of students to choose digital theoretical courses necessary to gain knowledge about the measuring principles to operate this device. It helps to significantly increase students' motivation, create a close connection between acquired knowledge and skills, and their practical application, make an individual training route, and thereby reduce time and increase the effectiveness of training.

A virtual laboratory site was developed and implemented at the "Center of Electrophysical Diagnostics" of the KNRTU-KAI and its effectiveness was confirmed in remote and full-time work.

6. Acknowledgments

We express our gratitude to the Department of Pedagogy of Higher Education for the expert and didactic assessment of the work. This work was supported by the programmatic strategic academic leadership of the Kazan (Volga Region) Federal University.

7. References

[1] K.A. Bazarov, Modern Digital Educational Environment in the Russian Federation. Science and Education, 3 (1), 2020. http://opusmgau.ru/index.php/see/article/view/1463

[2] Joachim, Fabini, et al., SecTULab: A Moodle-Integrated Secure Remote Access Architecture for Cyber Security Laboratories. The 16th International Conference on Availability, Reliability, and Security. 2021. pp. 1-11. https://doi.org/10.1145/3465481.3470034

[3] Ferreira Paulo, Andre Fidalgo, and Manuel Gericota, E-Engineering Education: Issues and Perspectives for Higher Education Institutions. International Conference on Remote Engineering and Virtual Instrumentation. Springer, Cham, 2020. DOI: 10.1007/978-3-030-52575-0_45

[4] L. Gomes, & S. Bogosyan, Current trends in remote laboratories. IEEE Transactions on industrial electronics, 56(12), 2009. 4744-4756. DOI 10.1109/TIE.2009.2033293

[5] A.V. Hoegen, R. W. D. Doncker, M. Bragard, & S.V. Hoegen, Problem-based learning in automation engineering: Performing a remote laboratory session serving various educational attainments. In 2021 IEEE Global Engineering Education Conference, EDUCON 2021. 2021 pp. 1605-1614. DOI: 10.1109/EDUCON46332.2021.9453925

[6] S. Lal, A. D. Lucey, E. D. Lindsay, D. F. Treagust, J. M. Long, M. Mocerino, M. G. & Zadnik, Student perceptions of instruction sheets in face-to-face and remotely-operated engineering laboratory learning. European Journal of Engineering Education, 45(4), 2020. 491-515. https://doi.org/10.1080/03043797.2019.1654433

[7] Y. Lyalina, R. Langmann, and V. Krisilov, Smart lab concept for different training modes as an extension of the remote lab. 2012 9th International Conference on Remote Engineering and Virtual Instrumentation (REV). IEEE, 2012. DOI: 10.1109/REV.2012.6293125

[8] Y. Makarova, et al. User profile creation and training mode determination in the "Smart lab" system. 2014 IEEE Global Engineering Education Conference (EDUCON). IEEE, 2014. DOI: 10.1109/EDUCON.2014.6826110

[9] F. Mercader-Trejo, A. R. López, G. L. Granada, L. N. Hernández, & R. H. Basurto, Technical internships as a means of acquiring professional skills for future metrologists. Measurement, 84, 2016. 1-6. https://doi.org/10.1016/j.measurement.2016.01.040

[10] N. V. Molotkova, & M. A. Sviryaeva, Model of Modern Engineer Competence as Basis of Educational Program Design. Questions of modern science and practice. University named after VI Vernadsky, (3), 2009. 40-46. http://vernadsky.tstu.ru/pdf/2009/03/rus_05_2009_3.pdf
[11] Mikhail Piganov, Sergey Tyulevin, and Ekaterina Erantseva. Individual prognosis of quality indicators of space equipment elements. The Experience of Designing and Application of CAD Systems in Microelectronics. IEEE, 2015. DOI: 10.1109/CADSM.2015.7230878
[12] Rodriguez-Calderón, Rosalino. In-home laboratory for learning automation at no cost. 2021 IEEE World Conference on Engineering Education (EDUNINE). IEEE, 2021. DOI: 10.1109/EDUNINE51952.2021.9429156
[13] Villar-Martínez, Aitor, et al. Towards Reliable Remote Laboratory Experiences: A Model for Maximizing Availability Through Fault-Detection and Replication. IEEE Access 9, 2021: 45032-45054. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9376937