RIGA TECHNICAL UNIVERSITY

Evija Mirķe

TEACHERS' READINESS FOR REMOTE LEARNING DURING 2020–2021 PANDEMIC

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of E-learning Technologies and Humanities
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"E-learning Technologies and Management"

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To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on September 7, 2023, at 12:00, at 14 Lielā Street, Room 227.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Evija Mirķe …….. (signature)
Date: ……

The Doctoral Thesis has been written in Latvian. It consists of an introduction, 5 chapters, conclusions, bibliography, 29 images, 49 tables, and 43 appendices; the total number of pages is 287, including appendices. The Bibliography contains 334 titles.

LIST OF DEFINITIONS, ABBREVIATIONS AND ACRONYMS USED IN THE THESIS

Combined learning – a form of learning education where on-site lessons are supported by means of online tools – discussion groups, forums, correspondence sites, own and mutual evaluation tools.

Covid-19 – Acute Respiratory Syndrome Coronavirus 2 (SARS-COV-2).

Digital literacy – one of the components of digital competence, the ability to use ICT for day-to-day activities, a basic level of understanding of how ICT works.

Digital competence – ability and skills to use ICT for the purpose of acquiring and stockpiling, gathering knowledge, obtaining, evaluating, and exchanging information, communicating securely with other people through ICT, exploiting all the opportunities offered by the Internet and technology in training, work, free time. Digital competence is the result of a set of individual skills.

Distance learning – the form of education acquisition in which the content of an educational programme implemented by an educational institution is acquired independently in an individual way, using specially structured teaching materials, various technical and electronic means offered by an educational institution.

Educator – a specialist in pedagogy or a person with the appropriate education to work as a teacher or lecturer in a higher or middle-level educational institution.

E-learning – training in an electronic environment (e-environment).

Hybrid learning – a form of training where a part of the learners learns in person, a part of which is remote. Training can be done both in synchronous and asynchronous ways.

Mathematical model – mathematical calculations performed to depict a process, system or its operation.

On-site learning – a form of educational learning in which the educational content of the student is acquired by visiting an educational institution, including remote learning, in conformity with the educational programme implemented by the educational institution.

Remote learning – the part of the on-site education process in which learners are trained, including using information and communication technologies, without physical presence in the same room or training site together with the educator.

Teacher – a specialist in upbringing and teaching a certain subject, who has obtained a teacher's qualification to work professionally in an educational institution or in private practice.

The learning process – the direct development of targeted organized teaching and learning as part of the pedagogical process, where new information and new skills are learned in the interaction between the teacher and the pupil, reinforces the previously acquired knowledge. The training process is a process of knowledge, communication, and personality development.

Self-directed learning – a form of learning where a student takes control and responsibility for his or her learning.

EC – European Commission
EU – European Union
ICT – Information and Communication Technologies
IKVD – National Education Quality Service
IZM – Ministry of Education and Science of the Republic of Latvia
LIIS – Latvian Educational Information Systems
LIZDA – Latvian Trade Union for Education and Science Employees
LSM – Latvian Public Media
LR – Republic of Latvia
MK – Cabinet of Ministers of the Republic of Latvia
OECD – Organization for Economic Cooperation and Development
PISA – OECD International School Assessment Programme
RL – remote learning
TALIS – The Teaching and Learning International Survey
UNESCO – United Nations Educational, Scientific and Cultural Organization
VISC – National Educational Content Centre
WHO – World Health Organization

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1. GENERAL REVIEW OF THE DOCTORAL THESIS

1.1. Subject topicality

Since the end of 2019 with an outbreak of acute respiratory syndrome Coronavirus 2 SARS-COV-2 (Covid-19) in China (Lin et al., 2020) so called "Covid-19 pandemic" started. In March 2020, the World Health Organization (WHO) declared a state of emergency due to the spread of Covid-19 (LSM.lv Ziņu redakcija, 2020). Mass school closures affected more than 90 % of students worldwide (UNESCO, 2020). On March 13, 2020, the Cabinet of Ministers of the Republic of Latvia (MK) announced an emergency situation and ordered all educational institutions to continue learning process in remote form (lost power – Par ārkārtējās situācijas izsludināšanu, 2020).

Neither in Latvian universities nor anywhere else in the world, until now, teachers were prepared for emergency remote teaching, and it cannot be compared with working in the classroom or online (Hodges et al., 2020). The professional competence of teachers was not sufficiently developed for organizing high-quality pedagogical work in remote setting. Teachers encountered difficulties and challenges when starting remote teaching process. Students' performance was related to emotional factors caused by isolation, loneliness, and the need to individually cope with lesson planning and task completion (Trust & Whalen, 2020; Wang et al., 2022).

When starting to work remotely in 2020, teachers were forced to significantly change their work organization and teaching methods. Since the beginning of the pandemic, educational researchers around the world have been actively studying how teachers can better manage remote teaching (Glazier, 2021; Hosny et al., 2021; Lemov, 2020; Martin, Budhrani, et al., 2019; Mirķe et al., 2019; Mirķe & Tzivian, 2021; Scherer et al., 2021; Serravallo, 2020; Stevens, 2020). Research has been conducted during the Covid-19 pandemic, and the results confirm the importance of cooperation in various teachers' professional peer groups for both the acquisition of professional knowledge as well as ensuring the emotional well-being (Justis et al., 2020; Olofsson et al., 2021; Ulla & Perales, 2021). In the spring of 2020, the Ministry of Education and Science of the Republic of Latvia (IZM) investigated the experience gains during the first remote learning semester. The results emphasized the importance of technological experience in achieving high results and concluded that the digital skills of many teachers were not sufficient to effectively manage remote learning process (Edurio, 2020; Jansone, 2020; Rozenberga, 2020).

Remote learning during the pandemic and its direct relationship with information and communication technologies (ICT) in some places widened the digital divide gap because of the physical availability of computers and Internet services (Stevens, 2020). Students needed specific types of learning materials and another form of assignments. Some required help in organizing their individual learning. Teachers learned how to organize and plan different types of learning. School management teams solved technical problems. Parents, entrepreneurs,

and students-volunteers were involved in solving technical issues and providing assistance, including helping with learning (Anstrate, 2020b; Goudeau et al., 2021). Studies conducted in schools with good technological equipment showed that the workload decreased, a rapid jump in the digitalization of the learning process was observed (Olofsson et al., 2021). Technologies can increase the efficiency of learning and improve learning outcomes, but their limited availability is a significant threat and risk to democracy. The most threatened are the most vulnerable groups of society (European Union, 2021; Goudeau et al., 2021).

Remote learning is useful in non-standard circumstances, such as natural disasters, war, long-term illness or injury that prevents attending school, long-term absence due to family circumstances, professional activity in sports and other circumstances (Glazier, 2021). Remote learning also provides an opportunity to organize lifelong learning activities for citizens who cannot attend full time classes. Well-planned remote learning and purposeful cooperation among several educational institutions can help solving the problem of the shortage of teachers.

Remote learning in a certain combination with face-to-face learning will continue playing a certain role in the education system. The ability to learn and teach using technology will be important both for students and teachers (Daniela, 2021; Lepp & Luik, 2021; Schleicher, 2020; UNESCO International Institute for Educational Planning, 2020b). Since November 2020, remote learning has been incorporated into the Education Law of the Republic of Latvia (LR) as one form of face-to-face learning. The procedure for organizing it in different class groups and limitations are described in the regulations of the Cabinet of Ministers on the procedure for organizing remote learning (LR Ministru kabinets, 2022; LV portāls, 2020). This means that it is necessary to develop a methodology for organizing remote learning for each subject area, it is necessary to get common understanding in how a teacher shifts from working in the classroom to working remotely.

Research on the use of information and communication technologies (ICT) in education has been conducted in the world for more than twenty years. However, from today's point of view, the field of research has been narrowed – technologies have so far been perceived as supplementary means to educators within the framework of existing educational models. Covid-19 created a new educational situation where ICT was unexpectedly assigned a central role. It created a large-scale societal experience that has the potential to transform into new models of future education. It is also important for Latvian science to be actively involved in understanding the new Covid-19 education situation and develop new scientific findings. Using the opportunities created by the crisis situation and the experience gained, it is necessary to assess the gap between the desired level of readiness to ensure a high-quality remote learning process and the real readiness of a teacher to work remotely at the given moment.

The knowledge about remote teaching and the analysed remote learning solutions in various fields of study collected in this Doctoral Thesis can help solve the shortage of teachers, as well as be useful in the development of methodology for remote teaching, promoting the popularization of remote learning.

1.2. Aim and objectives of the research

The purpose of this study is to describe the readiness of teachers at general education schools in Latvia to organize remote learning during the pandemic of 2020–2021 and to develop an emergency remote teaching skills acquisition model that can be used to improve teachers' professional development and lifelong learning processes.

Research questions:

1. How did the emergency remote teaching during the 2020–2021 pandemic affect the readiness of teachers to organize pedagogical work during remote learning and how was it related to teachers' professional development and lifelong learning processes?
2. How do teachers' professional development and lifelong learning processes differ in various subject areas during emergency?
3. How to use the mathematical learning curve models to describe and interpret teachers' remote learning organization skills development in an emergency?

The author has set the following objectives to carry out the research:

1. To study pedagogical literature, scientific publications, and other bibliographic sources on organization of e-learning and remote learning, teacher's professional competence development and readiness for remote teaching, as well as mathematical learning curve models.
2. To describe the Latvian teacher's readiness for remote learning, compare research data from spring 2020 and spring 2021, and identify differences in various subject areas.
3. To develop a learning curve model for evaluating the remote learning pedagogical work organizational skills in an emergency situation.

The object of the study is Latvian general education teachers' professional competence required for the organization of pedagogical work in emergency remote learning situation.

The subject of the study is the experience of remote learning pedagogical work during the pandemic.

The basis of the study are the general education teachers in Latvia who worked in schools in school years 2019/2020 and 2020/2021.

1.3. Scientific novelty and practical significance of the research

Theoretically analytical collection of scientific literature and empirical studies on the readiness of teachers for remote learning can be considered an important information base in the field of educational science in Latvia. For the first time in Latvian educational science the readiness of teachers for remote learning in an emergency situation has been evaluated, its influencing factors have been described, as well as the differences in various subject areas have been analysed.

The survey questionnaire used in the study is practically applicable for evaluating teachers' readiness for remote learning in an emergency.

The mathematical models of remote learning organizational skills acquisition described in the Doctoral Thesis can be used in teacher training and professional development events to assess the knowledge dissemination factor in a group of individuals in an emergency.

The author's conclusions and recommendations will be useful for further development of the education science sector in Latvia.

1.4. Theses for defence

The author puts forward the following theses for defence:

a. The emergency situation and the remote work related to it affect the process of professional education and lifelong learning of teachers, increase the digital competence and readiness for remote learning. In an emergency situation, teachers purposefully try out new communication platforms, digital evaluation tools and other technological means in their pedagogical work to ensure the continuity and quality of the learning process. Teachers of different fields of study learn the skills of organizing distance learning pedagogical work at different speeds.
b. The organization of remote learning in an emergency situation for Computer Science teachers is a new application of existing information technology knowledge, which these teachers have individually acquired in the long run as part of their professional competence. For teachers of other subject areas, the organization of remote learning in an emergency situation must be learned as a new skill, and it was quickly acquired through the knowledge dissemination in teacher groups and collaboration.
c. Teacher collaboration and knowledge sharing in formal or informal learning groups of larger or smaller size, is the most important learning activity in an emergency situation to achieve the highest possible professional competence and readiness for distance learning in all learning areas except Computer Science.
d. The model and metrics developed in the thesis quantitatively describe the dynamics of the remote learning work organization skills development and knowledge dissemination in groups of teachers. Relationship between the dynamics of skill acquisition and individual characteristics such as previous experience in working with ICT, education, place of residence and others has been observed. The developed knowledge and skill learning curve models can be adapted for use in traditional settings to evaluate the interaction of individuals and the spread of knowledge of different nature in a group.

1.5. Future research perspectives

To find the best solutions for the future, it is necessary to look back and evaluate the experience of remote learning during the pandemic, analyse successful examples and understand what constitutes a successful remote learning formula.

The author considers the Doctoral Thesis to be a statement of the status quo, based on which other studies in the future can be developed, for example:

- The learning curve model with the dissemination of knowledge in the group should be applied to other types of situations (non-emergency), other groups (for example, specialists in other fields who learn some skills in professional development or are continuing education courses) to improve the learning curve model and adapt the developed mathematical equations to normal life for the situation.
- It would be necessary to conduct research on how knowledge dissemination in a group occurs in a situation where there is no crisis and no external motivation as school lock-down. Since people are social beings, it is natural to share knowledge. It would be important to understand human behaviour and find out what factors hinder the knowledge sharing in a larger or smaller group.
- When studying the dissemination of knowledge in a group of individuals, which is essential for the organization of pedagogical work, it would be necessary to study the factors affecting the size of the group and to what extent. These can be, for example, manager's leadership potential, the work of the management team, the personality characteristics of the individual or other factors.
- The developed learning curve model with knowledge dissemination in a group should be tested in different organizations and countries, studying and drawing conclusions about the differences of different cultures and their influence on knowledge dissemination in a group.

1.6. Approbation of research results

The course of development of the Doctoral Thesis and the research results have been presented in 16 scientific publications and scientific conferences.

1. Mirķe, E. (**2023**) *Development of Teachers' Readiness for Emergency Remote Teaching During Pandemic and Its Connection to Learning Area* (In Press). International Conference of Collaborative Learning (ICL 2022). https://doi.org/10.1007/978-3-031-26876-2_41 (**SCOPUS**).
2. 81st International Scientific Conference of the University of Latvia (online). February 16, **2023**. Presentation of the results of the study "Teachers' Readiness for Remote Work in the Spring Of 2020 and 2021". Report "Community Learning Model in Teachers' Communities of Practice Triggered by Covid-19 Pandemic".
3. International scientific conference "International Conference of Collaborative Learning (ICL 2022)" (Vienna, Austria), September 27–30, **2022**. The results of the studies "Teachers' Readiness for Remote Work in the Spring of 2020" and "Teachers' Readiness for Remote Learning in the Spring of 2021" were presented at the conference.
4. Mirķe, E., Tzivian, L. (2021). *Teachers' Readiness for Remote Teaching During Covid-19 Pandemic: The Case of Latvia*, 2021 IEEE Global Engineering

Education Conference (EDUCON), pp. 537–542, https://doi.org/10.1109/EDUCON46332.2021.9454088 (**SCOPUS**)

5. Mirķe, E., Tzivian, L. (**2021**). *Factors of Successful Work in School During Covid-19 Pandemics in Latvia.* From Daniela, L. & Visvizi, A. (Red.), Distance Learning in Times of Pandemic: Issues, Implications and Best Practice (1st ed., pages 211–225). *Taylor&Francis*.
6. International scientific conference "2021 IEEE Global Engineering Education Conference (EDUCON) (online). April 21–23, **2021**. The conference presented the results of the study "Teachers' Readiness for Remote Learning in the Spring of 2020".
7. 79th International Scientific Conference of the University of Latvia (online). February **2021**. Presentation of the results of the study "Teachers' Readiness for Remote Learning in the Spring of 2020". Paper "How to Become a Successful Remote Learning Teacher in Three Months?" (05.02.2021.). Report "Information and Communication Technologies in Emergency Remote Learning (Case of Latvia)" (19.02.2021).
8. 61st International Scientific Conference of Riga Technical University (online). October 16, **2020**. Presentation of the results of the study "Teachers' Readiness for Remote Learning in the Spring of 2020". Report "Prerequisites for Teachers' Success During the Covid-19 Pandemic".
9. Mirķe, E., Cakula, S., Tzivian, L. (**2019**). *Measuring Teachers-as-Learners' Digital Skills and Readiness to Study Online for Successful e-Learning Experience*. Journal of Teacher Education for Sustainability, 21(2) 5–16. https://doi.org/10.2478/jtes-2019-0013 (**SCOPUS**).
10. Mirķe, E., Kašparová, E., Cakula, S. (**2019**). Adults' Readiness for Online Learning in the Czech Republic and Latvia (Digital Competence as a Result of ICT Education Policy and Information Society Development Strategy). Periodicals of Engineering and Natural Sciences, 7(1), 205–215. https://doi.org/10.21533/pen.v7i1.366 (**SCOPUS**).
11. Mirķe, E., Cakula, S. (**2019**). Adults' Digital Competence and Readiness for Online Learning: Preliminary Findings on Latvian Adult Learners' Readiness to Study Online. International Journal of Advanced Trends in Computer Science and Engineering, 8(1), 22–27. https://doi.org/10.30534/ijatcse/2019/0581.12019 (**SCOPUS**).
12. International scientific conference "*SOCIETY. TECHNOLOGY. SOLUTIONS 2019"* (Valmiera, Latvia). April 25–26, **2019**. Presentation of the results of the study "Teachers' Readiness for E-learning". Paper "Evaluating Teachers' Digital Competence and Readiness for E-learning for a Successful E-learning Experience".
13. International Conference on Communication, Management and Information Technology 2019 (ICCMIT 2019) (Vienna, Austria). March 26–28, **2019**. Presentation of the paper "Adults' Readiness for Distance Learning in the Czech Republic and Latvia (Digital Competence as a Result of ICT Education Policy and Information Society Development Strategy)".

14. University of Latvia International Scientific Conference in Medicine (Riga, Latvia). February 22, **2019**. Presentation on the results of the study "Latvian Teachers' Readiness to Study Online".
15. 58th International Scientific Conference of Riga Technical University (Riga, Latvia). October **2017**. Presentation of the study "Adults' Digital Literacy and Readiness for Distance Learning: The Results of Latvian and Czech studies".
16. International Conference on Communication, Management, and Information Technology 2017 (ICCMIT 2017) (Warsaw, Poland). April 3–5, **2017**. Paper "Adults' Digital Literacy and Readiness for Distance Learning: Conclusions on the Readiness of Latvian Adults for Distance Learning".

1.7. Structure of the Doctoral Thesis

The Thesis consists of an introduction, five chapters, conclusions, theses put forward for defence, list of bibliographic sources and appendices.

The introduction is devoted to the description of the actuality of the work in the context of Latvian and global education.

Chapter 1 describes the impact of global change processes and technologies on the professional development and education processes of teachers; it describes various forms of distance learning and the form of remote learning caused by the pandemic.

Chapter 2 describes the teacher's professional competence and the related digital competence as an essential prerequisite for readiness for remote learning, as well as explores the main factors that influence the preparation of teachers for remote learning.

Chapter 3 describes knowledge or skills acquisition (learning) curves, the forgetting curve and their mathematical models, lists the factors influencing the learning curve, and describes the possibilities of applying the learning curve.

Chapter 4 describes the empirical research conducted by the author on the history of informatization of Latvian schools and the related development of teachers' digital literacy, the results of the study conducted in 2018 to study the digital literacy of teachers, as well as the results of the empirical study conducted during the pandemic on teachers' readiness for remote learning.

Chapter 5 describes the developed innovative method for ascertaining and evaluating the real level of acquiring the skills of organizing the pedagogical process of remote learning – the mathematical model of learning curve and its results.

2. OUTLINE OF INDIVIDUAL CHAPTERS

2.1. The impact of the changes taking place in the world on the organization of pedagogical work at school

In Chapter 1 of the Doctoral Thesis, the author describes changes in educational processes and development trends in Latvia and the world, which have been affected by modern technologies, the Covid-19 pandemic and other world events. This chapter describes how the research task of studying the pedagogical literature, scientific publications and other bibliographic sources on e-learning, combined learning, distance learning and remote learning, teacher's professional competence, teachers' readiness for remote learning (RL), as well as mathematical models for calculating skills acquisition was realized. This chapter defines and briefly explains the concept and goals of the science of pedagogy, describes the learning process, forms of learning with a certain amount of online content – combined learning, e-learning, distance learning, and remote learning and describes changes in educational processes, future forecasts and trends of educational development in Latvia and the world, which has been influenced by information and communication technologies (ICT).

During the pedagogical process, someone acquires new skills or improves existing skills or knowledge under the guidance of someone or something considered suitable for organizing and evaluating the pedagogical work (Boettcher & Conrad, 2016). The learning process is "the direct conduct of purposefully organized teaching and learning as a part of the pedagogical process in which new information, new skills and abilities are acquired through the interaction between the teacher and the student, and the previously acquired knowledge is strengthened" (Nacionālais Apgāds, 2002), (Letonika.lv. Enciklopēdijas – Latvijas Enciklopēdiskā vārdnīca. Mācību process, n.d.). The social nature of learning was described by Bandura as a process influenced by the interaction between individuals and the object of learning. Individual learning is considered a part or result of a social process that largely depends on the interaction of an individual with other individuals (Gould, 2012).

Education must continuously adapt to the current requirements of the labour market of the time (Moore, 2013). Changes have also affected the education system of Latvia. New standards of general primary and secondary education (Noteikumi par valsts pamatizglītības standartu un pamatizglītības programmu paraugiem. Ministru kabineta noteikumi Nr. 747, 2018; Noteikumi par valsts vispārējās vidējās izglītības standartu un vispārējās vidējās izglītības programmu paraugiem, 2019) have brought forward changes in both the content (curriculum) and teaching approach, focusing attention on the development of the student's personality as a future citizen. A school is a "learning organization" in which everyone learns – not only students, but also teachers and other employees (Skola2030, n.d.).

The beginning of the distance learning can be traced back to the end of the 19th century in Great Britain, the USA and Canada (Burke & Ločmele, 2021). Since the beginning of the 21st century, the Massachusetts Institute of Technology (MIT)

Table 2.1

Types of courses by amount and ratio of online and face-to-face content (after Boettcher and Conrad, 2016)

Proportion of online content	Form of learning in the course	Course description
Less than 14 %	Traditional face-to-face learning	Learning is entirely or mostly face-to-face (with very little online content). The content is presented orally. There are scheduled face-to-face meeting times, workshops, or face-to-face tasks. Tests are done on paper or to a lesser extent online. Possible course website on some online platform or learning management system (LMS) where teaching or handouts are available, emergency communication.
15–39 %	Mild blended learning or hybrid learning, also called "flipped learning"	Technology is used to offer learning that has traditionally been delivered face-to-face. An LMS or some online platform is used where the syllabus, assignments and some lectures are published. In general, the course is similar to face-to-face learning.
40–79 %	Blended or hybrid learning*	Face-to-face and online learning are combined. Much of the content is presented online. The discussions are most often encouraged online. There are some face-to-face or synchronous online meetings.
More than 80 %	Online learning or e-learning	Most or all content is taught online. Increasingly, regular synchronous online meetings are included.

* In 2016, the term "hybrid learning" was referred to a form of combined learning during which face-to-face or synchronous online meetings take place (Boettcher and Conrad, 2016). After the pandemic, hybrid learning describes synchronous face-to-face and online meetings, when some learners participate in face-to-face classes, while some learners are online at the same time (UNESCO International Institute for Educational Planning, 2020a).

and other large universities also offer online learning (The Economist, 2012). The term "e-learning" appeared in the USA in the mid-90s of the 20th century. Pollard and Hillage described e-learning as learning where learning is supported by ICT solutions, thus promoting the individual development of each student. E-learning is not technology, but learning through technology (Armstrong, 2006).

The author uses Boettcher and Conrad's categorization to demonstrate the differences between different forms of learning depending on their proportion of face-to-face and online learning (Table 2.1). It has been mentioned that the proportion (%) may change depending on the development of the situation, technology, or global trends (Boettcher & Conrad, 2016).

Blended learning is one of the pedagogical work organization forms that can be used after the pandemic. Blended learning refers to technology support for traditional teaching methods when face-to-face classes are supported by online resources – discussion groups, forums, chat sites, audio broadcasts, and

self-assessment tools (Chew, 2008). Great attention is paid to preparatory work before face-to-face classes in order to devote more time face-to-face to pronouncing incomprehensible questions, analysing information and seeing connections, solving problem situations and discussions that promote a deeper understanding of the specific learning topic (Priedīte, 2018).

Emergency remote teaching emerged as a response to world events and travelling restrictions. The main condition was to ensure the learning process using all available resources and technologies until the restrictions are reduced and students can return to the classroom (Burke & Ločmele, 2021). Unlike earthquakes, floods, or other natural disasters, which in the past could cause a disruption in the education process around the world, this time schools were closed completely, but learning was supposed to continue (Anderson & Hira, 2020).

During the pandemic, educational institutions in Latvia were closed longer than in other OECD countries – secondary schools in Latvia were closed for 151 days (for comparison: OECD – 78 days on average), primary school grades 5–9 were closed for 146 days (OECD – 55 days on average), while primary school classes in Latvia were closed for 67 days (OECD – 101 days on average) (OECD, 2021). As a result of closing schools, students were exposed to several risk factors – domestic violence, addictions, lack of wholesome food, inability to learn due to lack of equipment or learning materials, unsuitable environment, lack of socialization with peers and others (UNESCO International Institute for Educational Planning, 2020a). During the pandemic and post-pandemic, an increase in the number of psychotherapists' patients was observed, more teenagers came under the supervision of specialists, parents of children needed psychological help. Due to the pandemic, the level of stress in society increased significantly, cases of domestic violence increased, and the number of teenagers with various addictions increased (Anstrate, 2020a; Dēvica, 2021; LSM.lv Bērnu satura redakcija, 2020, 2021). The study conducted by the National Quality Control Department (IKVD) also brought up to date the management of educational institutions implemented by the Ministry of Education and Culture (IZM) and other institutions and the quality of the decisions made by them regarding the closing of schools in Latvia (Vispārējās un profesionālās izglītības kvalitātes izvērtējums, 2021). The consequences of these decisions on the quality of education and student success will be observed only in the long term.

In the conclusions on the remote learning quality during the academic years 2019/2020 and 2020/2021, IKVD found several factors that had significantly affected the quality of education:

1. Educational institution management work.
2. Availability of technology and digital literacy of all parties.
3. Management communication with parents and students.
4. The attitude of the institution management and teachers towards change, readiness and ability to introduce change.
5. Availability of group or individual lessons or consultations.
6. The management of the education system, the decisions made by the Ministry of Education, the public announcements and the crisis communication implemented, which affected the work of all educational

institutions (Vispārējās un profesionālās izglītības kvalitātes izvērtējums, 2021).

According to the November 2020 amendments to the Education Law (LV portāls, 2020), the following forms of education are currently available in Latvia, which affect the topic of the Doctoral Thesis (Izglītības likums, 1998):

- **full time** – "form of completion of education where a student acquires the education content by attending an educational institution, including remote learning, according to the educational program implemented by the educational institution";
- **extramural studies** – "educational activities conforming to the interests and demand organized outside of formal education";
- **remote learning** – "a component of full-time education process where students learn without being physically present in the same room or venue as the teacher, which also includes the use of information and communication technologies";
- **distance learning** – "the form of the acquisition of education in which a student acquires the content of an educational program implemented by an educational institution independently and individually, using specially structured study materials offered by the educational institution, and different technical and electronic means of communication; achievements of the student are assessed according to the requirements of the relevant educational programs" .

In the context of this work, the author uses term "ICT" for everything related to technology in education, such as computers, smart phones, interactive blackboards, as well as software and applications used by teachers in learning process (Haelermans, 2017). ICT has changed the way and shape of people's learning, work and social networking (Ulla & Perales, 2021). The physical presence of technologies does not mean their high quality and didactic targeted use. Integration of ICT into the learning process should be done with a certain goal (Plauka, 2017). Children use technology differently than adults have intended it (Nylander, 2019; Nilsen, 2018). Prensky's theory about "digital citizens", whose digital language is a "native" language, and "digital immigrants" who learn technology over the course of life, is popular (Moore, 2013), but also criticized, pointing out that no child is born with the skills to use technology effectively and meaningfully – it must be taught by an adult (Kirschner & De Bruyckere, 2017; Plauka, 2017). Latvian pupils' reading skills are relatively poor and have deteriorated in the recent years (LR Izglītības un zinātnes ministrija, 2019). One of the causes could be excessive use of smart devices from early childhood, as viewing the images on screen requires less effort and cognitive load (Plauka, 2017).

Global trends and research have shown that online education will continue playing an important role in the future and should be taken into account (Ehlers, 2020). Over time, it may become clear which subjects or study courses can only be learned remotely, combined or only in person (Vasiļevska, 2020). The knowledge acquired during the pandemic on the organisation of a remote learning pedagogical process and the use of ICT in this process will be useful in the future for those who

will use different forms of learning (Burke & Ločmele, 2021). Teachers should learn new methods specifically designed and validated for this type of work (Kaden, 2020).

2.2. Teacher's professional competence and readiness for remote learning

In Chapter 2 of the Doctoral Thesis, the author describes the professional competence of the teacher as a precondition for readiness for remote learning. Motivation for teachers' professional development in pandemic conditions and other factors may also influence readiness for remote learning (RL) with a view to determine how to assess teachers' readiness for RL and what factors affect it. This chapter describes authors' work on studying pedagogical literature, scientific publications and other bibliographic sources on e-learning and organization of remote learning, teachers' professional competence, teachers' readiness for remote learning, and mathematical models for the skills acquisition learning curve.

The preparation, retention and motivation of competent and professional teachers is one of the priorities of the Latvian National Development Plan for 2021–2027 (NDP2027) (Par Latvijas Nacionālo attīstības plānu 2021.–2027. gadam (NAP2027), 2020). Teachers need to continuously develop their professional expertise. Unlike professionals of other professions, the teacher should develop competence from two different aspects: be prepared to acquire and develop his or her professional competence and to improve the learners' competences (Namsone, Volkinšteine, et al., 2018). The term "teacher's professional competence" includes a few essential elements in the work of a teacher: knowledge in the subject, psychology, pedagogy, and ability to use skills in practice (Fig. 2.1.). Competence also consists of attitude to teaching, teachers' and students roles, personal characteristics and personal motivation, which can be observed in real work with students (Namsone, Volkinšteine, et al., 2018).

In European Union documents, competences are referred to as key competences, which each individual must develop for the successful functioning of the society (Directorate-General for Education, 2019; Eiropas Parlamenta un

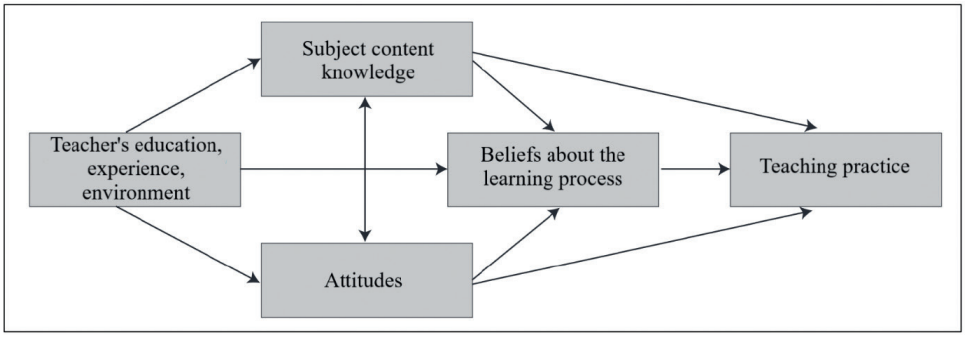

Fig. 2.1. Teacher's professional competency model (Namsone after Wilkin, 2008).

Padomes ieteikums (2006. gada 18. decembris) par pamatprasmēm mūžizglītībā, 2006). Digital competence is one of the basic skills or competences defined by the European Commission. It is "the ability to use technology to acquire, build, develop and exchange information, communicate and participate in collaborative/social networks through opportunities offered by the Internet and technology, and the ability to use information technology convincingly and critically both for learning as well as in job and leisure" (Dudareva, 2018, pp. 189–190). Digital competence is considered to be the most important competence for a modern person (Ilomäki et al., 2011). It is also part of a "teacher's professional competence" (Skantz-Åberg et al., 2022). Teacher's digital competence gained its importance during the pandemic for the purpose of organizing remote learning (Margeviča-Grinberga, 2021). Digital competence describes the skills of a teacher to use any technical device and digital resource needed for work, including the development of their digital learning materials, knowledge of security issues, and other aspects.

The Digital Competencies Framework for European Teachers, or DigCompEdu, describes twenty-two competences needed for modern educators. The framework describes how all 22 competences are connected (European Commission, n.d.; Redecker, 2017) and refers to seven key aspects: (1) technological competence, (2) attitudes to ICT, (3) pedagogical competence, (4) knowledge of the content of the subject, (5) cultural awareness, (6) professional engagement, and (7) critical approach (Skantz-Åberg et al., 2022). Research has shown that teacher's digital competence has an impact on students' performance; therefore, the development of digital competence in the process of vocational training and further training of teachers should be given greater attention to the development of digital competence (Núñez-Canal et al., 2022).

The digital competence of the teacher affects pupils' performance. Nowadays teachers must be able to use technology to demonstrate ICT opportunities and potential for students and to use ICT to ensure a more efficient learning process (Stocchetti, 2014). The role of the teacher is to use and teach students to use ICT tools in a meaningful way (Namsone, Oliņa, et al., 2018). In order to increase the use of digital tools, experts recommend developing a culture of cooperation and sharing, reorganizing workloads so that it leaves more time for teachers' personal and professional growth (Jansone-Ratinika et al., 2021).

To successfully integrate ICT into the learning process, the teacher needs three types of knowledge: knowledge of technology, pedagogy, and the content of his subjects. These three form Technology, Pedagogy and Content Knowledge (TPACK) framework (Koehler et al., 2013). The Technology Framework defines a teacher's skill in handling different technologies to achieve a learning goal in the subjects. The pedagogical framework places responsibility for organizing learning in such a way as to improve and develop the competences of learners. The content framework means focusing on the content of your subject, managing the methodology for learning it, and its suitability for a particular parent of the pupils (Sarwa et al., 2020).

For teachers to be able to work remotely without prior experience in remote learning, different forms of professional development, such as courses, online

trainings, webinars, independent learning, played an important role. The adult learning process is different from the children. Dewey concluded that the adults' training, professional development, and lifelong learning should be based on practical experience and links to the real life (Spalding, 2014). Knowles observed that adults quickly lost motivation when they were taught using the same methods as children (Aubrey & Riley, 2016). As regards teacher readiness for remote learning, the author draws attention to the importance of learning motivation. Since regular professional development is a mandatory requirement in the work of a teacher in Latvia, it is necessary to know what determines whether the teacher wants and can develop himself professionally. Bruner considered that the internal motivation for learning consisted of three key forces: curiosity, achievement orientation and the need to belong to the learning community. Illeris mentioned three key dimensions of learning motivation: the internal psychological learning process (content), interpersonal cooperation, the desire to acquire knowledge and its knowledge (Illeris, 2018b, 2018a; Weitze, 2014). Knowles believed that when a person gets older, motivation internalizes, that is, personal desire to learn and develop oneself becomes more important than external motivation (Gould, 2012).

The fact that the overall performance of the group is better, if the members of the group complement each other and cooperate purposefully in achieving or improving the outcome, can also be explained by the principle of synergy between the group (Thompson, 2020). Synergy (from the Greek "*συνεργός"* (*synergos*) to "helpful") is a process whereby exposure to a substance changes or increases the effect of another substance (Letonika.lv. Enciklopēdijas – Terminu un svešvārdu skaidrojošā vārdnīca. sinerģisms, n.d.). Hattie wrote about the importance of the interaction between individuals, pointing out that individual work creates a higher cognitive burden because there is "literally no-one else to shoulder the burden" (Hattie & Yates, 2014, p. 152). Thus, cooperation with others is essential for both social and practical reasons: working together with a number of individuals gives greater results than for each individual alone (Hattie & Yates, 2014).

In total, there are four elements in determining the organization's readiness:

1. Organization (institution).
2. Faculty (teachers, administrative, technical staff).
3. Courses (learning materials, assessments).
4. Learners (Palloff & Pratt, 2002; Simonson et al., 2014).

Teachers' readiness for RL is closely associated with several factors. The Latvian Internet dictionary "*Thesaurus*" explains "readiness" as a state of being *"prepared, prepared (to be carried out); peace-of-mind (to be carried out)"* (Spektors, 2009).

If teachers are qualitatively prepared both for work in the classroom and remote learning, they can create a lasting, engaging and meaningful learning experience, even from a distance, while maintaining the quality of the learning content (Hoppe, 2015). Targeted training of teaching staff is highlighted as a primary necessity to ensure successful training (Hoppe, 2015). A teacher without prior experience with e-learning needs special preparation or training and methodological guidelines to conduct e-learning (Boettcher & Conrad, 2016).

When compiling the recommendations of other researchers for the assessment of readiness for RL, the following list of relevant factors has been obtained (Chi, 2015; Martin, Budhrani, et al., 2019; Serravallo, 2020):

- technical (digital) skills;
- experience in RL;
- attitude (awareness of importance) to RL;
- time management skills;
- the ability to engage pupils and promote socialization during RL;
- the need for the assistance of the management and colleagues of the institution;
- skill in building teaching materials and adapting them to RL.

2.3. Learning curve models

In Chapter 3 of the Thesis, the author describes the theories of the learning process organization and research on the skills or knowledge learning curve to visually represent the learning process. The author describes several learning curve models, e.g., univariate, hyperbolic, exponential, multi-factor, and combined learning curve models, and factors that influence them. The author describes the results of her studies of pedagogical literature, scientific publications, and other bibliography sources on mathematical models for the skills acquisition models.

The learning curve is a graphical "curve plotting performance against practice; the course of progress made in learning something" (Merriam-Webster, n.d.). A learning curve can show the performance of one individual in a particular group, the performance of one department in an organization, or even the overall performance of an organization itself (Jaber, 2016). At least three data points are required to create a learning curve that reflects the individual performance against the invested resources (costs, work, effort) in time units (Howard et al., 2021). Initially, the learning curves were used in production industry where employees had to acquire new technical skills through repeated activities in the production of a product, as well as by the introduction of new production technologies and/or equipment (Speelman & Kirsner, 2005). These types of models are used today in manufacturing, health, biology, sociology, financial and economic models, information technologies, urban planning, and other areas of public interest (Tingyan, 1990).

Mathematical expressions may be used to display a system or its operation, process, or part thereof. Such a mathematical expression is called a mathematical model (Valsts izglītības satura centrs, n.d.). If the data shows a long-term trend, or trending, the mathematical functions can be used to forecast the land (Počs, 2003). Trendline models for calculating the learning curve initially became popular with the aim of reducing and calculating production costs more precisely (Boone et al., 2022).

Wright was one of the first who described learning of knowledge with a mathematical formula describing his observations in the publication "Factors affecting the cost of airplanes" in the manufacture of airplanes – at a higher

number of packages (number of repetitions) of a particular aircraft model, the costs decreased (Jaber, 2016). Wright estimated that each time when production doubled, costs fell by about 20 percent (Malyusz & Pem, 2014). Wright's (1936) mathematical equation is referred to as the **Wright's Log-linear model** (Straight-line Model) and is considered the first known learning curve model (2.1):

$$y = Ax^{-b}, \tag{2.1}$$

where y is the average time or cost per unit to produce x units, while the theoretical time or cost needed to produce the first unit is indicated by A. The variable b must be between 0 and –1 and it represents the learning rate represented by the slope of the curve. The closer b is to –1, the faster the performance is, so the curve is more steep (Jaber, 2016). It is assumed that the amount of work needed to produce (x +1) units will always be less than the amount of work needed to produce x units (Malyusz & Pem, 2014).

Other researchers developed the Wright's model by adding new variables, e.g., a time constant c describing the steady performance of an individual (**Plateau model**) (Peltokorpi & Jaber, 2021), a constant B that describes human-acquired prior experience (**Stanford-B model**) (Malyusz & Pem, 2014; Peña et al., 2022), an incompressibility factor M that describes the process's automation factor, in other words, the fraction of the work performed by a machine (**DeJong's model**) (Malyusz & Pem, 2014; Peña et al., 2022), and others.

In general, their simplicity is considered one of the advantages of log-linear models (Peña et al., 2022; SaravanaPrabhu & Vidjeapriya, 2021), but there are also shortcomings: in these models, at a certain amount of repetition, performance time is approaching zero, which is not possible in reality (Gunawan, 2009; Peña et al., 2022). One of the most fundamental flaws in the log-linear models is that there is no sign of a slowdown in the learning rate, since the individual's learning rate cannot grow endlessly. Boone and others offered a new version of the Wright's model (2018), introducing variable c ($c > 0$) denoting a learning slowdown factor ("*decay*" from the mechanics) (Boone et al., 2022; Hogan et al., 2020).

Mazur and Hastie published a **"two parameter hyperbolic learning curve model**" (1978) (Jaber, 2016; Peña et al., 2022), shown in Equation(2.2):

$$z = k\left(\frac{x}{x+r}\right), \tag{2.2}$$

where x is the quantity of units produced according to the standard, r is the quantity of units produced not conforming to the standard, the constant k represents the quantity of units produced consistently, whereas z represents the product of the number of parts corresponding to the standard with a constant k. Later, the model's authors supplemented it with an employee's previous experience parameter q, developing a **"three parameter hyperbolic learning curve model"** (Anzanello & Fogliatto, 2011; Jaber, 2016; Peña et al., 2022).

The advantage of hyperbolic learning curves is that both the acceleration and deceleration of learning and the quality of work can be included at the same time,

while the complexity of these models can be mentioned as shortcoming, as the complexity makes it more difficult to assess the data obtained (Peña et al., 2022).

Knecht integrated the exponential function into the Wright's log-linear model to improve the long-term production forecasts. His proposed model (1974), called the **"combined exponential log-linear model"**, is shown in Equation (2.3):

$$y = Ax^b e^{cx}, \tag{2.3}$$

where the variables *y, A, x, b* of the log-linear model are complemented with the variable *c* denoting the second constant, which can be assumed or calculated by optimization (Jaber, 2016). The variable *y* is the time or cost needed to produce x units and *A* is the time or cost needed to produce the first unit. Variable *b* represents the slope of the curve (range 0 to –1) (Malyusz & Pem, 2014).

At the end of the twentieth century, Towill developed a **"constant time model"** (1990). He discovered that it is better suited to assess the learning curve after the individual has had some practice time and has adapted to the new task (Anzanello & Fogliatto, 2011), as shown in Equation (2.4):

$$p = p_c + p_f \left(1 - e^{-\frac{x}{\tau}} \right), \tag{2.4}$$

where p_c denotes the employee's performance at the beginning of the process (measuring units produced per unit of time) and p_f denotes the maximum possible performance of the employee at the time the acquisition is complete. Variable *x* denotes cumulative operating time, while τ is the time constant of a defined curve. This type of equation helps to calculate the time needed to achieve a certain performance level (Jaber, 2016; Peña et al., 2022). The constant time model is considered to be rather simple with only three parameters (Gosling et al., 2019) and is recommended for use when an employee is given an adaptation time before data is collected (Anzanello & Fogliatto, 2011).

The advantage of the exponential models is that these models include a slowdown in the learning rate, as human learning rate cannot be increased endlessly – humans have their natural capacity limits. Disadvantage – exponential models are more complicated because they have two or three parameters and it is more difficult for the researcher to choose the right variables to include in the model (Gunawan, 2009; Peña et al., 2022).

For scenarios where learning processes are influenced by both quantitative and qualitative elements, multi-factor models have been developed, including several independent variables, such as "production costs", "production rate", "duration of training programme", "costs of learning programme", "task complexity", and others. These types of models are considered to allow the calculation of variable effects, but it should be noted that the quality of the results can be influenced by the addition of less significant variables that weaken the design model (Jaber after Badira (1992).

There are processes that cannot be represented by a single learning curve, and it is recommended to develop a mathematical model of a complex or combined

curve (Murre, 2013), but current information on these models is not enough to draw conclusions on their advantages or disadvantages.

There is a wide scope for applying the learning curves. By integrating two methods – learning curve models and machine learning data collection – more accurate data can be collected to be entered further into resource management systems, but there are certain limits that need to be considered:

1. In different industries, learning curves can be completely different.
2. The development of the learning curve is based on data collected at a specified time. It is therefore important to collect this data in the most accurate manner. The collection of data should be repeated at regular intervals.
3. For each organization/unit, the learning curve pattern is unique and accurate exactly with the individuals whose data is included in the model. If people in the organization/unit change, new measurements must be taken and a new model should be developed (Peña et al., 2022).

There are several individual and organizational factors influencing the learning curve:

- recruitment of employees;
- previous work experience;
- motivation;
- the degree of complexity of the work;
- duration of the job/task to be performed;
- number of times repeat (practice);
- the quantity of forgotten units;
- the number of errors committed;
- development of working methods;
- professional development, training (Dar-EL, 2000).

It is concluded that there are many factors that may affect the learning curve. For each situation and study group a new learning curve model should be developed, examining the significance of each variable for the learning process result. The author concludes that the learning models described in literature and scientific articles rarely include cooperation or the synergetic effect mentioned above, where the interaction of individuals has a positive impact on the outcome of the group (Hertel, 2011).

2.4. Empirical study

In Chapter 4, the author describes the results of an empirical study based on a theoretical analysis of distance learning methods and recommendations for organization of emergency remote learning. The duration of the empirical study, including a feasibility study to assess the digital literacy of teachers, is overall four years. This chapter describes how the study has been carried out to describe the readiness of Latvian teachers for RL, comparing the results in spring 2020 and 2021 and identifying differences in different subject areas.

To assess the basic skills or digital literacy of the ICT use of Latvian teachers, in 2018 the author carried out a quantitative study involving teachers at general

education schools (N = 1092). The "Test of Online Learning Success", developed by Kerr and Rynearson, was chosen (Texas Weslayan University, n.d.). The digital literacy question block covered 11 items. The maximum number of points – 55.

At the beginning of the pandemic (March 2019), the author concluded that it was difficult to assess the readiness of Latvian teachers for RL, because RL had not previously been carried out on such a large scale either in Latvia or in the world. The conditions of the pandemic had created both technical and psychological burdens.

To assess the readiness of Latvian teachers for RL, the author carried out a quantitative study in 2020–2021 involving teachers of Latvian general schools (N = 2111). A self-assessment questionnaire was developed based on teachers' readiness for distance learning assessment tools developed by other researchers in the field of education (Chi, 2015; M. L. Hung, 2015; M.-L. Hung et al., 2010; Martin, Wang, et al., 2019). None of the instruments had been used in an emergency. In the questionnaire prepared by the author, 32 items were listed in several blocks of questions:

- individual and institutional support needed for the teacher (hereinafter referred to as *"Assistance*", 3 items);
- engagement of and communication with pupils (hereinafter referred to as "*Engagement*", 7 items);
- work organization forms and teaching methods (hereinafter referred to as "*Work Organization*", 5 items);
- attitudes towards remote learning in general (hereinafter referred to as *"Attitude*", 7 items);
- use of digital resources ("*Digital resources*", 7 items).

The main conclusions of both stages of the empirical study are described in Chapter 3 of the Thesis summary ("Conclusions").

2.5. Development of a model for acquiring pedagogical work organizational skill for remote learning

Chapter 5 of the Doctoral Thesis describes how the author has carried out the task to develop a model of RL pedagogical work organizational skill learning curve (RL organizational skill learning curve model). The author describes three different models, applicable in different situations.

The author used the constant time model developed by Towill (described in Chapter 3 of the Thesis), which includes performance indicators at the beginning and the end of the learning process (Anzanello & Fogliatto, 2011). A system of equations was created (2.5):

$$\begin{cases} p_1 = p_f \left(1 - e^{-\frac{t_1}{\tau}}\right) \\ p_2 = p_f \left(1 - e^{-\frac{t_2}{f}}\right), \\ t_2 - t_1 = t_x \end{cases} \tag{2.5}$$

where p_1 is the teacher's readiness at the beginning of the RL study (first measurement in 2020), p_2 is readiness at the end of the RL study (second measurement in 2021), p_f is the maximum possible level of readiness for RL and is known (p_f = 32), t_1 indicates the time when the teacher reached the level p_1 of RL, t_2 is the time when the teacher reached the level p_2 of RL. The time between the first and second measurements is indicated by t_x. Given the dates of the study, this variable value is known: t_x = 12 months, while τ in this equation represents a time constant, that is, a time that includes a certain experience for each individual or the time during which the teacher would acquire the necessary knowledge independently.

Three models of the RL organizational skill learning curve were developed in the study:

1. learning curve without previous experience;
2. learning curve with accumulated experience;
3. learning curve with knowledge dissemination.

In developing the "RL organizational skill learning curve without previous experience", it was assumed that each teacher had acquired digital skills independently, at least at the basic level, sometime in the past (before the pandemic) before the RL was launched (Fig. 2.2.).

On the basis of the original equations system (2.5), the author developed (more calculations in Appendix 1) a mathematical model (2.6):

$$\begin{cases} -\frac{t_1}{\tau} = \ln\left(1 - \frac{p_1}{p_f}\right) \\ -\frac{t_1 + t_x}{f} = \ln\left(1 - \frac{p_2}{p_f}\right) \end{cases}. \tag{2.6}$$

The model was evaluated experimentally with computer science (Comp.Sc.) teachers' data. The Comp.Sc. group has been selected deliberately because these teachers have the greatest experience with ICT and their computer skills are objectively the highest.

Variables for the Comp.Sc. group were as follows:

p_f = 32
p_1 = 28.83
p_2 = 28.97
t_x = 12 months,

where p_f is the maximum possible readiness for RL, p_1 is the readiness for RL at the time of the first measurement, p_2 is the readiness for RL at the second measurement, t_x is 12 months (there were 12 months between the first and second measurement). As a result, the time t_1 for the Comp.Sc. group was calculated 614 months (December 1969). It is known that the subject "Computational Mathematics and Programming" was introduced in Latvian schools in 1964 (Vēzis, 2005), it is assumed that this learning curve model is valid for the computer science teachers' group.

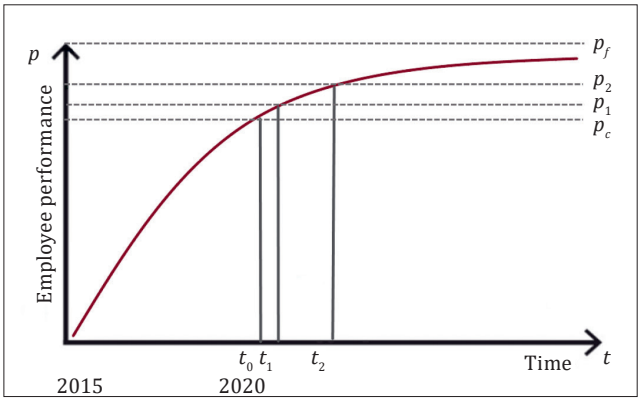

Fig. 2.2. RL organizational skill learning curve without previous experience.

To assess the mathematical model in other subject areas, calculations were re-conducted with data from all other subject areas. The time periods calculated did not have a logical justification or significant event in the educational ecosystem. The author concludes that the model is not applicable to other subject areas.

The "RL organizational skill learning curve with accumulated experience" was developed on the assumption that teachers' experience in ICT is an important part of readiness for RL (Blue line in Fig. 2.3.). Equations (2.7) describe the sum of the learning curve of the pandemic and the learning curve of previous knowledge p_v:

$$\begin{cases} p_1 - p_v = p_f\left(1 - e^{-\frac{t_1}{\tau}}\right) \\ p_2 - p_v = p_f\left(1 - e^{-\frac{t_2}{f}}\right) \\ t_2 - t_1 = t_x \end{cases} \tag{2.7}$$

Two data measurements from the empirical study were used to calculate the time when the process of developing readiness for RL could have started. In addition to the above-mentioned Equation (2.5), a variable p_v was introduced to describe teacher's previously acquired skills (sometime before the pandemic). This model assumes that each teacher individually improves his/her professional competence. Doing calculations with all subject area (SA) group results (except Comp.Sc.), the previous experience was calculated as a negative figure. A negative experience factor is an impossible situation. As a result of the calculations, it was concluded that teachers' learning process had significantly changed during the pandemic.

The first two models described traditional further education situations where each teacher individually learns how to use the new technologies. As a result of the Covid-19 pandemic, the situation had rapidly changed; the pandemic conditions

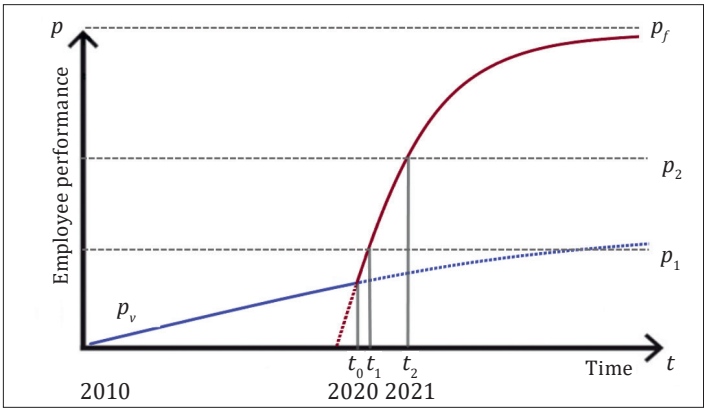

Fig. 2.3. RL organizational skill learning curve with accumulated experience.

cannot be regarded as a traditional education situation. The author assumed that the acquisition of RL organizational skills had been different in the event of an emergency within the education ecosystem. There could have been a rapid dissemination of knowledge among individuals, resulting in an increase of the readiness for RL in the entire group of teachers. It was concluded that a new RL organizational skills learning curve model should be developed to represent the process of disseminating knowledge within the group of individuals.

The graphic image of the third model "RL organizational skill learning curve model with knowledge dissemination" could be as shown in Fig. 2.4, where t_0 coincides with the beginning of the pandemic (March 2020), and the curve rises rapidly as individuals rapidly acquire new knowledge in a very short period of time.

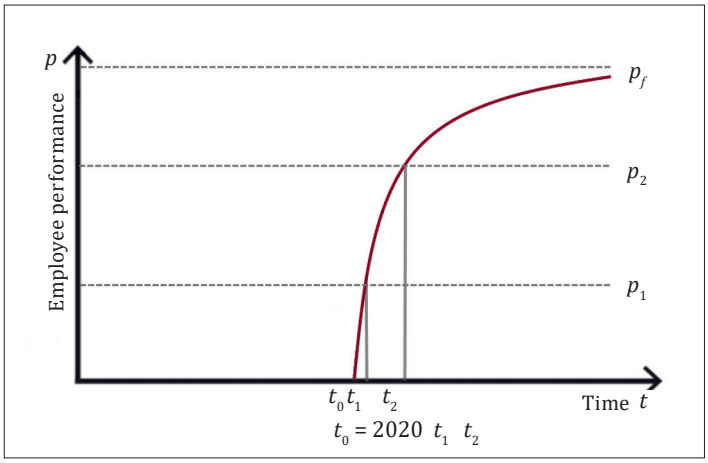

Fig. 2.4. RL organizational skill learning curve model with knowledge dissemination.

The author reminds that the RL organizational skill learning curve for the Comp. Sc. teachers' group has been calculated based on the learning curve model without prior experience, therefore the computer learning curve in this part is no longer calculated.

None of the two previous models included rapid knowledge transfer processes within a group, therefore it is concluded that there must be a factor influencing the slope of the learning curve. It could be that a certain amount of simultaneous learning processes took place at the same time. A variable c is introduced to describe the knowledge dissemination factor ($0 < c < 1$). While 1 learning process happens, there are n number of other cases happening at the same time using rapid knowledge dissemination. When an individual acquires the RL organizational skill, the new knowledge is quickly shared with others with the same subject area or others.

During the pandemic, teachers acquired the skills needed for remote work more quickly, shared knowledge with each other, and this learning curve can be described by Function (2.8):

$$\frac{p}{p_f} = \left(1 - e^{\frac{t}{\tau}}\right)^c, \tag{2.8}$$

where c is the variable of knowledge dissemination ($0 < c < 1$). Other variables are as in the previous equation. A system of equations was created (2.9):

$$\begin{cases} \frac{p_1}{p_f} = \left(1 - e^{-\frac{t_1}{\tau}}\right)^c \\ \frac{p_2}{p_f} = \left(1 - e^{-\frac{t_2}{f}}\right)^c \\ t_2 - t_1 = t_x \end{cases}. \tag{2.9}$$

The author selected the technology subject area (except Comp.Sc.) group for calculations. The variables for technology group are:

$p_f = 32$
$p_1 = 26.05$
$p_2 = 28.19$
$t_x = 12$ months.

It follows from the calculation that c can be expressed by Equation (2.10):

$$\frac{\ln 0,814}{ln\left(1 - e^{-\frac{3}{\tau}}\right)} = c = \frac{\ln 0,881}{ln\left(1 - e^{-\frac{15}{\tau}}\right)}. \tag{2.10}$$

Numerical methods (Appendix 2) were used to determine c.

For the subject area of technology, factor *c* was 0.05. Data and estimated knowledge dissemination factors for all subject areas (except Comp.Sc.) are shown in Table 2.2.

The highest figures in terms of RL organization skills at the beginning of the pandemic (p_1) were observed in the fields of foreign languages, mathematics and natural science (Table 2.2), the lowest "starting point" (p_1) was in the subject areas of health and physical activity, technology, culture and self-expression in arts. This can be explained by the prior experience of these subject areas in the use of ICT during lessons. If the subject includes more practical work and requires physical presence of the teacher to avoid major errors, the use of ICT in technology hours in the learning process is limited compared to practical activity.

If the exponent *c* was a whole number, it would be clear that there had been two processes to be summed, but since $c < 1$ (Table 2.2) in all subject areas (except Comp.Sc.), it is concluded that the start of the learning curve has not significantly affected the learning curve during the pandemic. The author concludes that the data from this mathematical model confirms that during the pandemic the RL organizational skills acquisition has been very rapid. The smaller is *c*, the smoother the curve. This means that knowledge was more rapidly spread, thereby increasing the level of RL organizational skills for the entire group.

Table 2.2

Performance and estimated learning dissemination factor in all subject areas

Subject area	**Number of respondents, *N***	**p_1, performance after 3 months**	**p_2, performance after 15 months**	**p_x, difference**	***c*, knowledge dissemination factor**
Health	61	24.95	28.05	3.1	0.076
Technology	240	26.05	28.19	2.14	0.05
Social and civic	263	26.88	28.71	1.83	0.042
Culture	177	26.45	28.21	1.76	0.040
Latvian	267	26.56	28.08	1.52	0.035
Natural sc.	174	27.28	28.71	1.43	0.032
Foreign language	193	27.21	28.39	1.18	0.026
Mathematics	299	26.9	28.03	1.13	0.026
Comp.Sc. *	77	28.83	28.97	*	*

* Comp.Sc. results are different due to the specific nature of the subject; knowledge distribution in group is minimal.

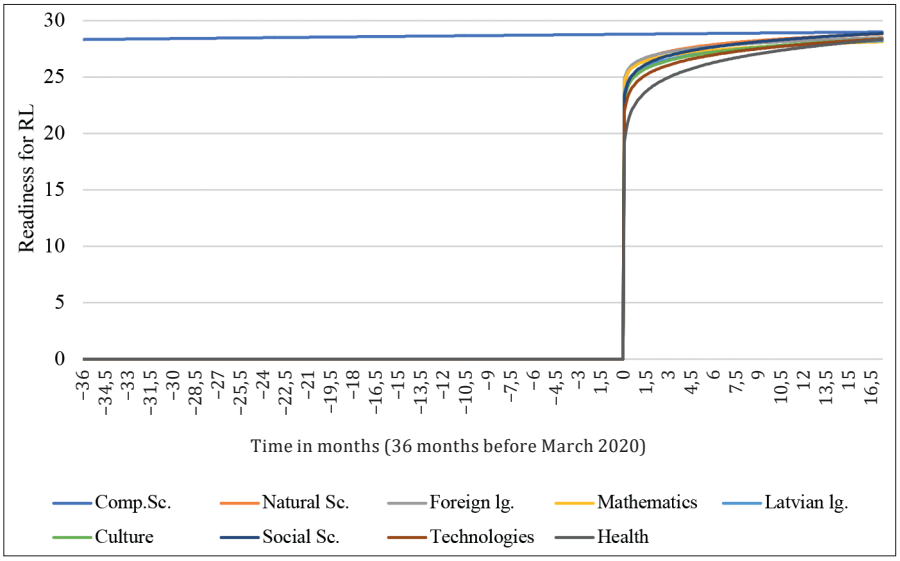

Fig. 2.5. Development dynamics of readiness for RL in all subject areas starting 36 months before the pandemic.

Although it is not quite objective to compare the Comp.Sc. teachers to others in terms of RL organizational skills because of the specific education of this group, the estimated data for this group shows a logical connection – Comp.Sc. teachers could easier conduct remote teaching because ICT use was a normal day-to-day process. It was easy for Comp.Sc. teachers to apply their skills in remote setting. Understanding of basic processes is sufficient to use the knowledge and transfer it to other areas, using it in a new way.

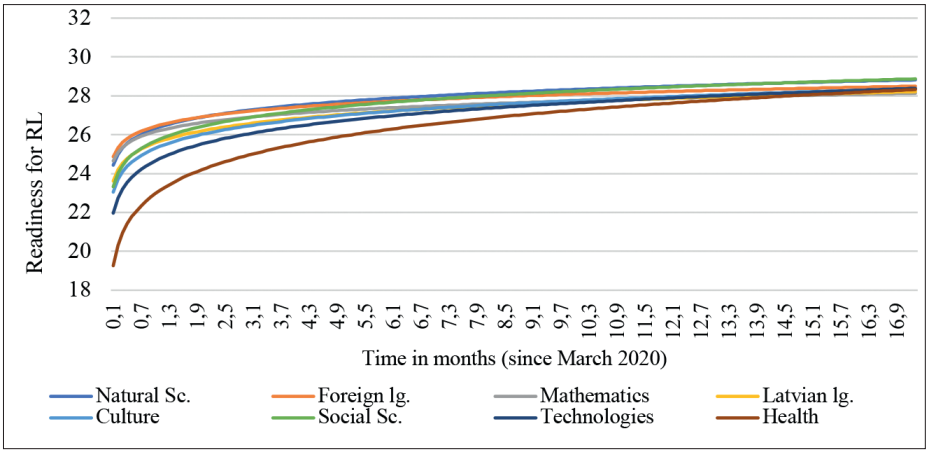

Fig. 2.6. Development of readiness for RL during the pandemic, except for Computer Science.

The illustration in Fig. 2.5. explains why the model with the knowledge dissemination cannot be applied to the Comp.Sc. group. When analyzing the results of the model based on the theory of learning curves and other research described in the theoretical part, it is concluded that the group of Comp.Sc. is located in the third learning phase of the RL organizational skills learning curve, or plateau, where knowledge is being acquired slowly (deep learning).

To further explore the learning curves of all learning areas (except Comp.Sc.), the results should be seen in the overall picture. Fig. 2.6. shows the learning curve and dynamics of all subject areas during the pandemic. The illustration shows that the starting point of the RL organizational skills acquisition was different in each subject area. During the second measurement (~15 months), the overall level of RL organizational skills in all subject areas has been aligned. It is also apparent that the growth was particularly rapid at the beginning of the pandemic in all subject areas, but in the last months it slowed down in some subject areas (mathematics, Latvian, foreign languages) while continued to grow in other (health and physical activity, social and civic, technology). The results (Fig. 2.6.) lead to the conclusion that in some subject areas teachers continued to learn new nuances of the organization of RL throughout the pandemic, while others were mainly improving their existing skills.

To examine the mathematical model of distribution of the knowledge of RL organization, the author performed calculations with other indicators which, following a statistical analysis of the data, showed a relationship with "Readiness for RL" – number of subject areas per teacher, number of pupils per teacher and at school, teacher's education, teacher's seniority, age, and place of living.

It was observed that the dissemination factor during the pandemic was also influenced by socio-demographic factors:

- **number of subject areas** taught by one teacher – the highest rate of knowledge dissemination was observed in a group of teachers in two subject areas, followed by teachers in one. Four or more subject area teachers' learning had been slower than others.
- **number of pupils per teacher** – the highest rate of knowledge dissemination was seen among teachers who teach 61–100 pupils and those who teach more than 160 pupils. The least active knowledge sharing was among teachers who teach less than 60 pupils.
- **number of pupils in school** – the highest rate of knowledge dissemination was seen in rather small schools (301–500 pupils), followed by small educational establishments (less than 150) and medium size schools (501–800 pupils). Teachers in large educational establishments with more than 800 pupils were the least active in knowledge dissemination.
- **teacher's education** – the highest ratio of knowledge dissemination was seen among teachers with a doctorate. They were followed by teachers-students. The learning curves for teachers with a master's and bachelor's degree were equivalent.
- **teacher's age** – the highest rate of knowledge dissemination was seen among younger teachers (18–25), with a similar result for three groups of

teachers: 26–35, 36–45, and 46–55. The smallest activity occurred in the age group of older teachers (over 55 years).

- **teacher's years of service** – the highest rate of knowledge dissemination was seen in a group of middle-aged teachers who had worked 6–10 years at school, followed by teachers with 20–29 seniority. The smallest increase was observed in the group of experienced teachers (more than 30 years of service).
- **teacher's place of living** – the most active dissemination of dissemination in the group took place in larger cities and other cities. Teachers from Riga, Pierīga and rural areas were less active in disseminating knowledge.

3. CONCLUSIONS

3.1. Main conclusions from the theoretical study

1. The widespread use of digital technologies has changed the perception and thinking of young people, but it has been observed that children and young people do not use technology in the way they are intended to be used, thereby failing to meet the intended learning goals. Education and technology professionals should invest in the development of methodology for working with ICT in schools at different ages.
2. As a result of the Covid-19 pandemic, when all schools were completely closed, a new form of organizing the pedagogical process – remote learning – was developed. During remote learning pupils are not located in one room with the educator and others. The learning content is learnt independently and under the guidance of an educator. ICT solutions are used wherever possible in the process. In times of crisis, remote learning also provides minimal necessary socialization.
3. Benefits of remote learning: differentiated learning, learning in small groups of pupils with similar interests, experience or learning goals, helping students who, for some reason, cannot participate in face-to-face learning, allowing students from anywhere in the world to participate in learning.
4. Remote learning shortcomings – lack of face-to-face socialization and excessive use of devices that can cause mental and emotional problems for all individuals, but especially for adolescents.
5. The readiness of remote learning is created from four elements: technological readiness (digital competence, technology), content readiness, teacher, pupil and parent readiness, system of control and assessment readiness.
6. The teacher's "readiness for remote learning" if created from digital competence, the ability to engage pupils, the ability to organize work in the form of remote learning, ability to give feedback and measure the performance remotely, attitudes to remote learning, and other factors.
7. Teachers who have no experience in remote work need special training to reduce their stress and provide students with high-quality remote learning experience, and to create a lasting and meaningful learning experience while maintaining the quality of their learning content.
8. To provide high quality learning remotely, the teacher must learn the methodologies for organizing remote learning in each age group and in each subject area, develop the remote learning organizational skills, have confidence in his or her abilities, and have a positive attitude towards remote learning. The teacher must believe that remote learning is necessary and useful.
9. During the pandemic, the importance of cooperation within groups of professionals was pointed out for several reasons – to share knowledge and experience, communicate with colleagues, and improve emotional wellbeing. These groups of professionals were the main pillars of the transition to remote learning.

10. The digital and technological competence of the school management is a prerequisite for ICT innovation. Teachers should be able to use technology to demonstrate ICT opportunities and potential for pupils and to use ICT to ensure a more efficient learning process.
11. The learning curve reflects the progress of skills learning by learning from their own mistakes (Collins English Dictionary, n.d.). The learning curve can show both individual and group performance or even the overall performance of an organization. At least three data points are required to represent the learning process, reflecting the individual's performance against invested resources (cost, work invested) in time units.
12. There are certain limits to the use of learning curves: (a) learning curves in different sectors, different organizations or even one organization in different units may be completely different; (b) the learning curve is based on certain data that must be collected accurately and repeatedly. If people or external circumstances change, a new learning curve model should be created with new data.

3.2. Conclusions from the empirical study

1. Conclusions on improving the digital competence of Latvian teachers

Informatization of the Latvian education system started with the "Latvian Education Informatization System" project, which was carried out between 1997 and 2006 and during which schools were equipped with computer classes, Internet connection was established in city and district schools, training materials prepared, organized training, as well as software developed for Latvian schools and education boards.

Computer science teachers have mostly learned individually. The acquisition of digital skills was initially offered on a voluntary basis within the framework of LIIS project.

2. Conclusions on the digital literacy study carried out by the author (2017–2018)

The digital competence of teachers was high. The highest results were in technology group, where computer science and programming teachers were also included. The lowest results were in culture and self-expression in arts, languages, and math.

Men's digital literacy was higher than women's. The digital literacy of younger teachers was higher than for older teachers. Teachers who lived in Riga and the big cities had higher digital literacy than those who lived in rural areas. Therefore, e-learning readiness had three "risk" factors: gender (woman), age (more than 40), and residence (rural area).

3. Conclusions on teacher readiness for remote learning (2020 and 2021)

In the first year, the readiness of teachers in the field of natural science was higher for the RL than of teachers in other subject areas, math, health, and physical activity. In the second year, readiness for RL had increased in several subject areas: mathematics, foreign languages, natural science, social

and civic, culture and self-expression in arts, health and physical activity, technology (except computer science). No statistically significant changes were observed in the answers of two teaching areas – Latvian language and computer science.

In the second school year in the pandemic (2020/2021), practical experience with technology use had increased teachers' readiness for RL and the differences observed in the first year in the different subject areas in the second year had reduced. The exception was mathematics, where readiness for RL in the second year was significantly lower than for other groups.

Different subjects have different options of how easy or difficult it is to transition from classroom to RL. This is due to the previous experience of teachers in each field of training with ICT, i.e., how many teachers in the respective subject area had used ICT in their daily lives before the pandemic.

In the second year, attitudes toward RL had become less positive. The attitude was more positive for teachers who did not teach the subjects of mandatory exams. The decrease in this indicator can also be explained by the specific nature of the subject, the number of contact hours in the specific subject, the complexity of the content of training, the availability of teaching materials, and the possibility of quality performance of various forms of tasks remotely.

4. Conclusions on the relationship of socio-demographic indicators with readiness for RL

Readiness for RL was higher for teachers who taught subjects of one or two teaching areas, who had a master's or doctoral degree, teachers-students, teachers who worked in schools with 800–1200 pupils, teachers in Riga and the big cities of the Republic, teachers with 11–19 and less than 5 years of service.

The lowest readiness for RL was for preschool or primary school teachers, teachers with Level 1 higher education, who work in small education institutions (<100 pupils), who work in rural schools, who work for more than 20 years at school. The least needed assistance was for teachers who taught subjects of one or two subject areas, who taught in all grades of education (from primary to secondary school), who had a doctoral degree or still studied, and teachers with less seniority. The most assistance needed during RL was for preschool and primary school teachers, teachers with Level 1 higher education, and teachers with 30–39 years of service.

The most active in the use of various digital resources were teachers who taught more than four subjects (preschool/primary school), as well as teachers who worked in Pierīga. The lowest scores were for teachers who taught subjects in one subject area or who worked in rural areas.

The most positive attitude to RL was for teachers who worked in medium-sized schools (500–800 pupils), teachers who worked at school for 11–19 years. A more negative attitude to RL was for teachers who work in small schools (<100 pupils).

4.3. Conclusions on the mathematical model of the educational process developed for advanced learning skills learning pathways in an emergency

1. The developed RL organizing skills model with knowledge dissemination is well describing the dynamics of readiness for RL during the pandemic and allows it to be determined how much teachers shared knowledge with their colleagues.
2. In developing a model of an individual learning curve for RL organizing skills without experience, the results of the calculations in the computer science group show that the learning process in that group started 51 years and 2 months before the first measurement (around December 1969). Since this period is indeed attributable to developments in technology worldwide and in Latvia, it is concluded that the model of RL organizational skills learning curve without experience shall be applicable to the calculation of the learning curve for the computer science.
3. For all other subject areas (except Comp. Sc.), it was concluded that the RL organizational skills acquisition process started in March 2020, and it was not significantly affected by previous development. Rapid knowledge transfer processes inside the education ecosystem had affected teachers' readiness for RL.
4. When developing the RL organizational skill learning curve model with knowledge dissemination factor, the model describes the experimental data. The data obtained shows that knowledge of the technologies and working techniques required to organize RL was disseminated from one teacher to another at a much faster pace than if teachers learned individually.
5. The existence of the knowledge dissemination factor c confirms the reality of a professional development situation during pandemic. Each teacher who had acquired a new skill for organizing RL shared the knowledge, i.e., training colleagues in some way (in his own or other subject areas). In interaction with colleagues, the probability of learning increased because learning new things with the help of others is easier. New knowledge becomes easily transferable at a time when there are enough people who use it.
6. The coefficient of dissemination of knowledge varied across the different subject areas in an emergency. According to the model developed, teachers acquire skills in a similar way, but the specific types of activities used in each subject area may vary. The training materials to be used are also different in each field. This means that teaching your colleagues to use ICT in health and physical activity is different than demonstrating how to use IC in Mathematics.
7. The results of the study show that teachers have their own groups, with active communication. According to the model, the knowledge dissemination ratio shows how active the formal or non-formal groups of professionals in each subject area were in sharing new knowledge and information during emergency.
8. The speed at which people share with others, grouped by different parameters, was different. The estimated knowledge dissemination rate during the pandemic was also influenced by socio-demographic factors:

- number of subject areas for one teacher;
- number of levels of education for one teacher;
- number of pupils per teacher and at school;
- last education acquired by the teacher;
- age of the teacher;
- years of service of the teacher;
- teacher's place of residence.

9. Other factors such as accessibility of training materials, digital resources, and training platforms suitable for RL work, pupil performance in the subject, collaboration with school management or parents, cognitive load, and scope of practical tasks may also have affected readiness for RL, but these factors have not been studied by the author of the empirical study. These would be orientations for future research.

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Evija Mirķe

APPENDICES

Appendix 1

Example of logarithmizing a function

$$\begin{cases} p_1 = p_f\left(1-e^{-\frac{t_1}{\tau}}\right) \\ p_2 = p_f\left(1-e^{-\frac{t_2}{f}}\right), \\ t_2 - t_1 = t_x \end{cases} \tag{1}$$

$$\begin{cases} \dfrac{p_1}{p_f} = 1-e^{-\frac{t_1}{\tau}} \\ \dfrac{p_2}{p_f} = 1-e^{-\frac{t_2}{f}} \\ t_2 = t_1 + t_x \end{cases} \tag{2}$$

$$\begin{cases} e^{-\frac{t_1}{\tau}} = 1-\dfrac{p_1}{p_f} \\ e^{-\frac{t_1+t_x}{f}} = 1-\dfrac{p_2}{p_f} \end{cases} \tag{3}$$

$$\begin{cases} -\dfrac{t_1}{\tau} = \ln\left(1-\dfrac{p_1}{p_f}\right) \\ -\dfrac{t_1+t_x}{f} = \ln\left(1-\dfrac{p_2}{p_f}\right) \end{cases} \tag{4}$$

Appendix 2

Example of the use of numerical methods for verifying variable value

Technology training (non-computer) data

p_f	32	p/p_f	= ln (1 – p/p_f)	
p_1	26.05	0.814063	–1.68234	ln1
p_2	28.19	0.880938	–2.12811	ln2
τ	26.92019		–0.44576	

	months	years
τ	26.9	2.2
t_1	45.3	3.8
t_2	57.3	4.8

log (p_1/p_f)	log (p_2/p_f)	o	log (1–exp (–3/τ))	log (1–exp (–15/τ))	log (p/p_f) / log (1–exp (–3/τ))	log (p_2/p_f) / log (1–exp (–15/τ))	the difference between the two sides
–0.206	–0.127	5	–0.796	–0.051	0.258	2.482	2.223810
–0.206	–0.127	6	–0.933	–0.086	0,221	1.480	1.259519
–0.206	–0.127	7	–1.054	–0.125	0.195	1.016	0.820653
–0.206	–0.127	8	–1.162	–0.166	0.177	0.761	0.584528
–0.206	–0.127	9	–1.261	–0.209	0.163	0.606	0.442397
–0.206	--0.127	10	–1.350	–0.252	0.152	0.502	0.349730
–0.206	–0.127	11	–1.433	–0.295	0.144	0.429	0.285612
–0.206	–0.127	12	–1.509	–0.338	0.136	0.376	0.239167
–0.206	–0.127	13	–1.580	–0.379	0.130	0.335	0.204282
–0.206	–0.127	14	–1.646	–0.419	0.125	0.302	0.177300
..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..
–0.206	–0.127	178	–4.092	–2.516	0.050	0.050	0.000115
–0.206	–0.127	179	–4.097	–2.521	0.050	0.050	0.000076
–0.206	–0.127	180	–4.103	–2.526	0.050	0.050	0.000037
–0.206	–0.127	181	–4.108	–2.532	0.050	0,050	–0.000001
–0.206	–0.127	182	–4.114	–2.537	0.050	0.050	–0.000039
–0.206	–0.127	183	–4.119	–2.542	0.050	0.050	–0.000076
–0.206	–0.127	184	–4.124	–2.547	0.050	0.050	–0.000113
–0.206	–0.127	185	–4.130	–2.553	0.050	0.050	–0.000150

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