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RIGA TECHNICAL UNIVERSITY

Svetlana Jurenoka

DEVELOPMENT OF METHODS AND MODELS FOR GENERATING THE ADAPTIVE CURRICULUM BASED ON THE STUDENT KNOWLEDGE LEVEL

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science and Information Technology
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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science, the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 4 October 2023 at 14.30 at the Faculty of Computer Science and Information Technology of Riga Technical University, 10 Zundas krastmala, Room 103.

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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 had not been submitted to any other university for the promotion to a scientific degree.

Svetlana Jurenoka ……………………………. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction, 4 chapters, Conclusions, 43 figures, 14 tables, 6 appendices; the total number of pages is 133, including appendices. The Bibliography contains 194 titles.

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INTRODUCTION

In 2020, the worldwide spread of the COVID-19 pandemic compelled educational systems, including those in Latvia, to shift to a remote format. This change spurred the digitalization of teaching aids and the integration of learning management systems in educational institutions. According to the Skola2030 concept (Skola2030, 2022), the e-learning platform will serve as the primary repository for study resources and will be accessible to both teachers and students in preschools and schools.

Currently, there are plenty of varied systems to ensure support for distance learning, among these, adaptive systems play a key role, as they implement the study process focused on students and tailored to their needs (Jurenoka & Grundspeņkis, 2023).

Adaptive learning systems were mentioned already at the end of the 20th century (Bruha, 1989; Lee, 2001; Stern & Woolf, 1998), and the main objective of these systems is to manage and monitor the study process adjusted to each student or a group of students, based on the student features and the speed of learning process acquisition, ensuring the supported and improved learning focused on users. The goal of adaptive learning systems is to create an elastic environment that ensures the study process by taking into account learning capabilities, needs, and other features of each student (Brusilovsky et al., 1998; Chen, 2008).

The study content today, regardless of the form of education (face-to-face or distance learning form), is adjusted to a student with the average level of knowledge. The curriculum is developed mainly in a manual format when the study process administrator, based on the knowledge level of students, chooses the appropriate rate of gaining knowledge and the sequence of study modules within the framework of the curriculum.

To monitor the acquisition of knowledge, digital study platforms use quiz. Quiz is a standardised check of knowledge and skills, where different types of tasks can be included. Such activities can be used for introductory assessment, formative assessment, and also for summative or final assessment of knowledge (Jonane, 2011). The assessment results show how well the curriculum has been learned, and they help to identify the student's learning speed and ability to engage in the learning process.

The adaptive learning management system (ALMS) is a tool that adjusts the student tailored learning and provides them with an opportunity to get access to the study content in a monitored way (Moisa, 2013).

Currently, there are different opinions about ALMS. Their deficiency is considered to be the method of evaluating the obtained knowledge, which assesses the competencies obtained by students based on the knowledge validation modules, assessing the learning outcomes during a certain time period. In the course of the study process, study materials are presented in a consecutive way and there is forgetting of knowledge, which determines the student knowledge level upon completion of the study process (Lange, 1983). At the final assessment upon the end of the study programme, the student has a different level of knowledge in the obtained competencies.

Regardless of the fact that modern learning management systems (LMS) can ensure a full educational process by using the earlier described way of presenting information, not always this way of presenting information is acceptable to all students. Whereas, by using ALMS, students have to select the module themselves and adjust themselves to the study course implementation requirements. By using LMS with a previously defined curriculum, students cannot select the learning style appropriate to their needs – in 39 % of cases this is the reason for terminating studies and in 40 % of cases, for omitting unclear or hard to cover materials and learn them by using other systems and courses (Jurenoks, 2017). One can conclude that the deficiency in ALMS is related to automatised adjustment of the curriculum to the knowledge level of students and their capability to obtain the study content.

Modern ALMS can be divided into two categories (Koch, 2001):

- systems with the previously prepared content, where the developed management is localised to perform certain tasks and cannot be adjusted to another study programme;
- adaptive study course development systems, which ensure the curriculum development based on the adaptation process management module included in the system.

The number of studies based on automation of the study process and the learning outcome assessment stage (Chen & Wang, 2021; Balogh et al., 2019) has increased, adjusting the process specific features to the face-to-face implementation form that allows to adjust the study content and the strategy of presenting the study materials to each user of different age and social groups.

Topicality of the Research

In recent years, the number of studies that are related to the usage of e-learning platforms in education and issues pertaining to possible adapting of the study content to the knowledge levels of students has increased. Such modern studies can be divided into two categories:

- Studies (Ciloglugil & Inceoglu, 2018; Verkhova et al., 2021) which are related to the integration methods of the adaptive learning platform, replacing the current form of presenting the study content and ensuring the distance learning process. The studies examine issues related to the digitalisation requirements and methods of the study content, ensuring transformation of lectures on e-learning platforms. It has been identified that a transfer to the distance learning form affects positively both the possibilities of students to complete the started studies and the quality of study materials. It has been concluded that there is no unified computerized platform capable of realizing the transformation of all forms of face-to-face content into digital format. The existing and widely used platforms of the study content mostly fulfil the data storage tasks, not ensuring adjustment of the study content to the student needs.

- Studies pertaining to adjustment of the study content to the student needs examine personalisation methods of the study content (Sharma et al., 2020; Tkachenko & Tyrkov, 2022) that ensure adjustment of e-learning resources based on the selected scenario. Some articles (Ibiyomi et al., 2022; Sihombing et al., 2020) offer to use the Felder-Silverman learning style model (FSLSM), which, by using four dimensions in perception, processing, introduction and comprehension, classify the learning styles based on questions asked to the student. In other studies (Muhammad et al., 2022; Pratap et al., 2022), it is offered to generate the study content by using the graph theory methods, but, when starting a study course, to base the curriculum development on searching for a shorter way to apply the algorithm by using the knowledge level of the student and the time anticipated to complete the curriculum.

Recently (Arnaudova, 2022), the research results related to using the student model for learning management systems were published. According to the study, there are significant deficiencies in the methods of the student model generation due to the increase of time allocated for the study process, adding knowledge validation processes.

In recent years, Riga Technical University has been researching issues pertaining to design and development of study systems. Studies have been performed for the student model development (Lukasenko, 2012), recognition of student emotions (Petrovica, 2019) and pedagogical aspects (Rollande, 2015). Studies have been performed with regards to the study content transformation opportunities, transformation of the set study course content and the knowledge testing form in the e-learning environment (Volodko et al., 2021), classification of distance learning platforms, and application of motivation methods for ensuring the study process by using the content personalisation approaches in the Moodle content management systems (Kapenieks, 2021).

Forgetting of knowledge during the study process is observed, which can be assessed with the knowledge forgetting parameters, enabling the assessment of the decrease in knowledge volume during the implementation of the study process. To assess knowledge of students, LMS uses formative assessment that determines the knowledge level in each examined competence at the time of its acquisition. At the end of the study programme acquisition, the knowledge level of students will differ in competences included in the study programme. When balancing the student knowledge level in competences, it is required to have the set requirements met in all competences by the end of the study programme. The Doctoral Thesis has the adaptive curriculum generation algorithm developed and has displayed its integration within the framework of the learning management system that allows adapting the study content to the knowledge level and learning capabilities of each student, balancing the obtained knowledge in each time unit, dynamically changing the curriculum topology.

Hypotheses of the Research

There are two hypotheses set in the Doctoral Thesis:

- The sequence of including study competences in the curriculum affects the student learning outcomes at the final examinations.
- Usage of the adaptive curriculum generation methods based on the student knowledge level allows balancing the knowledge level between all competences included in the study course.

The Goal of the Research

To study and develop the curriculum generation models and methods that allow balancing the student knowledge level at the end of the study course and increase the curriculum life span.

Objectives of the Research

- To analyse models and methods of the adaptive learning process implementation.
- To develop models of determining the student knowledge level.
- To determine the learning module factors that prescribe limitations of the study content presentation and requirements for their inclusion in the curriculum.

- To develop the assessment model of the curriculum life span.
- To develop the curriculum generation algorithms that allow to balance the student knowledge level for each competence included in the study course.
- To perform experimental approbation of the developed model in a real learning management system.

Object and Subject of the Research

The **object of research** is the learning management system.

The **subject of research** is the curriculum generation methods and algorithms of the learning management system.

Research Methods

The following theoretical methods have been used in the theoretical part of the Doctoral Thesis:

- study and analysis of the related scientific literature, special literature, state regulatory enactments;
- study and analysis of the technical documentation;
- analysis, evaluation and comparison of the existing solutions.

The following empirical methods have been used in the practical part of development:

- data acquisition methods:
  - data mining methods for obtaining technical data;
  - polling methods;
- data processing and analysis methods:
  - descriptive statistics (arithmetic mean, standard deviation, median, minimum and maximum);
  - inferential statistics (Kolmogorov–Smirnov and Shapiro–Wilk test of normality, Mann–Whitney U-test and T-test for comparing the means of two independent samples).

Scientific Novelty

The Doctoral Thesis has the following scientific novelty:

- Summary of the used learning strategy in the adaptive learning management systems and the related terms have been developed, reflecting their relation and significance in the study process.
- A summary of the functions implemented by the components of the adaptive learning system and the mutual interaction of the components has been created.
- Comparative analysis of the existing learning management systems has been offered, identifying the most significant deficiencies in adjusting such systems in the study process.
- The curriculum life span evaluation model has been developed, allowing to determine the time when the curriculum needs to be reconfigured.
- The curriculum generation method has been developed, balancing the student

knowledge level for each competence included in the study course.

- The adaptive curriculum reconfiguration method has been developed, ensuring adaptive management of the study content with account of the student knowledge level.

Practical Significance of the Research

The curriculum life span evaluation model and experimental approbation of the curriculum reconfiguration methods form the practical significance of the research. The Doctoral Thesis has the following practical significance:

- The experimental study content management prototype has been developed, ensuring evaluation of the curriculum life span in the course of implementing the study process.
- The adaptive curriculum evaluation model has been experimentally tested on the existing learning platforms (dpc.lv, macam.lv, digima.lv, das.lv) that ensure implementation of the adaptive learning process for certain target audience groups.
- The curriculum life span evaluation algorithm has been integrated in the Moodle system for correcting the curriculum on the courses supervised by the Road Traffic Safety Directorate (CSDD).
- the Norwegian financial tool – Norway Grants has been used to develop a prototype of the study programme adaptation for preschool educational establishments.

Practical results of the Doctoral Thesis can be used at educational establishments willing to automatise presentation of the study content in an autonomous mode that allows increasing the achievable knowledge level by students and decrease administration costs for systems with a large number of users.

The developed curriculum life span evaluation model and reconfiguration methods have been approbated in practice:

- o The study content on the macam.lv platform has been divided into learning modules, ensuring the centralised and supervised by the regulator adaptive teaching of the theoretical course for B and C category drivers without time limits.
- o The study content on the das.lv platform has been divided into learning modules, ensuring the adaptive teaching of the major study courses in accordance with the student knowledge level to achieve the most efficient learning outcome within a limited time for mastering the course.
- o The student model has been developed and the initial curriculum has been generated on the dpc.lv learning platform, ensuring the learning trajectory development in order to increase the volume of obtained knowledge in each included competence, based on the student model parameters.

Approbation of the Research Results

Results of the Doctoral Thesis have been reported at the following international conferences:

- o 58th International Scientific Conference of Riga Technical University, Riga, Latvia, 12–15 October 2017.
- o 17th International Conference Perspectives in Business Informatics Research (BIR

2018), Stockholm, Sweden, 24–26 September 2018.

- 10th International Conference on Education and New Learning Technologies (EDULEARN18), Spain, 02–04 July 2018.
- 10th International Conference on Studies in Education, Business, Economics and Interdisciplinary Studies (EBEIS-18), Kuala Lumpur, Malaysia, July 23–25, 2018.

The results of the Doctoral Thesis have been reflected in the following publications:

1. Jurenoks, A., Jurenoka, S., Novickis, L. Online Fault Detection Methodology of Question Moodle Database Using Scan Statistics Method. In: Information and Software Technologies: 23rd International Conference, ICIST 2017: Proceedings. Communications in Computer and Information Science. Vol. 756, Lithuania, Druskininkai, October 12–14, 2017. Cham: Springer, 2017, pp. 478–486 (SCOPUS) (contribution to the paper 40 %).
2. Katalnikova, S., Grundspenkis, J., Jurenoka, S. Intelligent Collaborative Educational System within the Framework of Competence Approach. In: Joint Proceedings of the BIR 2018 Short Papers, Workshops and Doctoral Consortium co-located with 17th International Conference Perspectives in Business Informatics Research (BIR 2018). CEUR Workshop Proceedings. Vol. 2218, Sweden, Stockholm, September 24–26, 2018. Cham: Springer, pp. 348–355 (SCOPUS) (contribution to the paper 35 %)
3. Jurenoka, S., Jurenoks, A. A Method for Learning Scenario Selection and Modification in Intelligent Tutoring Systems. In: BIR-WS 2018 [online]: BIR Short Papers, Workshops and Doctoral Consortium: Joint Proceedings of the BIR 2018 Short Papers, Workshops and Doctoral Consortium co-located with 17th International Conference "Perspectives in Business Informatics Research" (BIR 2018). CEUR Workshop Proceedings. Vol.2218, Sweden, Stockholm, September 24–26, 2018. Cham: Springer, pp. 335–340 (SCOPUS) (contribution to the paper 60 %)
4. Jurenoka, S., Bobrovskis, S., Jurenoks, A. Using Fuzzy Logic for Behavior Scenario Selection in Moodle Systems. In: EDULEARN18 Proceedings: 10th International Conference on Education and New Learning Technologies, Spain, Palma, July 2–4, 2018. Valencia: IATED Academy, 2018, pp. 4837–4842 (SCOPUS) (contribution to the paper 70 %)
5. Jurenoka S., Grundspenkis J. Development of Methods and Models for Generating an Adaptive Learning Plan Based on the User's Level of Knowledge, Baltic Journal of Modern Computing, Vol. 11 (2023), No. 1, 90–113 (SCOPUS) (contribution to the paper 90 %)

Structure of the Thesis

The Doctoral Thesis contains an introduction, four chapters, conclusions, bibliography, 43 figures and 14 tables and 6 annexes. The total volume of the Doctoral Thesis is 133 pages. The list of references contains 193 sources.

The introduction substantiates topicality of the research, formulates the goal and objectives of the research, as well as describes scientific novelty of the research and practical significance of the achieved results.

Chapter 1 "Adaptive Learning Management Systems" provides a summary of the current situation with learning management systems and describes the existing examples of the practical application of computerised learning. Several models and standards of the existing adaptive learning management systems (ALMS) have been verified using their application ways and technical specifications. Factors have been excreted that affect the quality of the ALMS plan generation and achieving the learning outcomes.

The chapter provides a general description of the ALMS curriculum life span, containing three basic models: a model for the content representation, a student model, and an adaptation model.

Chapter 2 "Development of the Adaptive Curriculum Evaluation Model" provides the developed curriculum life span evaluation model, which determines the relevance of the curriculum to the student knowledge level, aiming to balance the competence knowledge levels during the study course.

The chapter presents the components, models, and algorithms that determine the learner's level of knowledge in each competence during the implementation of the learning process. They are as follows:

- assessment of the student knowledge level;
- determining the knowledge forgetting volume;
- assessment of the student digital competences.

The chapter examines the curriculum development process, which determines the requirements and limitations of arranging the learning components during the course programme acquisition.

To adjust the quality of presenting the study materials, external factors are defined in the chapter and their impact on the study process implementation by using the student technical provision validation during the study process implementation at each connection session.

The chapter defines the factors affecting the curriculum life span, which determine the curriculum generation stage based on the student current knowledge level and the study content elements.

At the end of the chapter, the curriculum generation task is described, determining the curriculum formation scenario, which balances the volume of knowledge obtained in each competence during the study course.

Chapter 3 "Development of an adaptive learning plan reconfiguration method" describes the adaptive learning plan reconfiguration methods, which, using the learning plan evaluation model, ensure the generation of a plan with the task of reducing differences in knowledge levels in learned learning competencies.

By using the curriculum generation method, the chapter provides a set of algorithms that ensure testing of each curriculum element to generate a new curriculum for acquiring certain competences. Algorithms are described that ensure the development of the sequence plan for the modules acquisition.

In cases when the study process feedback in real time is limited, the methodology of using the genetic algorithm is described for including the study modules in the curriculum.

At the end of the chapter, the substantiation for the need to change the curriculum topology is defined, which controls the curriculum life span during the study process implementation.

Chapter 4 "Experimental Testing of the Developed Methods and Models" is devoted to the experimental approbation of the developed methods and models aiming to research:

- the results of using the developed adaptive curriculum evaluation model during the study process implementation;
- the usage of the offered curriculum reconfiguration methods to balance the student knowledge level during the study process implementation.

The chapter describes three experiments made by using the adaptive learning management module developed during the research that ensures monitoring of the Moodle learning management system.

1. ANALYSIS OF THE CURRENT SITUATION WITH ADAPTIVE LEARNING MANAGEMENT SYSTEMS

Analysis of the reference sources provided in the chapter has shown that the adaptive learning management system is a perspective technology widely used to implement the remote study process, creating individual learning plans for students with account of their current knowledge, capabilities, motivation and other features.

The chapter provides explanations of concepts related to adaptive learning management systems (ALMS), a summary of the current situation with ALMS, including its architecture, and describes the available examples of the practical application of computerised learning. Based on (Deborah et al., 2021), ALMS ensure that each group of users or the user has an adjusted learning process management by using the study content defined in the automatic mode.

The performed review of the reference sources has shown that creation of the learning management system plan is based on three core principles:

- A set of the study content is a module.
- ALMS ensure mutual interaction of the modules, where the connection is provided by using the classification of modules and metadata sets.
- The module structure is formed by the curriculum elements that ensure the sequence of presenting information, for example, theoretical information, media data, and knowledge check assessments. Each activity is considered as a separate unit, which contains a metadata set required for using the algorithms to form a plan during the study process.

The chapter provides a comprehensive description of the existing ALMS models and standards, their application ways and technical specifications and distinguishes factors that affect the quality of the ALMS curriculum generation and achieving the learning outcomes. Based on adaptation model overview, it has been concluded that to form the existing ALMS curriculum, different adaptation methods are used. Modern ALMS widely use the model that ensures selection of the next study module based on the previously performed activities by the student during the study process.

Based on information in (Sridharan et al., 2021), generation of the curriculum depends on the volume of information offered by the system for generating the student model knowledge base. The chapter examines the student model formation methods. Analysing the user's influence on the ALMS operation, the necessity has been identified to determine the student parameters for selecting the next study module.

Guidelines for the curriculum generation and the study process implementation have been examined in detail, based on the content representation models. Influence of the student model knowledge base on the study content representation models and the curriculum generation methods has been examined.

To perform a comparative analysis of the learning management systems, 25 criteria have been defined in the Doctoral Thesis that allow evaluating the relevance of ALMS for implementing the student-centred study process.

When analysing the existing ALMS, it has been concluded that:

- commercial products are anticipated for performing certain tasks and they do not support the curriculum adjustment;
- software has a limited possibility to use one module repeatedly for different courses;
- within the framework of software, there are no study module management systems;
- the student knowledge assessment process is not automated, so the author of the study programme needs to manually define scenarios for knowledge evaluation;
- knowledge validation modules do not affect the curriculum structure and the sequence of presenting study materials, thus not allowing to adjust the curriculum for the user needs;
- the educational programme curriculum is defined as a constant structure and is not adjusted to the student.

A survey of the existing open code of ALMS and their modules have shown that there are no universal solutions to ensure an adaptive study process based on the student knowledge level in the automatic mode. Existing systems are divided into two parts:

- Static representation of the study course according to the previously defined scenario that uses the content set model for representing the study course. Systems have a limited use of activities and the content representation is ensured by using the HTML standards. Feedback is ensured by using knowledge assessments modules, which serve as an indicator for monitoring the achieved study level. Systems have limited possibilities to modify the published course plan, as well as to add topical information and correct the course programme. Systems of this type are used in informal education for teaching a certain theoretical course.
- Data storage of study activities that ensures the study process implementation based on the structure of frame content model. Study activities are stored on the course webpage. The course administrator determines the activity depiction conditions that allow adjusting the course plan for each group of users. Within the framework of the course, the administrator can improve and change modules, making changes only in the specific module that does not affect the entire course plan and the sequence of its acquisition.

The Thesis concludes that currently there are no ready solutions allowing to ensure the curriculum adjustment for each student. In accordance with Skola2030, it is not possible to create one study material that could be adjusted for students with different knowledge acquisition capabilities (Skola2030, 2022a; Skola2030, 2021).

Main conclusions of the chapter:

- A general model is required that allows assessing the student knowledge level during the study process implementation.
- The effect of each element of the computerised study process on the student knowledge level has to be examined comprehensively in order to assess the knowledge level obtained within the study programme.
- It is required to develop the adaptive curriculum generation methods.

The conclusions allow formulating the objectives, which are solved in the Doctoral Thesis and described in the next chapters.

2. DEVELOPMENT OF THE ADAPTIVE CURRICULUM ASSESSMENT MODEL

The chapter describes the developed curriculum evaluation model, which ensures the evaluation of its life span using the data obtained during the implementation of the learning process. The curriculum life span is the time to be used by the student to acquire the study materials from the start and until the position in the curriculum, when it is required to make changes in the curriculum to achieve the anticipated results. The curriculum life span depends on the volume of the obtained information and the student knowledge level at a certain stage.

The task of ALMS is creation of the curriculum based on the student's capabilities to master the study course, achieving the maximally possible knowledge level in the competences. The chapter describes factors that affect the curriculum life span.

The knowledge level determining model has been developed. It can estimate the student knowledge level increase during the study process implementation. Determining of the student knowledge level consists of the application of three models:

- the competence determining model based on the knowledge level;
- the knowledge level determining model based on the competences;
- the model determining the knowledge forgetting volume.

It has been described that during the study programme mastering the knowledge level decreases after some time, as the student forgets a part of the knowledge after the study materials obtained. The model determining the volume of knowledge forgetting has been described, which prescribes revision of the study materials with account of the student knowledge level in each competence included in the study process. The model is based on the Ebbinghaus' knowledge forgetting curve model (Lange, 1983), which is improved with the knowledge check during the study process implementation.

The curriculum evaluation model has been developed, which includes several components and algorithms for assessing the knowledge level in the considered competences during the study process implementation:

- assessment of the student knowledge level;
- determining of the knowledge forgetting volume;
- evaluating of the student digital competences.

The chapter defines external factors and their effect on the study process implementation, which use validation of the student technical provision for the study process implementation at each connection session: the student knowledge level in each competence, the knowledge level of digital competences, and the technical provision effect.

To determine parameters affecting the curriculum life span, an algorithm is developed in the Doctoral Thesis (Fig. 2.1). The algorithm describes determining of the initial knowledge level of the student in each competence included in the study programme by using the knowledge level-based competence determining model and the competence-based knowledge level determining model. The ALMS obtains the student knowledge level in each competence included in the course *User[c]* by using information available in the system about the student or by making knowledge tests in the event the ALMS has no student knowledge level in a certain competence. Next, the learner's level of knowledge of digital competence *User*(*Dk*) and the parameter of technical support influence *User*(*QTsys*) are determined, which use methods of determining the impact of technical support and the learner's digital competencies developed in the Thesis. The student digital competence knowledge level *User*(*Dk*) is determined at the initial algorithm activation, whereas the value of the technical provision effect parameter *User*(*QTsys*) is determined at each activation of the algorithm.

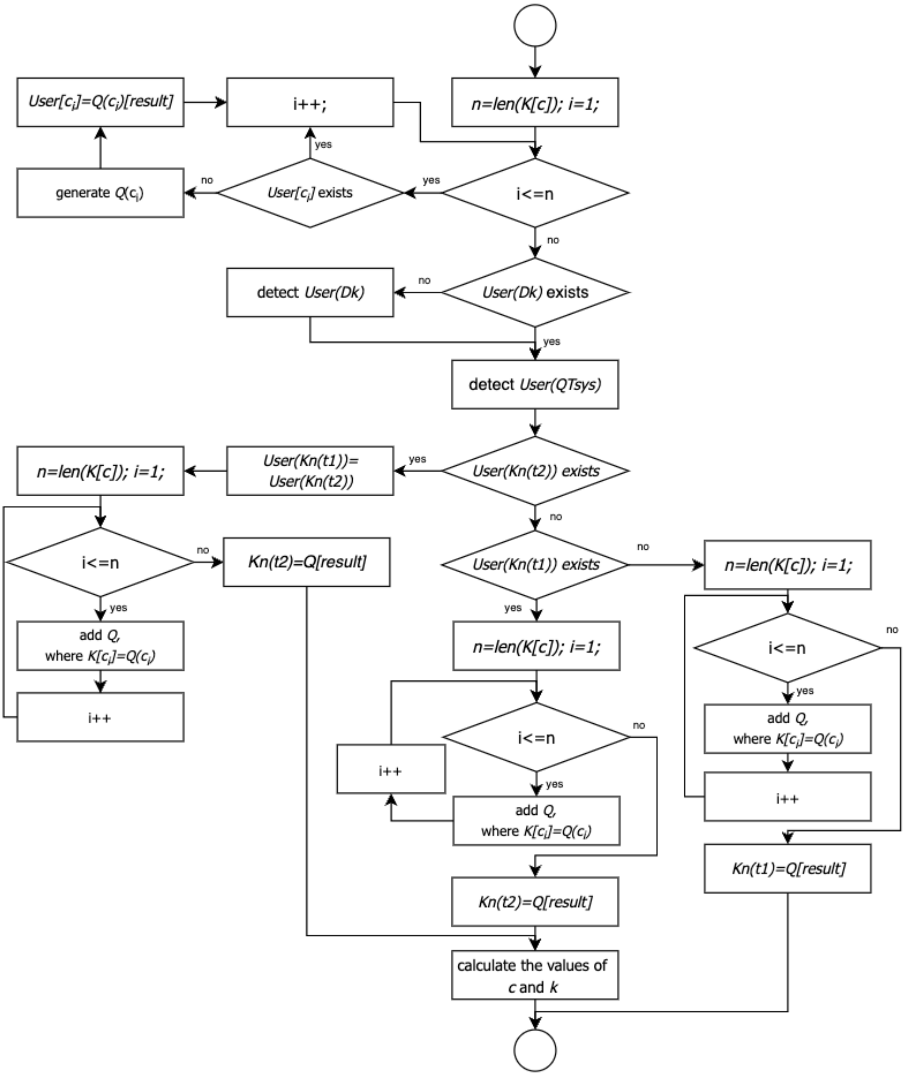

Fig. 1.1. Algorithm determining the curriculum life span affecting parameters.

To determine the knowledge forgetting volume coefficient *Kn*, the model determining the knowledge forgetting volume is applied, which uses two knowledge checks, determining the

$Kn(t)$ values. At the initial activation, only $Kn(t_1)$ is determined using knowledge test, but $Kn(t_2)$ is not identified, as an interval between the knowledge assessments is required. When activating the algorithm next time, the system determines the $Kn(t_2)$ value by using two approaches:

1) if the $Kn(t_2)$ value has not been determined before, a new knowledge assessment is generated to determine $Kn(t_2)$ and the $Kn(t_1)$ value is not changed;
2) if the $Kn(t_2)$ value has been already obtained, the system changes $Kn(t_1)$ performing the activity $User(Kn(t_1)) \leftarrow User(Kn(t_2))$ and to determine $Kn(t_2)$, the system generates a new knowledge test.

To evaluate the curriculum life span, the Doctoral Thesis offers an algorithm depicted in Fig. 2.2.

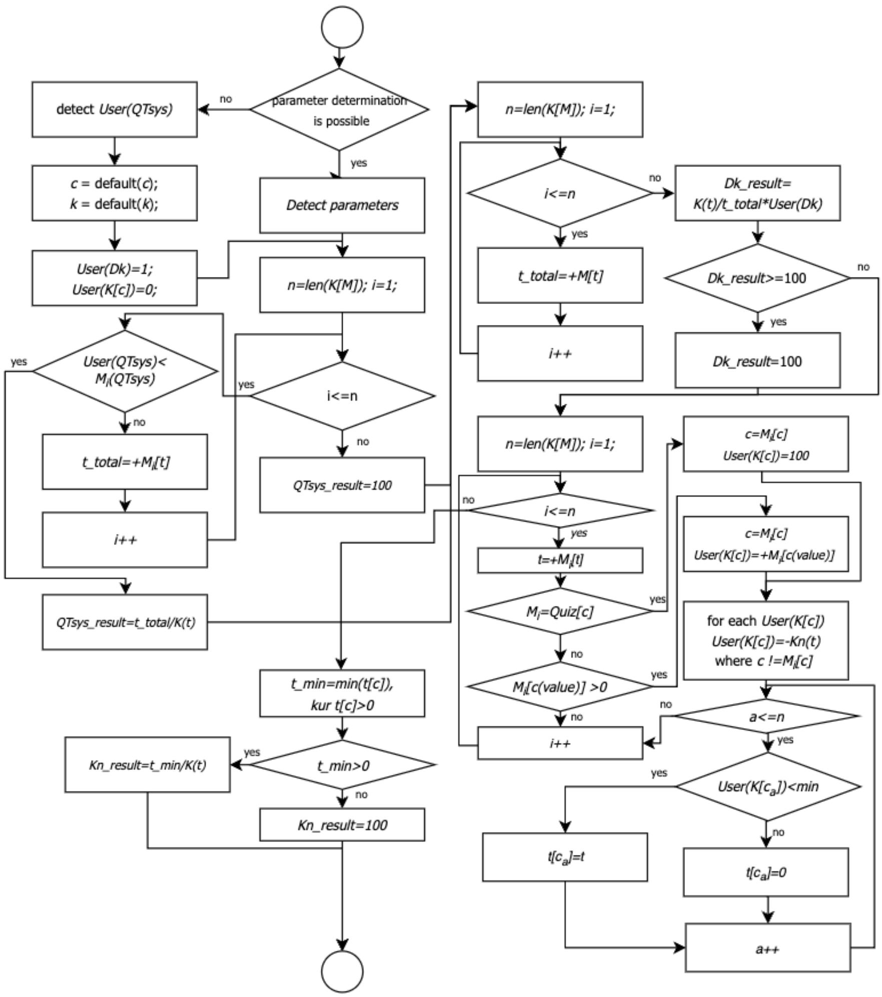

Fig. 1.2. Curriculum life span evaluation algorithm.

At the start of the algorithm, it is checked whether it is possible to determine the curriculum life span affecting parameters: the student knowledge level in each competence included in the course, the digital competence knowledge level, the technical provision effect parameter, and the knowledge forgetting coefficient. It is assumed that the curriculum life span depends on the sequence of presenting the study materials and abilities of the student to obtain information by using the distance learning form. When applying the algorithm for curriculum life span determination, fulfilment of the current plan is evaluated, determining the student knowledge level in the included competences at the end of the study programme and the position in the curriculum when changes have to be made to achieve the anticipated results.

The operation result of the curriculum life span evaluation algorithm includes three values:

- The curriculum life span depends on the student technical provision (*QTsys_result*).
- The rate of obtaining information by the student and their capabilities to use digital competences (*DK_result*) effect the curriculum life span.
- The curriculum life span depends on the result achieved in the study process (*Kn_result*).

The task of generating the adaptive curriculum is to create the sequence of modules for mastering the study content that allows increasing the knowledge level in each competence included in the study process. The learner, while learning the course, improves his competences, which are defined in the course and are linked to modules, where the level of acquired knowledge is determined using test modules.

When mastering the study module, the student can improve one or several competences; thus, it can be assumed that each study module ensures knowledge for improving at least one competence.

The ALMS curriculum is generated during the study process implementation. The number of modules to be mastered by the student can change, depending on the student knowledge level and capabilities to obtain new information. The sequence of selected modules is represented by the weighted graph (Fig. 2.3). In the Doctoral Thesis, the curriculum *MP* includes the sequence of obtaining a set of modules $MP\{M_i\}$, where i = 1, 2..*n*.

The study process implementation time is limited by time t defined for each study course. When obtaining the study module, the student acquires a competence, which is measured on the scale from 0 % to 100 %. When mastering the study course by observing the knowledge forgetting volume determining model, at each final assessment, the student achieves the total competence knowledge level, which includes each competence knowledge level results. The curriculum generation algorithm produces such path in the graph (Fig. 2.3) where the competence knowledge level achieved at the course completion $K[c_i]$ in the specific period of time is the highest $K[c_i](P,t) \rightarrow max$, where P is sequence of obtaining the study modules (path in the graph).

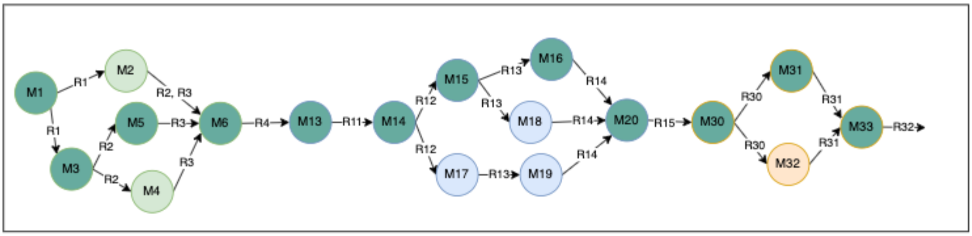

Fig. 2.3. Curriculum for obtaining the course.

Requirements to the curriculum generation algorithm have been defined:

1. To generate the curriculum by including the competences with input values which determine requirements to obtaining the competences and the sequence of their presenting. The curriculum generation algorithm must ensure determining the sequence of obtaining the competences with the aim to reduce the knowledge volume forgetting percentage for each obtained competence at the end of obtaining the study programme.
2. The time of implementing a remote study process depends on study capabilities of each student. Based on study time used for obtaining the course, the student knowledge level for each competence during the study process implementation has to be determined.

To generate the curriculum, a model has been developed, which determines the scenario, using the assessment of the learner's knowledge level and the structure of the curriculum, the time of the implementation of the learning process, as well as factors affecting the learning process (Fig. 2.4).

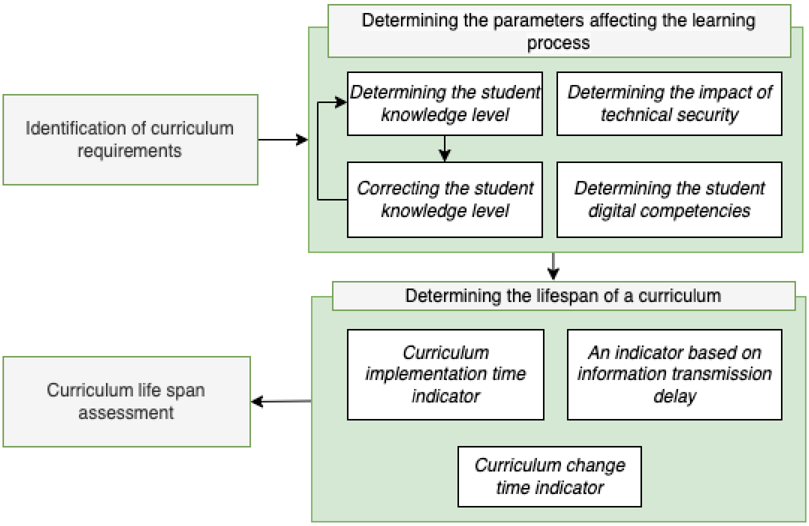

Fig. 2.4. Diagram of models, methods, and components described in Chapter 2 for the curriculum life span evaluation model.

Usage of the model consists of the following stages:

1. To build the student model, parameters are defined, which determine the selection of the relevant module at the time of obtaining the specific curriculum. Based on the classification of factors in other works (Aseere et al., 2011; Jaukovic et al., 2020), the Doctoral Thesis examines the factors that affect the study process mastering by using functionality of the distance learning system.
2. When determining the knowledge level, the chapter offers a model to determine the student position during the curriculum obtaining time. If the study period exceeds the time allocated for the module and the time when the student knowledge level is below the minimum requirements defined for the study course, the curriculum regeneration algorithm is initiated.

By using the models described in this chapter, the adaptive curriculum reconfiguration method is developed in the Chapter 3, which manages the curriculum development process by balancing the obtained knowledge.

3. DEVELOPMENT OF THE ADAPTIVE CURRICULUM RECONFIGURATION METHOD

The adaptive curriculum reconfiguration method is developed in this chapter, which, by using the curriculum evaluation model results, ensures generation of the curriculum with the aim of reducing the knowledge level differences in the obtained competences.

The curriculum generation algorithm consists of two mutually connected parts: inclusion of study modules for obtaining competences and determining the sequence of obtaining competences.

Algorithm of Conducting Study Modules

The Doctoral Thesis defines the curriculum configuration graph G, which consists of a set of vertices $V = \{1, 2 \ldots n\}$ depicting the study modules. In the process of developing and improving the content, new study modules can appear, providing the knowledge required to obtain certain competences. The study module is described by using the input requirements for obtaining the module and the time for its fulfilment, as well as the learning outcome. It is possible that modules have no defined requirements for mastering them; thus, the regulation algorithm can place them anywhere in the curriculum.

Every module is set for the minimum time required for obtaining it. Therefore, the interaction of the c_1 competence modules can be depicted by using the weighted graph, where the graph vertices correspond to the study modules and the weights indicate the required time for obtaining the modules and the learning outcome (Fig. 3.1).

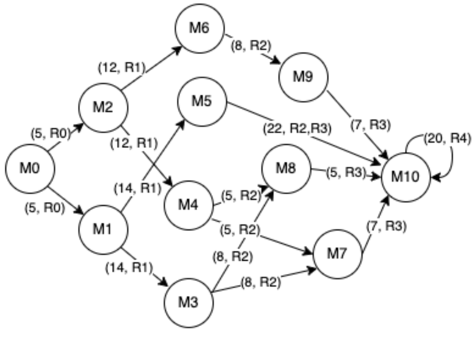

Fig. 3.1. Interaction of the study modules to obtain the c_1 competence.

When developing the curriculum, it is required to identify time required for the obtaining of each competence by using the set of data of the study modules. To determine a shorter study time, the Thesis offers to use the Dijkstra's algorithm, which determines the shortest path in the graph.

When obtaining the competence repeatedly, with account of the study course time limitations, the ALMS objective is to include repeatedly the curriculum themes that are related to the competence in which the student knowledge level is lower that the course defined minimal values $K[c_i(min)]$. The Doctoral Thesis offers to choose the shortest path for the competence repeated obtaining, which is substantiated by the time limitation. The algorithm of conducting the study modules within the framework of one competence is depicted in Fig. 3.2.

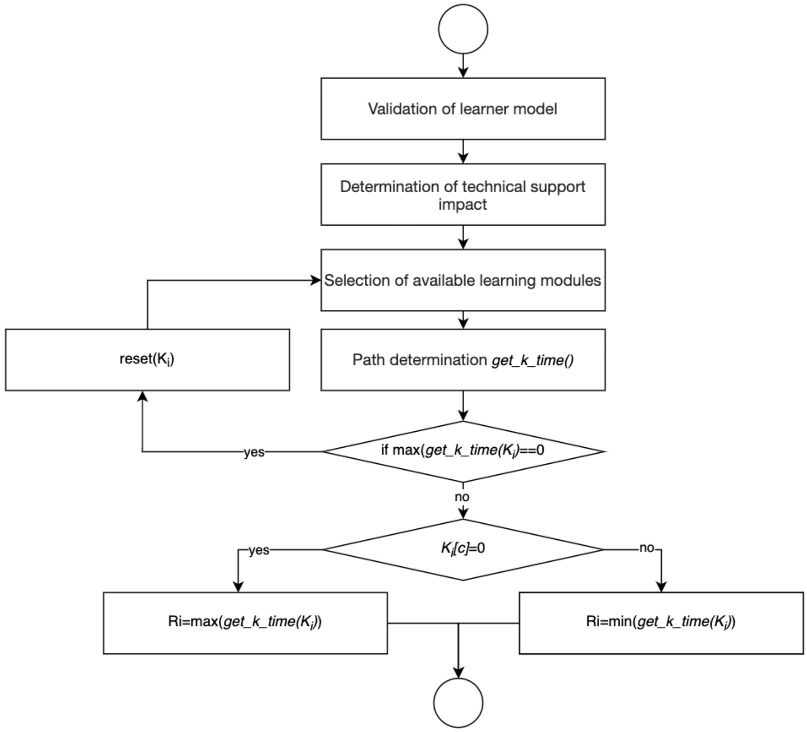

Fig. 3.2. Algorithm of sorting the study modules within the framework of one competence.

As a result of selecting the modules, their number for obtaining knowledge in each competence can differ; however, it can be neither less than 1 nor exceed the number of all modules for obtaining the competence. It is considered that, when obtaining the study competence for the first time, the maximum time for in-depth learning of the competence knowledge should be chosen. On the other hand, if the competence is learned repeatedly, the shortest possible time is chosen.

Competence Sorting Algorithm

The goal of the study competence sorting algorithm is to balance the obtained knowledge levels between all considered competences. By using the knowledge level determining model, the *MP* array is introduced, describing the modules to be obtained by the student during the study process. It is assumed that each competence is obtained when all modules included in the curriculum for obtaining this competence, which are selected by using the study module sorting algorithm, have been fulfilled. The array $MP[k,m]$ is defined, where k is the available number of competences and m is the maximum number of modules of one competence. The study programme can include competences, the obtaining of which depends on some earlier obtained competences. Competences can be divided into three main categories: main competences, optional competences, and additional competences. Thus, the study programme MP consists of three sets:

$$MP_i = \{Kmain_1, Kmain_2 \dots, Kmain_n\} \cup \{Kadd_1, Kadd_2, \dots, Kadd_m\} \cup \{Kopt_1, Kopt_2, \dots, Kopt_z\} = \overline{1, n},$$

where $Kmain$ is the main competence included in the study programme, $Kadd$ is optional competence included in the study programme, and $Kopt$ is additional competence included in the study programme.

Main competence is the one inclusion of which in the curriculum and obtaining is mandatory. Main competences can have or have not input requirements for their obtaining. The student may select an optional competence, but its inclusion in the curriculum is determined by the remaining time for the study process implementation. Additional competence contains recommended additional study materials for independent learning that can supplement the knowledge in some main competence, and the time of obtaining it does not affect the total time for obtaining the study course. The student can obtain this competence beyond the study process.

The goal of the main competence selection algorithm is to determine competences, defining the maximum possible time of obtaining each competence, which in total does not exceed the total time allocated for all competences of the study course. If the time defined for the obtaining of all competences exceeds the time allocated for the study course, the least time for the obtaining of each competence is elected (Fig. 3.3).

When developing the curriculum, the system determines the time required for the obtaining of each competence by using the module sorting algorithm. Initially, the set of main competences, which is compulsory for obtaining the study course, is determined $MS = \{Kmain_1, Kmain_2 \dots, Kmain_n\}$.

When determining the set of main competences, the following condition is to be observed: $MP(t) > \sum_{i=1}^{n} K_n main_i\,(t)$, i.e., such sequence of obtaining the modules has to be selected that allows to obtain all main competences $K_n main_i$ during the time period $K(t)$ defined for the study course. In the event of $\sum_{i=1}^{n} K_n main_i(t) > MP(t)$, the system selects modules with the least time for the obtaining of certain competences.

The algorithm of selecting main competences is provided in Fig. 3.3. The main objective of ALMS is to ensure the obtaining of main competences in full volume. During the algorithm fulfilment time, the system performs validation of the student knowledge level in the obtained competences by using the knowledge forgetting volume coefficient.

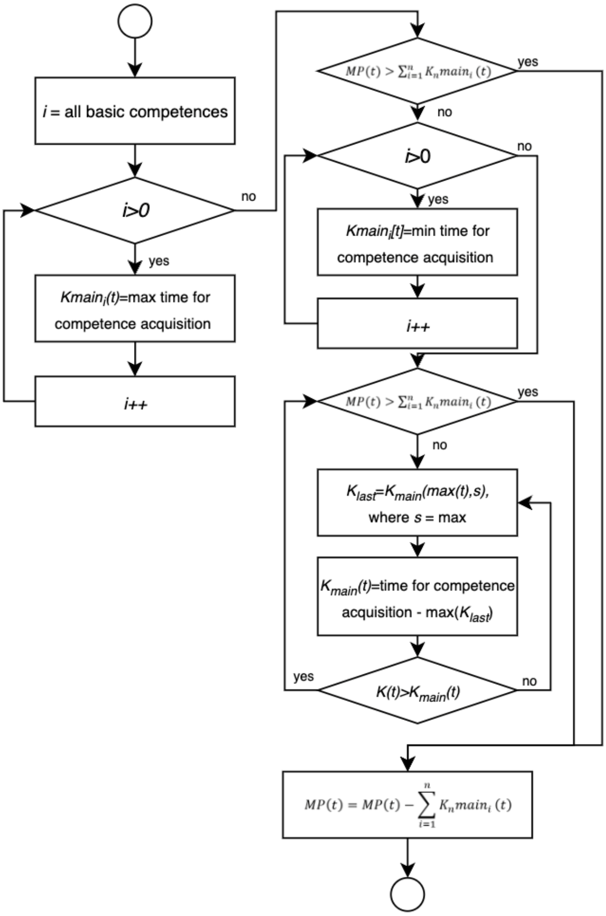

Fig. 3.3. Main competence selection algorithm.

Operation of the optional competence selection algorithm is determined by two factors:

- time for obtaining main competences;
- the student knowledge level in main competences.

The set of optional competences is determined by the remaining study process implementation time and the maximum number of optional competences that can be obtained during the set time. The algorithm of selecting optional competences is provided in Fig. 3.4.

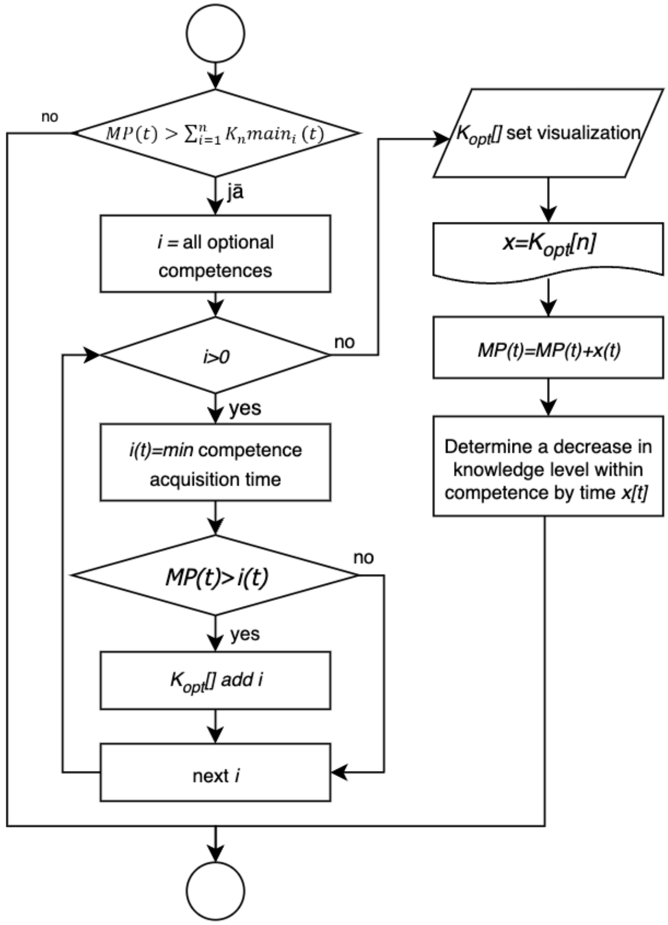

Fig. 3.4. Optional competence selection algorithm.

During the time of obtaining optional competences, the knowledge forgetting volume determining model is applied to all main competences.

In cases when the knowledge level of main competences is lower than minimal values defined in the system, the main competence selection algorithm is initiated for repeating the study materials.

The time of obtaining additional competences is the one not affecting the total study course time, as additional competences contain recommended additional study materials for independent learning. Therefore, the number of additionally included competences does not affect the curriculum structure and can be integrated in any place within the framework of the study course. To select the number of additional competences, it is offered to use two approaches:

- the module related to other competences included in the course where the link is defined at the time of developing the study materials;

- the module related to other competences included in the course where the link is determined by using a comparative analysis of descriptive text parts. (There were no studies performed in the Doctoral Thesis pertaining to research of text fragments comparison methods. To identify the connection of study competences, the keyword search in descriptions of other competences has been used.)

In cases when a link is established with some main or optional competences included in the study course, then, following the obtaining of additional competences, the knowledge level of competences with the available link is restored.

In cases when there is no sample plan of the study course or it is required to develop an individual curriculum prior to starting the study process, the Doctoral Thesis offers to use the genetic algorithm for including the study module in the study programme. The genetic algorithm is anticipated for solving the optimisation problems. In comparison with the randomised algorithm, where a new accidental solution is generated at each iteration, the genetic algorithm determines the best solutions at each iteration to include them in the next generation (Liashchynskyi, 2019). The genetic algorithm is used in the Doctoral Thesis to generate several options of curriculums, of which the best solution is selected as the optimum curriculum to achieve the best learning outcomes.

To avoid an inexpedient change of the curriculum, its reconfiguration method is developed, which is based on the time evaluation allocated for the study process and determining the student knowledge level. With account of the research results, the following conditions are set for changing the curriculum:

- the time required for obtaining the remaining study modules exceeds the time for obtaining the unmastered modules;
- the student knowledge level in the competence is less than the defined minimal value $K[c_i(min)]$;
- the student does not continue movement within the framework of the study course and the expectation time exceeds the defined border value.

4. EXPERIMENTAL TESTING OF THE DEVELOPED METHODS AND MODELS

The chapter provides experimental approbation of the methods and models developed in the Doctoral Thesis by using experiments in the real learning environment. In the beginning of the chapter, requirements and limitations of the systems used during the experiment are defined, as well as functional and non-functional requirements to the examined systems are described.

The chapter describes three experiments using the developed adaptive learning process management module ensured on the Moodle learning platform:

1. Approbation of the curriculum life span evaluation model with the static curriculum.
2. Approbation of the adaptive curriculum generation algorithm with the determined study process implementation time.
3. Approbation of the adaptive curriculum generation algorithm for balancing the knowledge level.

For the implementation of the methods and algorithms developed in the Doctoral Thesis, a developed control module (CM) has been used in the Moodle open source LMS, which provides control of the adaptive learning process using LMS resources (Fig. 4.1).

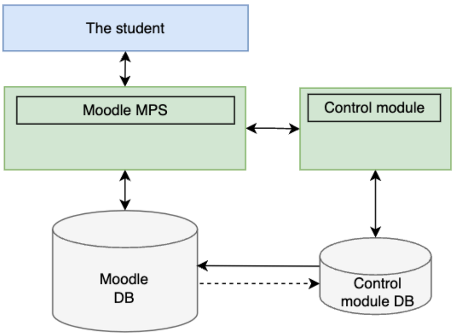

Fig. 4.1. Interaction between Moodle and the control module.

The team of "Steam Education" Ltd was involved in the development of the CM, which ensured the integration of the methods and algorithms described in the Thesis in the merchant's projects, which use the Moodle system for storing and managing learning resources.

4.1. Approbation of the Curriculum Life Span Evaluation Model with the Static Curriculum

By using the training implemented within the ESF project “Improvement of Professional Competence of Employed Persons” in cooperation with “Steam Education” Ltd, the study course “Information Digitalisation and Publishing Methods” was developed, ensuring the obtaining of 12 competences in the online mode. The learning management system included 92 modules, which ensured obtaining of the required knowledge and achieving the required level. The sequence of presenting the study programme modules was developed based on the licenced study course curriculum.

In the experiment, the entire supervision and management of the study process was ensured by a teacher.

Goals of the experiment

1. To test the curriculum life span evaluation model offered in the Doctoral Thesis by using the defined curriculum.
2. To evaluate the curriculum life span growth by generating the curriculum manually based on the model of determining the student competency knowledge level.
3. To evaluate the curriculum life span growth by changing the sequence of presenting modules manually with account of the model of determining the knowledge forgetting volume.

Description of the experiment

The first step is to establish benchmark for the lifespan of the curriculum. The reference value is the curriculum implementation time t_s required for the student to obtain the competences included in the study programme by using the defined sequence of obtaining the modules.

During the experiments, the student could not obtain the study materials repeatedly. The minimum knowledge level $K[c_i(min)] = 50\ \%$ was set for the target audience group of the experiment. It is assumed that the curriculum can be considered active as long as the knowledge level of the competence acquired during the learning is above the minimal defined value for the course $K[c_i(min)]$.

The curriculum implementation coefficient δ_e was introduced in the curriculum, indicating its implementation time with regards to the reference model:

$$\delta_e = \left(\frac{t'}{t_s} - 1\right) \cdot 100, \tag{4.1}$$

where t' is the curriculum life span during the examined stage (minutes) and t_s is the reference value of the curriculum implementation time (minutes).

Let us introduce the cost coefficient δ_p of persons involved in the study process management, which determines the economic efficiency of the study course implementation:

$$\delta_p = \left(\frac{C_{st}/t_s}{C/t'} - 1\right) \cdot 100, \tag{4.2}$$

where C/t' is the system costs during the examined period and C_{st}/t_s is costs of the reference model in monetary units.

During the experiment, the study course implementation costs are determined by the teacher's rate during the project implementation, which is EUR 30 per academic hour. It is assumed that the teacher spends 5 minutes for the curriculum activation per each student at the beginning of each lesson, ensuring manual adjustment of the curriculum.

The coefficient δ_r is introduced, indicating the total learning outcome of the student knowledge level during the study course in the defined group of students:

$$\delta_r = \left(\frac{\sum_{n}^{i=1} User[c_i]}{\text{n}}\right)/100, \quad (4.3)$$

where $User[c_i]$ is the level of knowledge in the i-th competence and n is the numbed of obtained study competence.

Table 4.1

Summary of the Experiment Results

Number of students	Stage 1 of the experiment: Static Curriculum				Stage 2 of the experiment: Generating a curriculum using a knowledge-based competency model				Stage 3 of the experiment: Generating a curriculum using a model for determining the extent of knowledge forgetting			
	t'	δ_e	δ_p	δ_r	t'	δ_e	δ_p	δ_r	t'	δ_e	δ_p	δ_r
1	1512	− 29 %	− 29 %	− 53 %	1708	− 20 %	− 20 %	− 63 %	1980	− 7 %	− 7 %	− 72 %
5	1586	− 25 %	− 25 %	− 68 %	1729	− 19 %	− 306 %	− 69 %	2030	− 5 %	− 377 %	− 77 %
10	1572	− 26 %	− 26 %	− 64 %	1760	− 17 %	− 727 %	− 68 %	1997	− 6 %	− 838 %	− 74 %
15	1603	− 25 %	− 25 %	− 59 %	1747	− 18 %	− 1131 %	− 65 %	2020	− 5 %	− 1324 %	− 75 %
20	1572	− 26 %	− 26 %	− 72 %	1729	− 19 %	− 1525 %	− 67 %	2008	− 6 %	− 1787 %	− 73 %
25	1608	− 24 %	− 24 %	− 67 %	1785	− 16 %	− 1997 %	− 66 %	1961	− 8 %	− 2204 %	− 77 %
t_s	2128											

When analysing three stages of the experiment, the value of the δ_e coefficient is negative, indicating the fact that during the study process conducted by the teacher, the student obtains information included in the study course, not exceeding the allocated time. Thus, it can be concluded that there is time $(t_s - t')$ at each stage of the experiment that can be used for the repeated obtaining of the study competences to improve the learning outcome. At the third stage of the experiment, the coefficient $\bar{\delta}_e$ (–6 %), compared to the first stage coefficient $\bar{\delta}_e$ (–26 %), is less, which indicates to the fact that there is less time left for revising the competences and the curriculum implementation duration maximally approaches the defined one in the course.

During the study process implementation time, the teacher spends 5 minutes per each student for the curriculum activating. The lesson duration cannot be less than 4 academic hours (45 min × 4). Thus, it can be determined that when implementing the study process by using the static curriculum (2128 minutes), salary of the teacher is EUR 39.41, which is determined by using Formula (4.4).

$$salary\ of\ the\ teacher = \frac{t'/lesson\ duration/number\ of\ lessons * teacher's\ working\ time\ in\ lessin \times teacher's\ rate}{lesson\ duration} \quad (4.4)$$

Results obtained during the experiment demonstrate that the achievable learning outcome (value of coefficient $\bar{\delta}_r$) depends on the study course duration and the curriculum generation method. In cases when the teacher adjusts the curriculum for each student at the second stage of the experiment (the $\bar{\delta}_r$ value is 67 %) and at the third stage (the $\bar{\delta}_r$ value is 75 %), the knowledge level has increased in comparison with the first stage result (the $\bar{\delta}_r$ value is 64 %).

To determine which of the compared stages in the experiment is more efficient, the obtained factors have been studied profoundly. During the first iteration, the results obtained during the first and third stages of the experiment have been checked. Two factors have been defined for the data research: statical (ST) – the factor describing the obtained knowledge level at the final assessment, when conducting the experiment with the static curriculum, and adaptive (AD2) – the factor describing the obtained knowledge level at the final assessment, when conducting the experiment with the generated curriculum, by using the knowledge forgetting volume model.

To determine which method can be used for data processing, the data distribution correspondence to the normal distribution has been checked. To compare two independent selections according to one parameter, the Mann-Whitney U-test has been used. At the start of the analysis, the zero hypothesis H_0 is set that the student knowledge level does not depend on the curriculum type (static or adaptive).

The U-test results have demonstrated that the difference between ST and AD2 parameters is statistically significant ($p = 0.001$). The H_0 hypothesis has not been proven; thus, it can be concluded that the achievable learning outcome, when implementing the study process with the adaptive curriculum and the static one, differs considerably with the probability of 99.9 % ($p = 0.001$).

During the first iteration, the results obtained during the first and second stages of the experiment have been checked. The adaptive factor has been defined for the data research (AD1) – the factor describing the obtained knowledge level at the final assessment, when conducting the experiment with the generated curriculum, by using the competence determining model based on the knowledge level.

To compare two independent selections according to one parameter, the Mann-Whitney U-test has been used. The zero hypothesis H_0 sets that the student knowledge level does not depend on the curriculum type (static or adaptive).

The U-test results have demonstrated that the difference between ST and AD1 parameters is statistically significant ($p = 0.034$). The H_0 hypothesis has not been proven; thus, it can be concluded that the achievable learning outcome, when implementing the study process with the adaptive curriculum and the static one, differs considerably with the probability of 96.6 % ($p = 0.034$).

Summary of the experiment results

1. With the increase of the number of tasks related to the supervision of curriculum fulfilment, the costs of the teacher of study process grow. Based on the results of the second stage of the experiment, it is recommended to use the curriculum reconfiguration method in the automatic mode.
2. By using the competence determining model based on the knowledge level for generating the curriculum, the curriculum implementation duration increases for obtaining only new, previously unobtained competences.
3. By using the knowledge forgetting volume model for generating the curriculum, it is possible to increase the student knowledge level at the end of the study course.
4. Results of the experiment have demonstrated that the curriculum reconfiguration method allows increasing the overall obtained knowledge level in all obtained competences of the study course (δ_r above 60 %).

4.2. Approbation of the Adaptive Curriculum Generation Algorithm with the Determined Study Process Implementation Time

By using the learning platform macam.lv, which ensures online training to obtain a

Category B driving licence, in cooperation with "Tālmācības autoskola" Ltd, the curriculum generation algorithm was integrated in Moodle ALMS to ensure the arrangement of the sequence of presenting modules for obtaining competences. The course consists of 7 competences, which are distributed between eight lessons. The total time of the study process implementation equals to 40 hours.

Goals of the experiment

1. To test the module arrangement algorithm for developing the curriculum with a determined study duration offered by the Doctoral Thesis.
2. To test the effect of the competence arrangement algorithm offered by the Doctoral Thesis on the quality of the achievable results in all competences.

Description of the experiment

In the experiment, it was considered that the curriculum has been completed when the learner has completed all the activities involved in the learning process and passed the final knowledge test. The reference value was the knowledge level $M[c]_s$ achieved in each competence by using the sequence of obtaining modules defined in the study programme.
The coefficient δ_v is introduced, which reflects the proportion of the obtained knowledge level in percentage for each competence included in the study course against the reference model:

$$\delta_v = \left(\frac{M[c]'}{M[c]_s} - 1\right) \cdot 100, \tag{4.5}$$

where $M[c]'$ is the obtained knowledge level in the examined competence and $M[c]_s$ is the reference model knowledge level in the examined competence.

During the experiment, the number of main competences was not changed. The curriculum generation algorithm used the number of study modules required for mastering the study course determined by the reference model. Results of the experiment are provided in Table 4.2.

Table 4.2

Summary of the Experiment Results

Competence	Minimum number of learning hours	Number of learning modules	Stage 1 of the experiment			Stage 2 of the experiment			Stage 3 of the experiment		
			Static Curriculum			Competence sorting algorithm			Modules sorting algorithm		
			Order of competence acquisition	Number of additional learning modules	Level of acquired knowledge	Order of competence acquisition	Number of additional learning modules	δ_v	Order of competence acquisition	Number of additional study modules	δ_v
c1	3	12	1		30 %	1		17 %	1	6	67 %
c2	3	14	2		50 %	3		30 %	2	4	20 %
c3	8	40	3	4	80 %	2	4	− 12 %	3		− 6 %
c4	4	20	4	4	80 %	6	4	0 %	4	2	0 %
c5	4	16	5	3	70 %	4	3	7 %	5	3	14 %
c6	7	35	6	2	90 %	5	2	0 %	6		− 6 %
c7	3	10	7	4	95 %	7	4	0 %	7		− 5 %

With account of the study course requirements, every competence has the required minimum of the obtainable modules, based on which the minimum number of study hours required for obtaining the competences is determined, which is an invariable value with the defined time. The total duration of implementing the study course is equal to 40 hours. Thus, upon obtaining the compulsory modules, the student has time remaining, which can be used for revising the information included in the course.

In the first stage of the experiment, using the curriculum developed by the pedagogue, all the competencies of the course were learned sequentially using mandatory modules, and the learning time for five competencies (K3, K4, K5, K6, K7) was increased by adding additional learning modules. As a result, with adding of new modules to the curriculum, the total time for obtaining the course equals to 40 academic hours. When evaluating the student knowledge at the end of the course, it was established that the knowledge level in competences obtained at the beginning of the course or by using only the minimum time for obtaining the competences was lower than in competences obtained at the end of the course, or the time for their obtaining was increased by adding new study modules.

At the second stage of the experiment, by using the study competence sorting algorithm, a new curriculum was developed, not changing the number of study modules included in each competence but changing the sequence of their presentation. By using the obtained values of the coefficient δ_v, one can see that the competence sorting algorithm allows increasing the obtained knowledge level in the competences, having placed them in the middle or final part of the curriculum (for example, the knowledge level increase in competence K2 is 30 % and the sequence of its obtaining in the curriculum was changed from the second to the third position). The competence obtained at the beginning of the study course retains a low level of the obtained knowledge (for example, reduction of the obtained knowledge level in K3 competence is 12 %).

At the third stage of the experiment, by using the study competence sorting algorithm, a new curriculum was developed, changing the time of presenting each competence by using the sequence of presenting the competences determined at the first stage of the experiment. By using the obtained knowledge level results, one can see that the module sorting algorithm allows balancing the obtained knowledge level results between all competences included in the study course (the obtained knowledge level in K1, K2 and K5 was increased).

To determine whether the sequence of obtaining the competences without a possibility of revising them affects the achievable results at the final assessment, the obtained factors have been profoundly researched. The achievable results of implementing the static curriculum demonstrate that the achievable result depends on the sequence of presenting the competences. Having analysed the data, it is seen (Fig. 4.2) that by using the static curriculum the average value of the achievable result of the competence included in the initial part (K1) is $\bar{x}$ = 30.22, the minimum value is 22 and the maximum value is 36, the amplitude (the difference between the biggest and the smallest values) is 14, the median equals to 32; whereas, the average value of the achievable result of the competence included in the final part (K7) is $\overline{x}$ = 94.889, the minimum value is 82 and the maximum value is 100, the amplitude (the difference between the biggest and the smallest values) is 18, the median equals to 96.

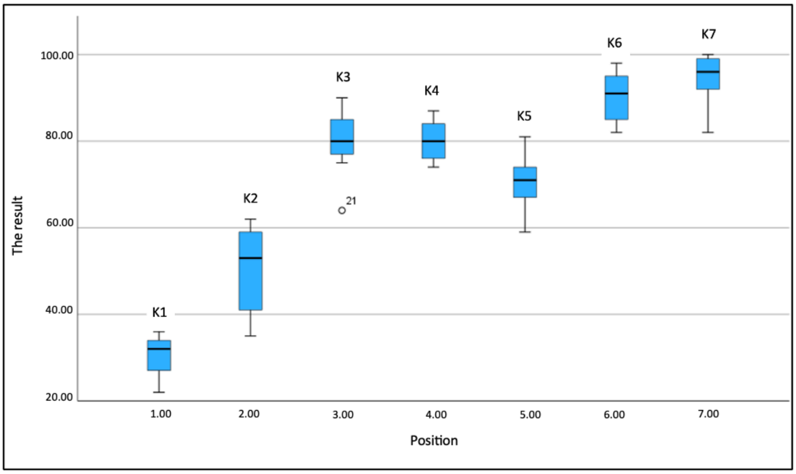

Fig. 4.2. Achievable results of the static curriculum at the final assessment.

The zero hypothesis H_0 sets that the competence obtaining position in the curriculum does not affect the achievable results. Competences included in the study programme do not have the set requirements regarding their inclusion in the study programme, thus the sequence of obtaining competences can be changed.

In the data analysis at the first stage, the results achieved in K2 competence when changing the sequence of presenting competences have been examined. Two factors have been defined for the data analysis: static (MP1K2) – the factor describing the obtained knowledge level in the second competence K2 at the final assessment by using the sample curriculum, (MP2K2) – the factor describing the obtained knowledge level in the second competence K2 at the final assessment by using the generated curriculum.

The empirical distribution of the researched data corresponds to the normal distribution. To determine the resulting differences between the selections, T-test has been used. For the T-test selections, when analysing differences between the scale measurements, it has been concluded that for all scale pairs the differences in assessment, when obtaining the competence as the second or third, are statistically significant ($0.001 \leq p \leq 0.018$). As the differences are statistically significant, they can be applied to the entire respective set of data with a high degree of credibility.

In the data analysis at the second stage, the achieved results in K3 competence when changing the sequence of presenting competences have been examined. Two factors have been defined for the data analysis: static (MP1K3) – the factor describing the obtained knowledge level in the third competence K3 at the final assessment by using the sample curriculum, (MP2K3) – the factor describing the obtained knowledge level in the third competence K3 at the final assessment by using the generated curriculum.

To compare two independent selections according to one parameter, the Mann-Whitney U-test has been used. The U-test results have demonstrated that the difference between MP1K3 and MP2K3 parameters is statistically significant ($p = 0.003$). The H_0 hypothesis has not been proven, i.e., as the differences are statistically significant, they can be applied to the entire respective set of data with a high degree of credibility.

Summary of the experiment results

1. Usage of the static curriculum does not allow to obtain the study competences at the appropriate level (the minimal 30 % were achieved at the final assessment). The knowledge level in competences obtained at the beginning of the study course with less time allocated for the study process has not been achieved in the sufficient volume.
2. Usage of the study competence sorting algorithm allows increasing the obtained knowledge level in competences with less time for their obtaining, by placing these competence modules in the final part of the curriculum.
3. By using the study competence sorting algorithm, the obtained knowledge level in competences is balanced between all competences obtained in the study course.

4.3. Approbation of the Adaptive Curriculum Generation Algorithm for Balancing the Knowledge Level

By using the learning platform das.lv, which ensures online trainings for adults, an experiment was performed with a goal of increasing the student knowledge level by obtaining the professional distance learning programme related to information technologies. During the experiment, the study course “Financial Data Analysis and Report Preparation in the Excel Environment” was used, which ensures obtaining of 160 hours of the study programme in the distance learning format. The distance learning form of implementing the study programme anticipates to conduct minimum 30 % of the study process in face-to-face format and the rest distance learning using the available study resources. In accordance with the study programme licence, 52 hours of theory lessons and 60 hours of practical work are implemented in the distance learning format. The required student knowledge level in each competence must be at least 55 %.

Goals of the experiment

1. To test the usage of the curriculum reconfiguration method developed by the Doctoral Thesis for achieving results in all competences within the shortest time possible.
2. To evaluate the effect of the competence knowledge level balancing method on the study process implementation time.
3. To evaluate the effect of the curriculum reconfiguration method on the obtained knowledge level in all competences.

Description of the experiment

It has been set at the experiment that the curriculum is considered to be fulfilled when the student fulfils all activities included in the study process achieving at least minimum requirements in all competences. The reference value was defined as time t_s for the implementation of the curriculum, which is required for the learner to learn the competencies included in the course at the required level, using a defined sequence of learning modules.

The competence obtaining deviation coefficient δ_i has been introduced, indicating the obtained knowledge level deviation in the examined competence from the average knowledge level in all obtained competences.

$$\delta_i = K[c_i] - \frac{\sum_{n=1}^{m} K[c_n]}{m}, \tag{4.6}$$

where $K[c_i]$ is the i-competence knowledge level of the study course and m is the number of competences included in the study course.

Table 4.3

Results of the Experiment

Competence	Stage 1 of the experiment			Stage 2 of the experiment			Stage 3 of the experiment		
	Static Curriculum			Cirriculim generation algorithm			Balanced knowledge level		
	Acquired knowledge level, %	Number of learning modules	δ_i	Acquired knowledge level, %	Number of learning modules	δ_i	Acquired knowledge level, %	Number of learning modules	δ_i
K1	69 %	5	8 %	66%	7	4 %	6 %	6	0 %
K2	61 %	7	0 %	61%	5	− 1 %	62 %	3	2 %
K3	63 %	8	2 %	63%	7	1 %	59 %	3	− 1 %
K4	64 %	9	3 %	64%	4	2 %	62 %	5	2 %
K5	61 %	7	0 %	55%	7	− 7 %	63 %	3	3 %
K6	66 %	8	5 %	62%	6	0 %	60 %	6	0 %
K7	62 %	9	1 %	60%	6	− 2 %	58 %	5	− 2 %
K8	63 %	4	2 %	60%	5	− 2 %	60 %	6	0 %
K9	57 %	5	− 4 %	57%	4	− 5 %	61 %	6	1 %
K10	65 %	6	4 %	67%	4	5 %	60 %	7	0 %
K11	55 %	8	− 6 %	71%	3	9 %	61 %	3	1 %
K12	57 %	7	− 4 %	56%	6	− 6 %	61 %	4	1 %
K13	55 %	8	− 6 %	64%	5	2 %	58 %	4	− 2 %
K14	61 %	9	0 %	57%	5	− 5 %	63 %	3	3 %
K15	55 %	4	− 6 %	64%	6	2 %	59 %	3	− 1 %
K16	58 %	1	− 3 %	61%	3	− 1 %	59 %	5	− 1 %
Average level of acquired knowledge	61 %			62%			60 %		
Programme implementation time in minutes	6660			5715			7020		

The objective of the experiment is to determine the deviation of the knowledge level in each competence at each stage from the average knowledge level in all competences.

At the first stage of the experiment, the static curriculum prepared by the teacher was used, which included 105 study modules for obtaining 16 competences (Table 4.3). The total time for obtaining the course is 6660 minutes, the average knowledge level in all competences is 61 %, the minimum knowledge level in the competence is 55 %, the maximum – 69 %. At the first stage of the experiment, knowledge in all competences included in the study course was evaluated at the end of the course.

At the second stage of the experiment, the generated curriculum based on the student knowledge level was used, which included 88 study modules for obtaining 16 competences. To generate the curriculum in the face-to-face class at the beginning of the course, the student knowledge level was assessed by using the knowledge-based competence determining model. The total time of mastering the course is 5715 minutes, the average knowledge level in all competences is 62 %, the minimum knowledge level in the competences is 55 %, the maximum – 71 %. It can be concluded that adapting the curriculum to the student knowledge level allows reducing the time required for learning the set competences, excluding the study modules that are considered to be learned. At the second stage of the experiment, knowledge in all competences included in the study course was evaluated at the end of the course.

At the third stage of the experiment, the generated curriculum was used with the model determining the knowledge forgetting volume, which included 118 study modules for obtaining 16 competences. At the start of the study course, the student knowledge level was assessed and the parameters affecting the model determining the knowledge forgetting volume, by using the knowledge-based competence determining model. At the third stage of the experiment, the results showed how to ensure balancing of the student knowledge level between all competences included in the study course, the time for obtaining the study course increased (the course implementation time is 7020), which did not exceed the maximum time defined for the course. The average knowledge level in all competences is 60 %, the minimum knowledge level in the competence is 58 %, the maximum – 63 %. The minimum knowledge level increased at the third stage, comparing to that during the final assessment at the second and third stages.

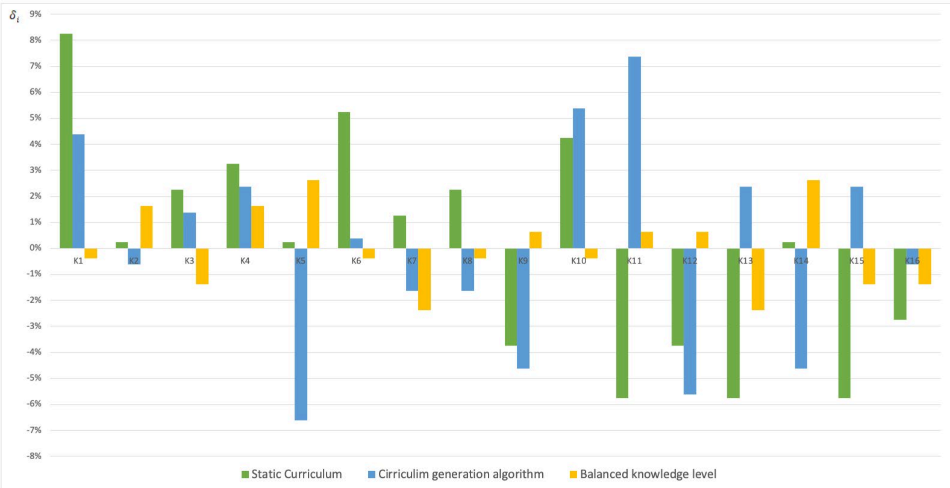

Fig. 4.3. Knowledge level deviation from the average knowledge level.

Figure 4.3 provides values of the coefficient δ_i, which indicate deviation of the knowledge level in each competence from the average knowledge level in all competences at each stage of the experiment. The biggest deviation is at the first stage of the experiment and the smallest at the third stage, balancing the knowledge level difference between all competences.

Summary of the experiment results

1. Using the static curriculum, it is possible to learn the content in the allotted time, reaching the defined requirements of the learning course – the minimum level of knowledge in each competence at least 55 %.
2. Using the adaptive curriculum reconfiguration method and the model determining the knowledge forgetting volume, it is possible to reduce the value of the competence deviation coefficient δ_i, balancing the knowledge level difference between all competences. When using this method, the study course implementation time increases.

OVERALL RESULTS OF THE THESIS, CONCLUSIONS AND FURTHER RESEARCH

The goal of the Doctoral Thesis was to develop the curriculum generation models and methods that allow balancing the student knowledge level at the end of the study course and increasing the curriculum life span.

The goal has been achieved and all defined objectives have been fulfilled:

1. Models and methods of the adaptive learning process implementation have been analysed.
2. Factors that prescribe limitations of the study content presentation and requirements for their inclusion in the curriculum have been determined.
3. The assessment model of the curriculum life span has been developed.
4. The curriculum generation algorithms that allow balancing the student knowledge level for each competence included in the study course have been developed.
5. Experimental approbation of the developed curriculum model in a real learning management system has been performed.

When analysing the scientific references, it has been concluded that currently there are no universal solutions that would ensure implementation of the adaptive learning process in an automatic mode, which would be appropriate for distance learning.

The Doctoral Thesis focuses on the curriculum adjustment to each student. The studies demonstrate that currently there is no solution that would ensure the curriculum adjustment to each student, ensuring balancing of the knowledge level of each student in all study competences, achieving at least the minimum knowledge level in each competence.

When analysing references on learning management systems and curriculum generation, the following has been concluded:

1. Online study process implementation systems use technologies applied in the business, public and private sector, ensuring education at all levels. The large number of scientific works related to adaptation of the online study process to the student needs and to issues described in the Doctoral Thesis substantiate the topicality of this theme.
2. Analysis of the scientific papers of recent years shows that the research object in online learning management systems is the curriculum adaptation to the student knowledge level and capabilities to acquire the study programme without the participation of a

teacher. Several methods have been developed recently that increase the study process implementation efficiency, ensuring a higher level of achieving the learning outcome in each competence included in the study process. The adaptive curriculum generation method based on the student knowledge level proposed in the Doctoral Thesis prescribes the study process implementation requirements that affect the dynamics of the student knowledge level in all competences included in the study programme.

Within the framework of the Doctoral Thesis, the adaptive curriculum life span evaluation model and the curriculum reconfiguration method for increasing its life span has been developed, balancing the student knowledge level in all competences included in the study programme. The offered models and methods have been approbated experimentally. Results of the experiments have demonstrated the following:

1. Curriculum reconfiguration methods should be used in automatic mode because as the number of tasks related to the monitoring of curriculum execution increases, the teacher's salary increases.
2. By using the knowledge forgetting volume determining model for the curriculum generation, it is possible to increase the student knowledge level at the end of the study course, reducing forgetting of information in the examined competences.
3. The curriculum reconfiguration methods allow increasing the overall obtained knowledge level in all obtained competences, not increasing the total time allocated for the study process.
4. Usage of the competence sorting algorithm allows to increase the achieved knowledge level in competences with a short learning time by placing these competences in the final part of the study programme.
5. By using the study module sorting algorithm, the achieved knowledge level in competences is balanced between all competences obtained in the study course.
6. The study programme implementation time depends on the defined learning outcome. When increasing the knowledge level limit, the time increases which is required for the repeated acquisition of competences to achieve the learning outcomes set by the programme.

The hypotheses put forward in the Doctoral Thesis have been proven:

Hypothesis: Usage of the adaptive curriculum generation methods based on the student knowledge level allows to balance the knowledge level between all competences included in the study course.

Proof: Results of the experiments have demonstrated that the curriculum reconfiguration method allows to increase the overall obtained knowledge level in all competences included in the study course, not increasing the total time allocated for the study process. By using the knowledge forgetting volume determining model in the curriculum generation, it is possible to increase the student knowledge level at the final assessment of the study course.

Hypothesis: The sequence of including competences in the curriculum affects the student learning outcomes at the final examinations.

Proof: Results of the experiments have demonstrated that usage of the static curriculum does not allow acquiring the study content in a full-fledged way if its revision is not possible.

Usage of the competence sorting algorithm allows to increase the student knowledge level at the final assessment.

Results of the Doctoral Thesis have been used in the implementation of the following projects:

- ESF project “Improvement of Professional Competence of Employed Persons” in cooperation with “Steam Education”Ltd during the period from September 2020 to June 2022. During the project, a tool for assessing the learner's knowledge level was developed.
- The adaptive curriculum evaluation method has been approbated in the www.macam.lv project, which ensures online training to obtain the Category B driving licence, in cooperation with “Tālmācības autoskola” Ltd. During the project, a curriculum generation algorithm was integrated into the learning management system, which ensures the order of delivery of the modules.
- The adaptive curriculum generation algorithm based on the student knowledge level has been used for the learning platform das.lv developed by the Software Engineering Department of Riga Technical University, ensuring online trainings for adults by implementing the distance learning educational programme for professional upgrading.
- In cooperation with “FIV” Ltd and the Innovation Voucher Program of the Investment and Development Agency of Latvia, a project was implemented at the Riga Technical University for the development of a method of balancing the student knowledge level, online training for obtaining a Category C and Code E95 driving licenses.
- In cooperation with SIA “FIV” Ltd and with the Norwegian Financial Instrument support the digital study content management module has been developed, ensuring the development of the adaptive curriculum based on the student knowledge level for preschool age pupils, implementing the preschool preparation study programme.

The research results have been used in two RTU study courses:

- Adaptive Data Processing Systems (DIP320),
- Applied Computer System Software (DIP392).

Further research areas:

- To integrate the adaptive curriculum evaluation model on the Moodle software level to ensure the user-selected curriculum life span evaluation and to provide recommendations during the study process implementation.
- To integrate the curriculum reconfiguration method for developing the initial curriculum on learning platforms to ensure recommendations during the study content development, identifying the number of modules pertaining to the curriculum implementation, in order to acquire each competence in the study programme context.

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