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Improving the Efficiency of Distance Learning with a Minimum Network Load

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Conflicts of interest

The authors declare that there is no conflict of interest.

Abstract. The rapid onset of the COVID-19 crisis compelled immediate responses to mitigate infection risks, particularly in education. A swift transition to e-learning became a necessity, posing myriad challenges for students and institutions. Issues ranged from technical considerations to educators' preparedness and students' readiness, necessitating a reevaluation of the role of information technology in education. The didactic potential of e-learning tools is considered, and methodological recommendations are formulated for their integration into pedagogical practice, adaptation to both distance and traditional conditions. An analysis of relevant international studies informs the development of a teaching method that optimizes distance-learning efficiency and minimizes network load. This method strategically balances synchronous and asynchronous learning, considering network traffic reduction, fostering equal educational opportunities regardless of location, health, or financial status. This study affirms the method's effectiveness through a comparative analysis of the results with those of previous traditional semesters. This research contributes valuable insights for navigating the challenges posed by the pandemic in the education sector. This study aims to explore the pedagogical possibilities of e-learning tools and offer methodological recommendations for their incorporation into teaching practices, adaptable to both remote and conventional environments. Additionally, it seeks to develop and validate a teaching approach that enhances the efficiency of distance learning, reduces network load, and promotes equitable educational access, addressing the challenges associated with the rapid development and widespread adoption of e-learning technologies.

Keywords: e-learning, learning management, network bandwidth, Quality of Service (QoS), educational technologies, digital accessibility

Authors' contribution

Al Hakim R.S. — development of the research methodology, data analysis, writing; *Kovaleva E.A.* — literature review, analytical support, methodological recommendations; *Andreeva L.O.* — research supervision, formulation of the research concept; *Bogacheva T.V.* — literature review. All authors read and approved the final version of the article.

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Повышение эффективности дистанционного обучения при минимальной нагрузке на сеть

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Авторы заявляют об отсутствии конфликта интересов.

Аннотация. Пандемия COVID-19 обусловила необходимость экстренного перехода образовательных учреждений к дистанционному формату обучения, что выявило ряд организационных, методических и технических проблем. Особое значение приобрели вопросы эффективности дистанционного обучения и обеспечения равного доступа к образовательным ресурсам при ограниченных возможностях сетевой инфраструктуры. Рассмотрены педагогические возможности электронных образовательных технологий и предложены методические рекомендации по их интеграции в учебный процесс в условиях дистанционного и смешанного обучения. На основе анализа зарубежного и отечественного опыта разработан авторский метод организации дистанционного обучения, основанный на рациональном сочетании синхронных и асинхронных форм взаимодействия, позволяющий повысить эффективность обучения при минимальной нагрузке на сеть. Эффективность предложенного метода подтверждена результатами педагогического эксперимента и сравнительного статистического анализа учебных достижений студентов в дистанционном и традиционном форматах обучения. Полученные результаты демонстрируют сопоставимый уровень учебных достижений и высокую степень удовлетворенности обучающихся, что свидетельствует о практической значимости предложенного подхода и возможности его применения в условиях ограниченных сетевых ресурсов.

Ключевые слова: электронное обучение, управление обучением, пропускная способность сети, качество обслуживания (QoS), образовательные технологии, цифровая доступность

Вклад авторов

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Introduction

The concept of “distance learning” was introduced for the first time in Europe in the XIX century. Students received educational materials by mail, corresponded with teachers, sent their written works to the teacher for verification and received comments from them by mail. The founder of distance learning is the British shorthand scholar

Isaac Pitman, who in the 1840s introduced an innovative system of learning using shorthand. As an English teacher, in 1837, he suggested introducing shorthand writing into teaching, which would allow better interaction with students [1].

Other educational institutions began to adopt this learning experience. Colleges began to create that mail-provided education in accordance with the university program. In 1850, Gustav Langen-

scheidt published the so-called “teaching letters” in Germany, which allowed everyone to learn the language [2].

In America, the first steps were also taken in the development of distance learning. In 1873, Anna Eliot Ticknor began developing a system of education for women that was conducted by mail. It was based on the English program “Home Education Support Society” [3].

In 1911, distance learning courses began appearing in Australia. They were conducted at the university level at the University of Queensland. Mail-order training was also organized for children living far from school [4]. In a fairly short period of time, the distance learning system has spread to many countries. This included the possibility of training for schools and technical colleges. At this stage, the training was conducted in a handwritten version. Textbooks were published in paper form and delivered via mail. Publications at that time were not distinguished by high-quality printing and paper.

In the subsequent phase, the books exhibited enhanced quality, accompanied by the introduction of color illustrations. The materials were also supplemented with audio and video recordings. This stage dates back to 1969, when the Open University was established in the UK [5].

The third stage is associated with the active development of information technologies. This includes working with e-mail, the possibility of using teleconferences, and working with graphics and multimedia. In other words, at the present stage of development, communication between teachers and students is arranged as technologically and conveniently as possible.

In the 2000s, distance learning became the dominant form of learning. The Internet system was improving and becoming more accessible, and distance education technologies were developing. Consequently, the number of universities using Internet technologies has increased.

Today, distance learning has reached a new level of teacher-student interaction. The use of the Internet and personal computers allows for real-time communication, and modern software makes it possible to work effectively with a variety of

multimedia information in virtual space, regardless of the actual location of the teacher and the student. Simultaneously, the quality of distance education is constantly growing, including the reliability of procedures for monitoring learning outcomes and the objectivity of evaluating educational achievements [6].

The coronavirus pandemic has changed the usual way of life worldwide. Companies adapt to new conditions quickly: online stores and courier services have already introduced contactless delivery, and office workers have gone into quarantine and work from home. The rules have also changed for education, and the situation in the world has forced schools, technical colleges, and higher educational institutions to mandatory switch to distance learning.

The COVID-19 outbreak transformed distance learning from a desirable alternative into an immediate necessity, at least in the short term, with considerable uncertainty regarding the duration of this shift. This has brought distance learning to a much wider audience. Consequently, schools have had to create or fast-track online education plans to get teachers and students on board with the latest technology as quickly as possible [7].

On the other hand, this crisis stimulated innovation in the field of education. Innovative approaches have been applied on a large scale to ensure the continuity of education, and solutions for distance learning have been developed quite quickly, thanks in no small part to the measures taken by the governments of many countries.

The changes that have taken place regarding the accelerated transformation of the ways of providing quality education have made us think not only about the promising prospects of learning in the future, but also about the problems associated with this transformation. This is primarily about the problems of students who suffer from a lack of resources or a favorable environment for access to learning, as well as the problems of teachers who need to effectively master new teaching methods.

All these factors have led to extensive discussions among education professionals regarding the state and accessibility of distance education, the impact of COVID-19 on distance learning, and

the role of teachers and administrators in ensuring effective online instruction, as further discussed in the following section.

1. Materials and Methods

In particular, the goal of our study was to solve the following tasks:

- Determine the best way to minimize network load without affecting the quality of distance learning.
- Analyze and compare the differences in learning outcomes between learners studying using web-based and conventional modes.
- Collect feedback from students concerning our e-learning method.

To optimize the distance learning process, a method was developed based on two key principles: maximizing instructional efficiency and minimizing network load. Improving the effectiveness of distance learning requires the integration of appropriate instructional approaches and a balanced combination of synchronous and asynchronous learning formats, while taking network load constraints into account in order to ensure equal learning opportunities regardless of students' location, devices, or network conditions.

1.1. Asynchronous Learning

Asynchronous learning allows students to study according to their own schedule for a certain period of time. They can access lectures, read materials, and do homework and research at any time during one or two weeks.

Advantages of asynchronous learning:

- Flexibility of the schedule
- Individually dictated tempo
- More democratic
- More accessible
- More time with the materials

Within the proposed approach, asynchronous training was performed as follows:

- Watching various videos on different topics.
- Further research on these topics.
- Preparation of a presentation on these topics for the seminars.

1.2. Synchronous Learning

Synchronous learning, by definition, refers to an educational event in which a group of participants is engaged in learning at the same time; for this, they must be in the same physical place, for example, in a classroom, or in the same online environment (as in our case), where they can interact with the teacher and other participants.

Advantages of synchronous learning:

- Exchange of knowledge and experience among participants.
- Real-time feedback.
- Students become more engaged in their learning.
- Students feel a stronger sense of collaboration.

Within the proposed approach, asynchronous training was performed as follows:

- Questions, debates, and games.
- Video discussions in lectures.
- Presentations and reports at seminars.

Figure 1 shows the weekly learning process.

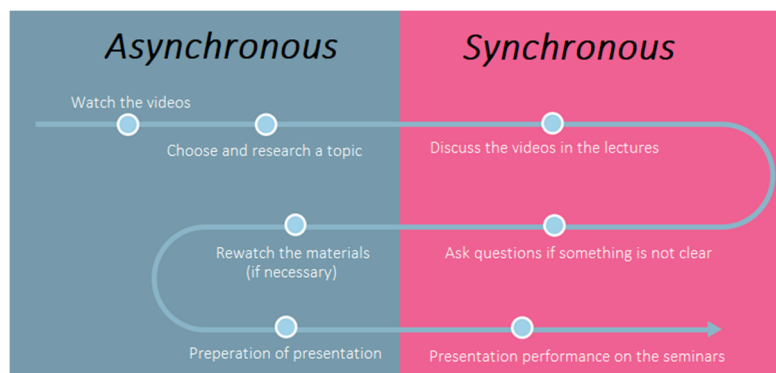


Figure 1. Weekly learning process

Source: by R.S. Al Hakim, E.A. Kovaleva, L.O. Andreeva.

As shown in Figure 1, the weekly cycle consists of seven steps. First, teachers send links to the required videos through WhatsApp 3–4 days before the lecture. Every student in turn chooses a topic and starts to study it, prepare it well, and write down his notes and questions about it. The third step is lectures, which are held synchronously on Microsoft Teams. The teacher asks questions about the given videos to determine the level of students’ understanding. The students also have the right to ask questions and receive real-time feedback from the teacher. After that, the students will have time to review their topics and prepare presentations on them. The last step is the delivery of presentations at the seminars, which also happens synchronously on Microsoft Teams and is evaluated by the teacher.

1.3. Network Requirements

Considering that more than 8000 foreign students from 155 countries study at our university, it is worth noting that not everyone has equal conditions due to the speed of the Internet and the presence of necessary materials. However, it is important for us that everyone has equal opportunities to act and gain knowledge. Therefore, it is very important to minimize the network load in our method so that everyone can acquire as much knowledge as possible, despite the different conditions for everyone. For this purpose, the minimum network requirements were analyzed and calculated for each stage of the proposed learning method (Figure 2). In addition, regular feedback from students was collected on a weekly basis to verify the stability and feasibility of the proposed approach under real learning conditions.

The highest Internet bandwidth requirement within the proposed approach is associated with video content consumption, which requires a minimum data rate of approximately 500 kbps. In contrast, activities such as web searching, reading academic materials, and collecting information for presentations can be performed with a substantially lower bandwidth of approximately 100 kbps.

Synchronous sessions were conducted using Microsoft Teams. During discussions and question-

and-answer segments, peer-to-peer audio communication is employed, requiring a minimum bandwidth of approximately 30 kbps. Presentation activities involve screen sharing and therefore require a higher bandwidth, estimated at approximately 130 kbps.

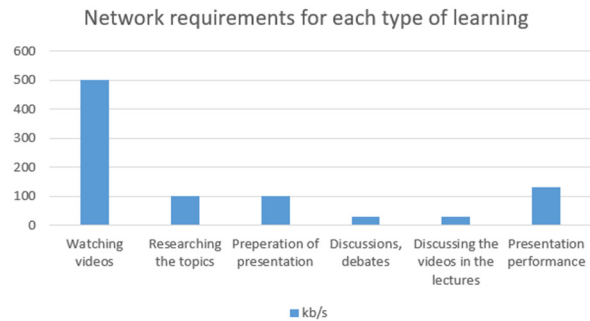


Figure 2. Network presentation delivery for each type of learning

Source: by R.S. Al Hakim, E.A. Kovaleva, L.O. Andreeva, based on Microsoft Teams technical documentation.

Overall, the analysis demonstrates that an Internet speed of 500 kbps is sufficient to support all components of the proposed distance-learning method, indicating its feasibility under limited network conditions.

2. Results

This section presents the characteristics of the three student groups, followed by an analysis of their academic performance with attention to identified differences. In addition, students’ perceptions of their learning experiences were examined.

As distance learning becomes an increasingly integral component of educational practice, understanding its technical characteristics and the requirements of different learning formats is essential for further improvement of the learning process.

2.1. Sample Characteristics

The data for the study were obtained from three groups of second-term full-time civil engineering learners through the subject “Basics of Engineering Economics and Management.” The first, second, and third groups consisted of 23, 22, and 19 students, respectively. The method was applied to the first

module of 2021–2022 semester (9 weeks). Table 1 shows the distribution of marks through the 9-week study plan of the module.

Unfortunately, not all the students could attend the module, due to the pandemic situation, some students took a gap year, or just stopped learning for personal reasons, 2 students didn't attend from the second group, and 3 from the third, they have been excluded from our statistics in order to get more accurate results, more details about the results of groups are shown at Table 2.

Table 1. *Distribution of marks*

Activity's type	Marks	Period	Maximum marks
Lectures	4	*8 weeks	80
Seminars	6		
Exam/paper/conference	20	Last week	20
–	–	In total	100

Source: by R.S. Al Hakim, E.A. Kovaleva, L.O. Andreeva.

Table 2. *Statistics of groups' results*

Group	Number of students	Average mark	Max	Min	Standard deviation
1	23	85.9	98	51	8.01
2	20	76.1	96	51	18
3	16	83.6	98	51	13.9

Source: by R.S. Al Hakim, E.A. Kovaleva, L.O. Andreeva.

Learners were assessed based on eight presentations, interaction with the teachers, and answering comprehensive questions, and the final activity, which could be presented as an exam, paper publication, or participation in conferences of their own choice.

2.2. Learning Outcomes

An important goal of e-learning is that it should not be less effective than conventional face-to-face learning in classrooms. According to [8], learning results can be evaluated at four levels:

Level 1. Reaction: This measures the students' reactions to the course.

Level 2. Learning: This measures what the students have learned.

Level 3. Transfer: This measures the changes in the learners' behavior when they return to their jobs after their training programs.

Level 4. Results: This measures the business outcomes that occur because the learners are doing their jobs differently.

In this study, we applied the first two levels of Kirkpatrick's learning evaluation as long as they are applicable in our case, Levels 3 and 4 require a more complicated and expensive study to collect the relevant data. There are many relevant variables and several complicating factors (such as motivation, trainability, job attitude, and personal characteristics) that make it difficult to evaluate the direct impact of learning on job performance and business outcomes [9].

Level 1 measures how the learners feel about their learning experience. It does not measure learning directly but simply measures the level of learners' satisfaction with their own learning experience. This measurement can be conducted using a reaction survey administered to learners. Here are some examples of survey questions to be asked: Are you satisfied with this course? Do you consider the material pertinent? Would you recommend this course to your friends or colleagues? Do you think the material is helpful for learners?

Level 2 consists of two main points: first, it requires a method to measure learning, which is commonly done by using an outcome assessment in the form of test scores. In the present study, an investigation was conducted into the outcomes of a specific e-learning module, comparing them with those previously obtained from a face-to-face module of the same groups. The comparison revealed a high degree of similarity between the results, indicating that e-learning implemented through the proposed method is not inferior to conventional instructional approaches. The detailed results of the comparative analysis are presented in Table 3.

As demonstrated in Table 3, no substantial disparities were identified. Furthermore, a t-test was conducted to ensure that no significant difference was detected in students' results between distance and conventional learning. P-values were calculated from the deviation between the observed value and

a chosen reference value, given the probability distribution of the statistic, with a greater difference between the two values corresponding to a lower P-value. In statistics, a P-value less than 0.05 is typically considered to be statistically significant, while P-value greater than 0.05 means that no effect was observed. The results are presented in Table 4.

Table 3. *Comparing results with previous conventional semester*

Group	Average mark		Max		Min		Standard deviation	
	Dist.	Trad.	Dist.	Trad.	Dist.	Trad.	Dist.	Trad.
1	85.9	86.3	98	98	51	51	8.01	6.74
2	76.1	76.6	96	95	51	51	18	17.5
3	83.6	83.3	98	98	51	51	13.9	13.3

Source: by R.S. Al Hakim, E.A. Kovaleva, L.O. Andreeva.

Table 4. *Test Results*

Group	P-value	Reject null hypothesis
1	0.23	Fail
2	0.35	Fail
3	0.30	Fail

Source: by R.S. Al Hakim, E.A. Kovaleva, L.O. Andreeva.

As demonstrated by the results analysis, no statistically significant discrepancy was identified between the outcomes of students in both traditional and distance education settings when our methodology was employed.

The second important point to evaluate in learning is the students’ comments and feedback. At the conclusion of each course, the learners were requested to evaluate the teachers and the method used, providing suggestions to improve their learning experience. Overall, 90% of the students were satisfied with their learning experience and agreed that they had learned the subject matter. They provided the following suggestions:

- Enhance animation and multimedia content.
- Videos should be shortened due to time limitations.
- Provide more topics related to their major.

The teachers, in turn, noticed that by the end of the course, the students became more confident

in presentations than they were in the very first weeks, which means that they acquired good communication skills through the course. The subjective views of the lecturers based on the depth of the questions and the comments of the students reflected the good level of knowledge gained by them.

3. Discussion

Previous studies have extensively examined the challenges and limitations of distance learning during the COVID-19 pandemic. A significant number of studies have focused on identifying the advantages, constraints, and general recommendations for online education in different national contexts [10–14], while other studies have relied primarily on surveys of students’ and teachers’ perceptions to assess the effectiveness of emergency remote teaching [15–18]. In addition, several researchers have investigated barriers to online learning, classifying them into technical, organizational, individual, and socio-economic categories [19; 20].

Despite differences in methodology and geographical focus, a common conclusion can be observed across these studies: technical constraints, particularly limited Internet bandwidth and unequal network conditions, represent a major challenge for effective distance learning. These constraints are strongly influenced by factors such as country of residence, type of Internet connection, available devices, and students’ economic conditions. However, in most existing studies, technical limitations are described as external factors rather than addressed through concrete, system-level solutions.

In contrast to prior research, this study addresses this gap by proposing a distance learning method that explicitly accounts for network Quality of Service (QoS) requirements. The proposed approach integrates synchronous and asynchronous learning formats while minimizing data transmission demands, thereby enabling effective instruction under heterogeneous and limited-network conditions. By aligning instructional design with network constraints, this method aims to improve learning efficiency while ensuring equitable access to education, regardless of students’ technical capabilities.

Conclusion

The rapid transition to distance learning during the COVID-19 pandemic highlighted the critical role of technical factors in ensuring the quality and accessibility of education. In this study, a distance learning approach was developed that integrated synchronous and asynchronous learning formats while explicitly accounting for network Quality of Service constraints.

The obtained results demonstrate that a balanced organization of learning activities makes it possible to reduce network load without compromising educational effectiveness. The experimental implementation of the proposed approach in real educational settings showed learning outcomes comparable to those of traditional face-to-face instruction, which was confirmed by statistical analysis.

Overall, the findings indicate that effective distance learning can be achieved under heterogeneous and limited network conditions when instructional design and network requirements are jointly considered. This confirms the practical applicability of the proposed approach in educational environments with constrained or unstable Internet connectivity and provides a basis for further research on its long-term effectiveness and scalability.

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