RIGA TECHNICAL UNIVERSITY

Laura Dzelzkalēja

NEW E-STUDY ENVIRONMENT ANALYTICS METHOD "COLOUR CODE METHOD" DEVELOPMENT AND PERFORMANCE RESEARCH

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of E-studies and Humanities
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Scientific supervisor
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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 (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 16 January 2022 at 15.30 at the Faculty of E-study technologies and Humanities of Riga Technical University, Riga, 1 Kronvalda Blv., Room 200.

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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.

Laura Dzelzkalēja ……………………………. (signature)

Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction, 5 chapters, Conclusions, 24 figures, 5 tables; the total number of pages is 144. The Bibliography contains 290 titles.

CONTENTS

1. GENERAL DESCRIPTION OF THE RESEARCH

1.1. Topicality of the research

In this transdisciplinary research, technological solutions have been developed in a form of a new learning analysis method, the method has been tested and usability of the method has been analysed. The proposed method is aimed at getting a real time feedback about students' learning process and indirectly also about the course material quality. This method belongs to the fast-growing learning analytics field. It is predicted that in the following years, along with the rapid development of the online learning, the role and possibilities of the learning analytics will grow because thanks to it, it is possible to evaluate learning process and course efficiency. The colour code method that was developed during this research will contribute to the development of this important field. Digitalisation, available education and lifelong learning importance and necessity of the development is stressed in the Latvian, EU and UNO strategic planning documents. Thus, the goal of this research is aligned with the overall direction and course in the world, contributing to reaching the goals of the knowledge society. This research is an engineering response to the challenges of social global society, which in the Horizon 2020 program are formulated as a set of three pillars – excellent science, industrial leadership, and societal challenges.

The new **Colour Code Method (CCM)** is meant to reflect the continuous real-time learning process. The main principle of the method is the three colour codes that are used by the students to inform the teacher about the state of their personal learning process workflow at each moment of the learning process. The codes are defined as follows:

- "Red" is used to show that the task is not clear, or difficulties have appeared during the process and an assistance is needed (in the form of teacher or some extra learning materials).
- "Yellow" is used whenever the task is being done and everything is clear – no need for assistance.
- "Green" is used when the task (or any other learning object) is finished and nothing studies related is being done.

The new CCM is a part of the Etalon model class according to the Atwell (Attwell, 2006) classification. There have been many attempts to create a set of criteria to ensure the quality of e-studies. But often they tend to set the quality standards of the e-study system and software. These, in turn, often do not consider the key characteristics in a wider learning environment, are based on the traditional learning process evaluation criteria (not taking into consideration the technological possibilities) or on the criteria which are connected to the students' achievements measurements according to the methods of the traditional pedagogy. Besides, the developers of these benchmark models are often "trapped" in one exact e-studies model, which restrict the transfer of benchmarks (Attwell, 2006). These considerations are taken into account when creating the colour code method and having as the base the idea of the requirements of universal usability, so that it would be possible to use the method and to compare the results in different environments and learning courses.

Situation analysis is used as the main validation technique of the method. During the situation analysis, as in other observations, it is necessary to set exact goals for the analysis –

usability, physical phenomenon, teacher's or students' behaviour (Šteinberga, 2011.). Both classroom and virtual environment experiments have been done with two independent groups of students, because according to Morrison (Morrison, 2015), artefacts give valuable clues about course quality, moreover so, when collected from two or more repeated courses and analysed together. In this case it contributes to efficiency evaluation of the method.

1.2. Goals and objectives of the Doctoral Thesis

The **goal** of the research is to develop a new technological solution of e-study environment learning analytics method for a real-time learning process and to create a prototype of the method, validate it and test it in performance research.

To reach the goal, the following **tasks** need to be performed:

1. To analyse computer science, e-study, and pedagogical literature; to select, study, and analyse information sources; to study information sources about e-study technological solutions, educational analytics, and e-study evaluation strategies in depth, identifying the most actual solutions and suggestions to take them into consideration during the development and implementation process of the colour code method (CCM).
2. To analyse the current situation and regulations in the field of education, e-studies in particular, in the context of CCM development and implementation.
3. To formulate and develop the CCM idea.
4. To develop the research theoretical basis and methodology for an on-site action research and for the on-site CCM prototype development.
5. To realise the on-site experiment and CCM tool performance research; to observe CCM experiments' participants and interview experts; to process and analyse the obtained data.
6. To develop the virtual CCM technological solution based on the results of the on-site experiments and analysis of the literature.
7. To develop the CCM virtual environment prototype and test it among students' groups in learning management system in two test cycles; to do data analysis and to improve the prototype or give improvement suggestions after each cycle.
8. To compare both virtual testing cycles – data processing and analysis and result evaluation –and draw conclusions about efficiency and future potential of the CCM.

Study object: E-study technologies, that support learning process in different groups of students.

Research hypothesis: Utilisation of the colour codes and analysis of the obtained real-time data improve the possibility to evaluate learning process and to perfect the content and teaching methods.

1.3. Research methodology

The following research methods have been used to study pedagogical process and students' attitude:

- Observation method – observing classes and students' reactions and attitudes towards CCM, their interest and activity in CCM. Effect of the method on student's engagement and activity.
- Research of the examination results in order to derive the course acquisition information, and to compare it to CCM usage activity.
- Expert-opinion method –interviews with the teachers involved in the experiment about the CCM implementation process and suggestions on the improvements to the method.
- CCM user survey – online survey for evaluation of the method's design, functionality, and idea.

General theoretical methods were used in literature analysis about learning analytics, e-studies, virtual systems, and similar topics. These methods are at the core of the CCM technological solution development for the e-studies environment as well as for evaluation and comparison of the competition criteria for the professions needed in the near future. For the evaluation of the results, the monographic method was used.

Statistical method for data processing

Mathematical statistics and data processing methods are used for the processing and analysis of the acquired raw data and for the quantification and analysis of the qualitative data. Mathematical statistics data processing methods directly reveal the research results with the help of *IBM SPSS Modeler, MS Excel 2007*, and R language statistical analysis tools. For a better visual result demonstration, the data has been put into diagrams, pictures, and tables.

1.4. Main results of the research

Colour code method was validated in the virtual environment by creating a plug in at the edX learning management system in which courses "Entrepreneurship" for the 1st year bachelor students (year 2017/18) and "Natural Science Modelling" for the 1st year master students (year 2018/19) were run.

In the group of 2017/18, the activity of colour code button presses was medium low – 32 % of the students had pressed the buttons at least once. If we analyse the data taking into consideration the gender of the students, it was revealed that both genders use the buttons similarly: 33.5 % of male students and 28.5 % of female students had used the buttons at least once. In the group of 2018/19, all students were females. In this group 75 % of the students had used buttons. This is a significant difference in comparison with the bachelors group. After observations of the courses, it can be said that overall, the students of the 2018/19 group were more motivated and the completed tasks were of higher quality during the course, there were proportionally less dropouts. This situation can indicate a correlation between interest in the course, learning and finishing motivation, and the colour code method.

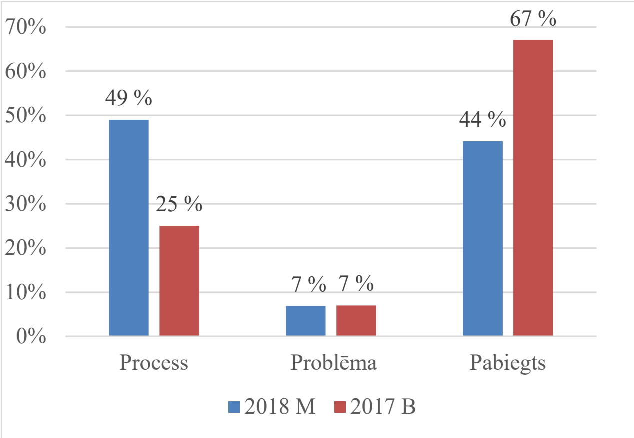

Fig. 1. Percentage of button pressing by the groups in 2017/18 and 2018/19.

If we compare the groups of 2017/18 and 2018/19 in terms of the pressed colours (Fig. 1), we can see that the percentage of the number of pressed green button in 2018/10 is 44 % during that year, but the group of 2017/18 used the green button considerably more – 67 % of the presses. In 2018/19, the percentage of the number of pressed yellow button was 49 % of the presses compared to considerably lower 25 % in the group of 2017/18. In the group of master students, the distribution between the "process" and "done" buttons are more balanced, meanwhile for the bachelors, the "done" button strongly dominates. It is interesting that the percentage of using the red "problem" button is the same for both groups– 7 % of the presses. It could point to a tendency that, for example, 7 % of the learning materials are of low quality or that this is the proportion of students that will have difficulties during the course, or perhaps it can be related to the structure of the course. Most likely, it is a combination of all those reasons and more. This is an area to be researched in future to find real reasons.

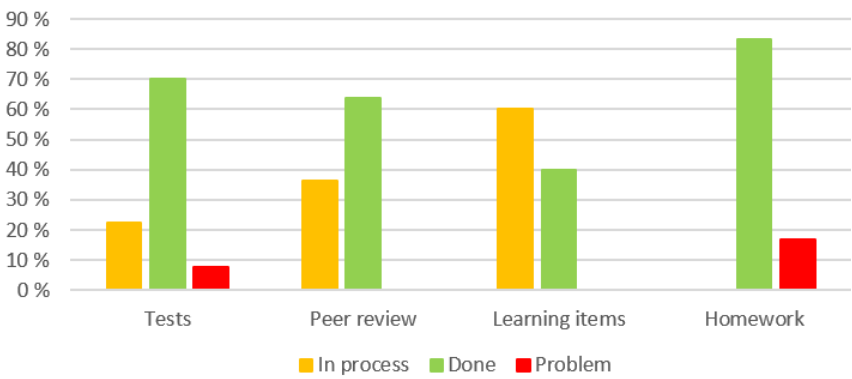

Fig. 2. Group 2017/18: buttons pressed in different learning material types.

If we analyse the gathered data about buttons pressed by the type of learning material (Fig. 2.), it can be seen that the green button "done" has been pressed the most in tests, peer review tasks and homework , but it differs for learning items (informative materials, not tests, homework, and peer-review), and the biggest proportion of pressed has the orange "in process" button, “done” being only the second and the “problem” button has not been pressed at all. The “problem” button has not been pressed in the peer review tasks as well. But in the homework, “in process” has not been recorded. Even though the buttons were used mostly during the tests, the colours were distributed quite similarly among different types of course material. It could mean that students consider the green button as a reward – a symbol of a job done. Data about the types of learning item were not gathered in the group of 2018/19 because the structure, content and tasks of the course were different and more closely linked to the face-to-face learning process in the classroom.

After the semester ended, a survey about colour code buttons was sent to all the students, and they filled it voluntarily. The survey consisted of nine questions and student background information. The background information provided student’s age, gender, and the study group in 2017/18, since the 2017/18 group was divided in four subgroups due to the size of the group, but the 2018/19 survey had an additional question – whether the student has finished the course. The questions were about noticing colour buttons in the learning platform, about the button design, the button usage frequency and reasons, and about situation when they used buttons, why and when they would use them.

Students responded positively about most of the button design features, except the button respond reaction, which got more negative votes than other design elements. In Fig. 3, the summary of the votes about the design section can be seen (Dzelzkaleja, 2018).

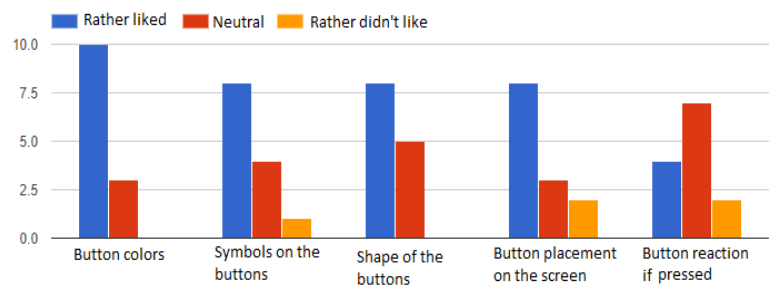

Fig. 3 a. Evaluation of button design by the students of group 2017/18.

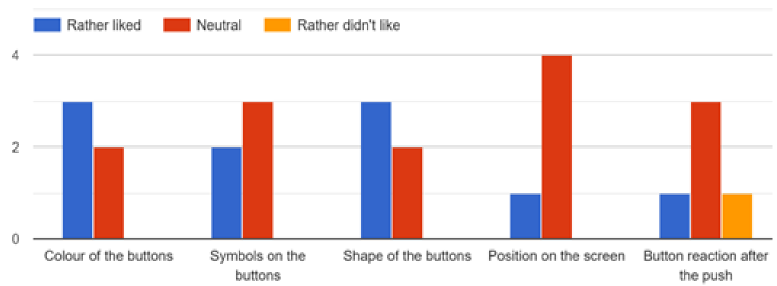

Fig. 3 b. Evaluation of button design by the students of group 2018/19.

The survey shows that some button design changes and a method description and user manual need to be added. After the oral presentation of the method, some of the students said that they had forgotten the meaning of the buttons. The survey also revealed that there are misunderstandings about the button meaning because this method differs from the existing ones, e.g., voting systems and emotion feedback systems.

In the 2017/18 group there were many students that had not finished the course after the end of the semester and the two additional weeks, so they had not received any mark and were not attested for the finishing – "NA". There were 47 (50 %) NA students, 32 (68 %) males and 15 (32 %) females. This proportion differs by 5 % from the overall course gender proportion – more female students had not finished the course. The research showed that most (83 %) of these students did not use the colour buttons as well. So, it shows that the students that are less engaged in the course overall are less engaged in learning tools as well. In the 2018/19 group 14 (64 %) of the registered 22 students finished the course and 8 (36 %) were NA students, which is 14 % less than in the 2017/18 group. It could be an extra proof that the master students were more driven and interested in the course.

Table 1 shows the summary of button usage and exam marks of both groups. The lowest mark gotten by three students was 6 (2017/18 group), those students had not used colour buttons. The second lowest mark was 7: in the 2017/18 group gotten by one student that did not use buttons, and one in 2018/19 (the lowest mark in this group) who used buttons. The situation differs among students who got the highest marks: for the 2017/18 group, 67 % of the 18 students who got 10, 25 % of 12 students who got 9 and 46 % of the 13 students who got 8 had also used the colour buttons; for the 2018/19 group, all 3 students who got 10, 50 % of 6 students who got 9 and 75 % of the students who got 8 had used the colour buttons. The proportion of button usage is considerably higher among those students who got higher marks.

Table 1. Comparison of Both Test Groups by Exam Marks and Colour Button Usage

Proportion of button users	**2017/18 group**	**2018/19 group**
Students with mark 10	18	3
Proportion of button users	67 %	100 %
Students with mark 9	12	6
Proportion of button users	25 %	50 %
Students with mark 8	13	4
Proportion of button users	46 %	75 %
Students with marks 6 or 7	4	1
Proportion of button users	25 %	100 %
Students with mark NA	47	8
Proportion of button users	17 %	36 %

In Fig. 4, the correspondence of curves to the equations is remarkably high. It shows a highly likely correlation between exam marks and button usage. Moreover, this correlation cannot be intuitively guessed – the biggest proportion of the users is by those with mark "7" (but since only one student in each group got this mark, we cannot consider these as very reliable results). The next biggest proportion is of those with mark "10", which is understandable because it correlated with a higher overall learning motivation. Very understandable is also the fact that the lowest button user proportion is by those with NA. A curious fact, which needs further research, is that the "9" receivers in both groups are considerably less active button users that the "8" receivers.

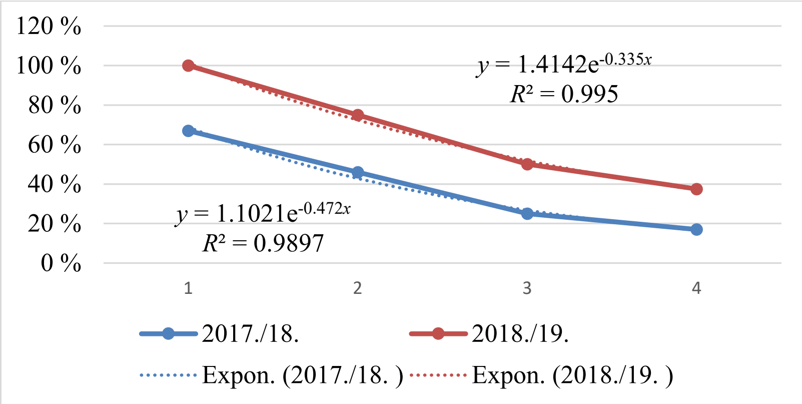

Fig. 4. Mark slopes without mark "7" for both test groups.

If we exclude those who got "7" from the analysis, taking into consideration the fact that we have only one data point (student) in each group for this mark, then the line equation for the 2017/18 group is $y = -0.171x + 0.815$ and for the 2018/19 group $y = -0.2125x + 1.1875$, the difference in gradient for both liner equations is little: 0.37. It indicates that slopes are similar in their gradient. Also, the exponential equations (Fig. 4) are similar: for the 2017/18 group $y = 1.1021e^{-0.472x}$, but for the 2018/19 group $y = 1.4142e^{-0.335x}$. What is remarkable is how high is R^2 for both equations – over 99 %.

Since the amount of data is low and only consists of two semester data of two different groups, it is necessary to do more experiments in the future to approve or neglect the assumption about existence of a correlation between exam marks and button usage, as well as to find reasons behind it.

Virtual implementation of technological solution of colour code method and performance research confirms the hypothesis that utilisation of the colour codes and analysis of the obtained real-time data improve the possibility to evaluate learning process and to perfect the content and teaching methods.

1.5. Thesis statements

1. Available learning analytics methods do not provide enough information about the reasons behind user's behaviour in real time continuously, and a creation of a novel method which would allow to evaluate the real-time processes in a simple and easily understandable way is justified and necessary.
2. Colour code method reflects three states of learning process: process, problem, done/break.
3. With the help of the colour code method plug in integrated in e-study environment it is possible to determine benchmarks for identifying learning items and students at risk and to give information that is useful to identify students and learning items that are outside the average values (7 % red button usage).
4. The experimental testing of the developed Prototype in the edX learning platform shows that it is possible to integrate the colour code method module in a MOOC type learning management system, successfully providing a conjunction among database, plug-in and

the learning management system (user), and automatically gather data about usage parameters of the plug-in.

1.6. Practical significance of the research

The Thesis is an attempt at covering the vast amount of information in the field of educational technologies and contributing to usage of meaningful and efficient technologies and online education through the developed colour code method.

The new colour code method provides students with a possibility to observe their learning process. There is a benefit also for teachers or instructors because the gathered data allow to conclude about the quality of the course elements, even if the teacher does not have specific data analysis and course evaluation skills. In this process knowledge and understanding about the learning process dynamics is created.

The colour code method created in this transdisciplinary research will contribute to the assessment of the didactic quality of the course by enabling the instructor to quickly and easily see the learning items (e.g., video, text snippet or task) or topics for which students press the "problem" button most; those parts of the course in which the problems appear the least; and those parts of the course where students are delayed the longest. The method will enable them to improve and more objectively assess the time required for studying and to respond to problems in a timely, faster and simpler way identifying students in need of change – assess real-time processes in a simple and easy to understand way.

The method can be used in any learning environment, both face-to-face, virtual blended as well as on many learning platforms. The author hopes that this idea and approach will contribute to raising the quality of the formation and development of a rapidly growing and evolving knowledge society.

This method also indirectly motivates students thanks to a possibility of raising awareness of their learning process, and thus students acquire skills to better control their learning process, plan time and achieve learning goals.

The colour code method developed in this research contributes to overcoming the barrier of study activity and study materials by providing students with a tool that helps to create a more conscious learning process and at the same time provides the instructor with feedback on the learning process and conclusions.

The colour code method will allow to better understand and evaluate students' behaviour and interaction with learning resources and learning management system and to obtain course data and new artifacts from learning sessions.

The colour code method is intended for use in learning management systems as a plug-in or system supplement, i.e., as a component of learning organizations. The author believes that the method cannot be fully revealed and does not provide much added value in the scattered types of teaching, as it is intended for a fully designed teaching course with interconnected students and other traditional components of the learning management system.

Based on observations and experience, it was concluded that the colour code method would be useful in non-formal and informal (courses, seminars, etc.) education and distance learning, where the teacher meets his/her listeners for a short time or very rarely, making it difficult for group dynamics and individual needs evaluation.

Correlations were found between the use of the colour code method in virtual environment and exam results as well as the proportion of the use of screen button types, which indicates the relationship between these elements and opens new directions for future research.

1.7. Approbation of the research results

The development and results of the dissertation are reflected in the following presentations and publications:

1. Juškaite, L., Dzelzkalēja, L., Ipatovs, A., Kapenieks, A. Mobile Apps for teaching Physics: situation in Latvia. In: Proceedings of the 12th International Conference on Computer Supported Education, Czech Republic, Prague, 2–4 May, 2020. Prague: INSTICC, **2020**, pp. 438–444. ISBN 978-989758417-6. ISSN 2303-4521. Available from: doi:10.21533/pen.v7i1.361 (**SCOPUS**) (*project FuturICT 2.0*)
2. Dzelzkalēja, L. "User Beahviour Study in Virtual Learning Environment" Presentation for the Futur ICT project meeting in Brasov, Romania (October **2019**)
3. Dzelzkalēja, L., Ipatovs, A., Kapenieks, J. Color Codes: Comparative Conclusions. International Journal of Engineering & Technology, **2019**, No. 1, pp. 1–3. ISSN 2227-524X. (**SCOPUS**) (*project FuturICT 2.0*)
4. Dzelzkalēja, L. Colour Code Method Design Evaluation and Data Analysis. International Journal of Engineering and Technology, **2018**, 7, No. 2 Special Issue 28, pp. 106–109 https://doi.org/10.14419/ijet.v7i2.28.12889 (**SCOPUS**) (*project FuturICT 2.0*)
5. Dzelzkalēja, L., Timšāns, Ž. Colour Code Method Digitalization in edX E-learning Platform. Proceedings of the 10th International Conference on Computer Supported Education, Portugal, Funchal, Madeira, March 15–17, **2018**, pp. 165–172. ISBN 978-989-758-291-2. (**SCOPUS**) (projects *TELECI and FuturICT 2.0*) (**Nominated for the best doctoral student article award**)
6. Dzelzkalēja, L. "Color code method digitalization" Presentation for the Meeting of Futur ICT project participants in Tallinn, Estonia (August **2018**)
7. Dzelzkalēja, L. Contradictions in Higher Education. Journal of Teacher Education for Sustainability, **2018**, 20, No. 1, pp. 124–144. https://doi.org/10.2478/jtes-2018-0008 (**SCOPUS**) (*project TELECI*)
8. Aleksandrs Gorbunovs, Iveta Daugule, Sabine Grīnberga, Raj B. Adamaram Seshadri, Viktors Zagorskis, Laura Dzelzkaleja, Zanis Timsans. Atskaite: Tehnoloģiska mācību e-ekosistēma ar gadījuma rakstura mijiedarbībām (TELECI) (*Technological Learning E-ecosystem with Random Interactions*) Activity No. 4 (WP4) "E-pakalpojumu informācijas sistēmas konceptuālais dizains" (*Conceptual Design of Advanced e-Services Information Systems*). Report period: **08.03.2017 – 28.02.2018.**
9. Dzelzkalēja, L. Real Time Color Codes in a Classroom. Proceedings of 9th International Conference on Computer Supported Education, Portugal, Porto, April 21–23, **2017**, pp. 111–117 (**SCOPUS**) (**Best position paper award**)

10. Dzelzkalēja, L., Kapenieks, J. Real time colour codes in assessing e-learning process. Procedia – Social and Behavioural Sciences International Conference. Meaning in Translation: Illusion or Precision MTIP2016 Proceedings, May **2016**, Riga, Latvia, pp. 263–269. Doi: 10.1016/j.sbspro.2016.09.101 (**SCOPUS**)
11. Dzelzkalēja, L. Nākotnes augstskola: jautājumi (*Future university: questions*) Riga Technical University 57th International Scientific Conference, 17 October 2016.

The colour code method and the results obtained during this research were also a part of the EU ERANET FLAG ERA project "FuturICT 2.0 – Large scale experiments and simulations for the second generation of FuturICT". It was an international project (futurict2.eu, 2020) that started in February 2017 and ended in 2020. Within the framework of this project, the results of the colour code method have been presented in two project meetings.

The challenge of the project was to manage limited resources and support people and communities at risk by building strong information systems based on big data and artificial intelligence. Digitalisation in the future will mean a huge structural change in the global economy, leading to a significant level of unemployment unless economic systems are reformed. The aim of the project was therefore to bring together the best academic minds from different sectors, such as social and computer sciences. Through jointly supervised research projects, workshops, exchanges and meetings, the project brings the latest knowledge in the field (big data, artificial intelligence, agent-based simulations, Internet of Things, blockchain technology). The interdisciplinary approach will lay the theoretical and organizational foundations for the future digital economy through an approach:

Smart technology + smart citizens = the economy of the future

The method included in this work and its ideas are also incorporated in the Technological Learning e-Ecosystem with Random Interactions (TELECI) project. Riga Technical University Distance Learning Study Centre started the project implementation on March 1, 2017. The aim of the project was to develop an improved e-student profile model and to create a support system for multi-screen e-learning scenarios. The project ended on February 29, 2020.

1.8. The structure of the Doctoral Thesis

Laura Dzelzkalēja's Doctoral Thesis *New e-study environment analytics method "Colour code method" development and performance research* was developed at the Distance Studies Centre of the Faculty of E-study Technologies and Humanities of Riga Technical University within the doctoral program "E-learning Technologies and Management as a Transdisciplinary Research in Engineering".

Research description in the Thesis is presented in five chapters. In the end of the work main conclusions, directions of the possible future research and the theses of the research are given.

The first chapter provides an overview of the problems and trends of the learning process in connection with the need for new evaluation methods in the digital age and the related framework of educational legislation and planning documents, especially in connection with university education and e-studies in Latvia and in the world. This framework and the analysis of the current situation allow identifying weak points and future development trends, thus helping to formulate the need for a new methodology and its place in the educational sector.

The second chapter presents the characteristics of the E-study system, describes its structure and practical application in relation to the requirements of the digital and global era. An analysis of learning theories that have influenced and are influencing modern education systems, including e-pedagogy, has been carried out, as well as the structure of the e-study system, its components and influencing factors have been characterized. This chapter helps to bring out the basic principles of the knowledge-based construction of the colour code method (CCM), as well as to give it a general place in the range of educational theories.

The third chapter gives a review of analytics and feedback methods in the context of the learning process and e-studies. Attention is paid to the need and methodology of course evaluation through learning analytics, also mentioning the importance of data mining and big data. This chapter provides an opportunity to cover the broad issues of learning analytics, to identify problematic issues and to create responses to them in the form of the colour code method.

The fourth chapter gives a description of the concept and essence of the colour code method, analyses the methodology used for validation and the conclusions about it. At the end of the chapter, a general evaluation of the concept of the method is given. The types of data that can be obtained using this method are defined, it is justified why these data types are important and explained how the CCM approach differs from existing solutions and the types of data that can be obtained.

The fifth chapter describes the performance research and approbation of the colour code method in a real and virtual environment. Observations and results are described.

The SWOT analysis of the method is included in the conclusions. The main conclusions of the study are presented and the directions for further research are outlined.

The bibliography contains 290 literature sources. The Doctoral Thesis comprises 144 pages, 5 tables, and 24 figures.

2. OUTLINE OF INDIVIDUAL CHAPTERS

2.1. A review of the problems and trends of the learning process in connection with the need for new assessment methods in the digital age

This chapter describes the current and actual situation in educational legislation and in the field of education in general. The emphasis is on current situation in university education, as e-studies and their solutions are more widely used in adult education.

E-study technologies and management is the main science sub-sector of this Thesis (*in accordance with Cabinet of Ministers Regulation No. 49 of January 23, 2018 "Regulations on Latvian science sectors and sub-sectors"*). E-learning technologies and management is a sub-field of science that studies the architecture, engineering and technologies of e-learning solutions, knowledge creation and transfer processes in them, using information and communication technology to create real-time, everywhere, always available high-quality e-learning solutions at the individual, organizational and societal level. Taking into account this explanation, it becomes understandable why so much time and attention is devoted to the feasibility study in this chapter – in order to successfully transfer knowledge using technological solutions, it is very important to familiarize oneself with the existing situation, the problems and needs of the users, draw conclusions about the shortcomings and advantages of existing solutions, to identify the necessary characteristics of a new method (colour code method) for it to be functional, to benefit the user and to promote the creation and transfer of high-quality knowledge.

This chapter examines such concepts as the knowledge society, the nature and definitions of education and sustainable development, including the role and importance of education in ensuring sustainable development, in connection with the UN sustainable development goals. This chapter also introduces the main regional, European, and world-level planning documents, their goals and challenges in relation to education and society, in order to give an insight into the trends embedded in the legislation, which gives an opportunity to see what is also relevant in the formal environment and in which direction it is going.

Based on the results of numerous studies and personal evaluations and experiences, seven groups of challenges in the university education have been identified, which should be addressed to achieve the goals of the digital society and to meet its challenges. This section is quite extensive and comprehensively analyses the problems and realities of the modern higher education. The identification of various contradictions, problems and needs in the educational sector, especially in higher education, which is the main target audience of the discussed virtual solution of the colour code method, provides an opportunity to create a method that is more sustainable and suitable for the current situation. In the identified groups of challenges, the relationship between the mission of universities and the understanding of the concept of education in universities crystallized. The colour code method contributes to solving several challenges, as it helps increasing access to quality education through the possibility of improving the online learning process and the quality of a course.

The topics and legislative framework discussed in this chapter give an opportunity to get an idea of the current problems and research directions that have helped to shape the idea, framework and meaning of the colour code method.

The new colour code method and its performance research have been developed in accordance with the UNESCO values (UNESCO, 2005), paying a lot of attention to the feasibility study of the situation, helping to map the development of the field and to offer a new technological solution that is innovative, scalable and easy to transfer. Research and analysis of policy and planning documents, and mapping of the current situation with recommendations and forecasts for the future make this Thesis also politically significant for the development of a more sustainable education and society. Thus, this transdisciplinary Doctoral Thesis is also a contribution to the creation of a richer common information, methods and knowledge base using the opportunities provided by ICT to promote understanding-based decision-making in the education sector.

In the latest Latvian National Development Plan 2021–2027 (Latvijas Republika, 2020) the concept of the Knowledge Society has already been fully implemented as an integral and a significant part of a sustainable future. It has been said that in order to create a knowledge society, the memorization of facts in the educational process is to be replaced with the acquisition of competencies. It is intended to emphasize integrated learning technical subjects, improving students' knowledge in science, technology, engineering, and mathematics. This document also identifies that the achievements of the ICT industry and its widespread availability are a catalyst for change in the economy, public administration, and society in general. The knowledge society, thanks to the purposeful application of ICT solutions, transforms existing and creates new processes, business models, habits and culture in any economy and sphere of life. The knowledge society not only understands, adapts and makes full use of the new reality transformed through digitization, but is a motivated, skilled and intelligent driver of the extensive digital transformation of Latvia. The knowledge society creates ever-new knowledge and moves from a low-cost labour economy to a productivity based on the commercialization of knowledge. Productivity is enhanced by new knowledge and technologies, extensive education and innovation support, investment in human capital, and a supportive institute environment that enables the development of internationally competitive products and services with higher added value.

This transdisciplinary study has been influenced by such development trends as globalisation, technological development, increasing transparency and efficiency of decision-making, as well as rapidly changing labour market demand. At the same time, these trends have created the need for a new evaluation method and have enabled the development of the conceptual framework and technological solution of colour code method.

The Latvian business sector still lags behind the EU average (see Fig. 5) not only in terms of digital technology integration but also in terms of human capital. Almost half of the population still lacks basic digital skills, and the number of ICT professionals trained is lagging behind the growing demand in the labour market. The use of digital technologies also lags far behind in enterprises, as Latvian companies do not use the opportunities offered by e-commerce. The indicators of Latvian companies in the use of social media are significantly lower than the EU average (see Fig. 5).

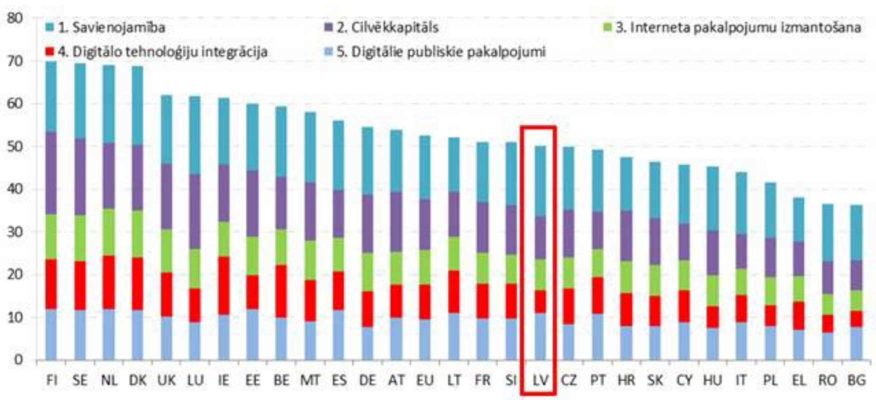

Fig. 5. Digital economy and society index (DESI) (Republic of Latvia, 2019) – ranking in 2019 (1 – Connectivity; 2 – human capital; 3 – usage of online services; 4 – integration of digital technologies; 5 – digital public services).

Despite numerous research papers, rapidly growing technical possibilities and rapid development of knowledge, higher education does not seem to be changing accordingly. It is therefore important to understand the underlying reasons for this situation to move towards sustainable higher education. The research identified and described seven main groups of contradictions in the higher education sector (Dzelzkaleja, 2018). The analysis focuses more on the situation in Latvia, where this Doctoral Thesis has been developed. The main focus of the contradiction study was on the university mission, as the analysis of the missions of different universities revealed a lack of clarity in the mission statement about the distinction between training and education, with a greater emphasis on training, which will be a challenge for the future in achieving the goals of sustainable education. The study of contradictions is quite extensive and provides much-needed insight into the problems and realities of modern higher education. Identifying the different contradictions, problems and needs in the education sector, especially in higher education, which is the primary target of the colour code method, provides an opportunity to make the method more sustainable and appropriate to the current situation.

It is important to look at the field of education broadly and holistically to see the connections that distinguish a good education from an excellent one. And it is important to take these findings into account and to incorporate them into concrete methodological and technological solutions that help to improve the quality of education, bearing in mind the components of excellence. During the development of the concept and technological solution of the colour code method in this transdisciplinary research work, the author has tried to take into account the ideas of education, in the purest sense of the term, and holism.

2.2. Characteristics, structure, and practical application of the e-study system in relation to the requirements of the digital and global era

This chapter describes approaches to the learning process, starting with a framework of learning theories that provide an opportunity to understand the basis of the education system and trends in this area. A new branch of educational science, e-pedagogy, is also mentioned. The e-study system is described and based on learning theories and e-pedagogy.

This chapter also discusses the structure and design of the e-study system and its elements and outlines the desired course design framework. This chapter talks about the concept of a system and its understanding in e-studies, giving its explanation in analogy with the ecological system. As the e-study system is a new and still developing concept, there is currently no comprehensive and unambiguously defined explanation in the literature, so the author's explanation with the help of ecological theories is especially important.

From a general system we move on to specific solutions in the implementation of e-studies, namely, the learning management system, or LMS, explaining its nature, elements, and types, as well as providing examples of LMS use.

In order to understand the target audience of the new colour code method and what educational systems and techniques this audience is currently familiar with and works with, this chapter of the Doctoral Thesis was created. Mapping was carried out, also in a historical context, allowing to create and justify the engineering and pedagogical solutions chosen later in the development of the colour code method.

The most recognizable are four theories of pedagogy: objectivism, cognitivism, behaviourism, and constructivism. More information about these theories can be found in the works of Schunk and Harasim (Schunk, 1997; Harasim, 2017). The colour code method developed in this transdisciplinary Doctoral Thesis is based directly on the constructivist approach, considering it the best-founded and most developed learning theory used in the modern distance learning process in research and methodology. It is not excluded that in a near future some other learning theories or approaches will gain sufficient methodological support and replace constructivism, but for now, they are still in the development stage.

Thanks to the development of online learning, a new research and action discipline, e-pedagogy, has also begun to develop. Traditionally, pedagogy is defined as the theory and practice of learning and education; as a scientific branch, it studies the unity of theory and practice. E-pedagogy as a branch of pedagogy is in its early stages of development (Baldiņš, 2016), and there is no common understanding of what it really is, how it differs and how it can be distinguished from ordinary pedagogy; however, there have been attempts to define it and create a structure and framework. E-pedagogy can generally be defined as “a learning design that contains the quality of education, values and effectiveness of teaching, learning and assessment activities provided by technology”.

Since e-studies is a relatively new branch of science and research, the definitions, and concepts in it are also in the stage of development, as a result of which there is often no common understanding of the meaning of different terms and concepts, as they are used with slightly different meanings in different sources. In this work, the concept of e-learning environment means a virtual environment in which learning materials are purposefully organized to achieve a certain learning goal (as opposed to searching for information on the Internet, where it is scattered among various sources), with which the learner interacts during the virtual learning process (user interface); the term learning management system (LMS) includes the learning environment, as well as the backend, as the data collection and analysis of user behaviour, and other technological systems that provide a comfortable user experience, such as error communication and the testing section, namely, the entire technical infrastructure; the concept of an e-study system contains both of the above-mentioned concepts, as well as users – learners, teaching staff, course instructors, their mutual interaction, the evolution of the course, etc. The boundaries of the system are determined in each case individually, depending on the need.

In terms of the e-learning ecosystem, separate subsystems of the global system can be distinguished, which can be identified and separated based on environmental differences and participant differences. However, unlike biological ecosystems, the e-learning ecosystem is quite homogeneous throughout the global system because the “abiotic environment” in this case is remarkably similar and the technological solutions that provide this environment are similar and in similar availability around the world. And yet, there is an opportunity to distinguish different subsystems of the global e-learning ecosystem, considering geographical regions, types of institutions, types of knowledge flows, types of content creation and transfer techniques, and types of behaviour and personal characteristics of participants.

In the case of an e-learning system, as the population could be considered a set of system participants using a certain type of infrastructure or located in a certain institution, which, thanks to the unifying element of the environment, can interact with each other, exchanging knowledge and influencing each other's opinions. Also, the concept of ecological succession, which tells about the transformation of the ecosystem over time, as both biotic and abiotic factors change mainly because of their interaction, can be applied to the e-study system. Predictable successions can be distinguished in the e-study ecosystem, starting from participants who tend to unknowingly and without clearly defined selection criteria choose or accept (because perhaps there is no choice) a not very high-quality courses with e-study elements, and ending with becoming an active knowledge creator – the participant feels so confident and comfortable in the new system that he is able to answer questions and provide information to other participants, perhaps even participating in the creation of educational content. The e-learning system can be compared to an organism in which individual parts cannot function effectively without the whole and the organism.

Over time, the complexity of e-learning systems has increased. The focus has shifted to the learner's interests and goals, trying to find tools that could collaborate with the learner. E-learning systems are becoming increasingly flexible and diverse. These systems are directly derived from learner actions and input to adapt to the learner. Adaptive information systems consider the learner's existing skills, prior knowledge, and interests. They adapt to the learner's needs and profile, creating a personalized learning path (Brusilovsky, 1998).

Therefore, the training courses and content are also adjusted – the system “reads” the learners, “thinks”, and decides for them about the delivery of the learning content that meets the needs of the learners and reduces the gaps in knowledge. The main challenges in the design of the e-study system are the demonstration of visual topics, static analysis before using a certain topic and creating a topic based on the topic, as well as the ability to collaborate to create new information about the topic (Gorbunovs, 2018).

The rise in the use of open source LMS is one of the trends in the field. This opens possibilities to develop different plugins and easily add them to the LMS. This principle was considered and used when developing the technological solution of the new colour code method.

Although the use of LMS in teaching is quite common in many institutions of higher education, teachers who use LMS in their courses often do not have the ability to monitor exactly what is happening in their online courses, how students behave in them, and how students approach learning from online materials or how they continue the process once they have started learning activities. LMS mostly does not contain deep data mining tools, while external data mining tools are too complex for teachers and their capabilities (Romero, 2008; 2010; 2016). Therefore, it is necessary to create new simple and sufficiently detailed analytics and data mining tools for teachers to observe student behaviour and interaction during online activities (Juhaňák, 2019). This Thesis is an attempt to move towards meeting this need by proposing a new method of real-time feedback analytics that would provide valuable information to the teaching staff in an effortless way and would not burden the student too much. The new method is meant to continuously reflect the learning process in real time.

2.3. Analytics and feedback methods in the learning process (e-study environment)

This chapter discusses the importance of course evaluation and why it is necessary and provides general guidelines on how to conduct an evaluation. Next, attention is focused on more specific methods of course evaluation, and by using analytical techniques, information on learning analytics, its nature and framework is provided. An important part of learning analytics, which helps to obtain valuable data for analysis in today's digital age, is big data processing and data mining methods, talking about the importance, possibilities and technological solutions and examples of data mining in the context of learning analytics. Also examples of evaluation methods and models, as well as examples of learning analytics methods and tools are mentioned.

Within the framework of this chapter, the developed colour code method is also evaluated by examining it through diverse types of analytical tools and evaluation types and indicating which types and approaches the colour code method applies to and contributes to. Since the colour code method is part of the range of course evaluation methods, it was important to get acquainted with the current situation and the disadvantages and advantages of the existing methods to take it into account during the development and testing of the new colour code method. The value of this chapter also lies in its ability to provide a structural framework for classifying, grouping, and subsuming the new colour code method among other methods.

Although the terms “assessment” and “evaluation” are sometimes used interchangeably, they should be distinguished. For example, in Garrison's (2011) (Garrison, 2011) study, the term “assessment” is used to refer to its role in evaluating the learning process and outcomes of students, and the term “evaluation” is used to refer to the activity of comparing learning objects (students), courses and programs against a set of performance or outcome criteria. Evaluation, rather than assessment, is therefore the term used for the purpose of this Thesis when referring to the quality of courses and learning facilities.

There is another concept that is very important in the context of this work. And that is monitoring. The main mission of monitoring is to collect accurate information about facts, opinions, reports, productivity, behaviour, error rate and complaints (dlsweb, 2022). Monitoring is a systematic and continuous collection and analysis of information about the progress of a development of an intervention (Gosling, 2003; Simister, 2017).

Traditionally, monitoring differs from evaluation with being conducted by internal rather than external personnel, being continuous rather than periodic, and focusing more on activities and productivity than on outcomes and impacts. In addition, monitoring is usually based on a system rather than being a one-time activity in a certain period of time (Simister, 2017). Today, these two approaches are beginning to converge. Three approaches can be identified in the world of monitoring and evaluation: results-oriented, constructivist and reflexive (Mierlo, 2011). The colour code method corresponds to the constructivist approach.

A new line of research has opened in relation to the analysis of student behaviour in LMS with the aim of finding specific behaviour patterns of students to help improve the learning process. Current e-learning platforms allow recording of student activity, thus enabling the possibility to study the events that are generated in the process of using LMS tools (Cantabell, 2019). The colour code method developed in this Thesis can be placed in the User Behaviour Analytics (UBA) according to the classification. That was emphasized when developing and testing the colour code method. UBA uses big data and machine learning algorithms to detect deviations from the norm in near real time. UBA technologies analyse historical data records, including network and authentication records collected and stored in record management and security information and event management systems, to identify flow-specific behaviour determined by user behaviour, both normal and malicious.

UBA collects different types of data (Bacon, 2017):

- user roles and names: access, accounts, permissions;
- user activity;
- geographical location;
- security alarms.

Privacy for students is relevant and it should be considered in the use of study courses and the corresponding tools, including data analysis (Hölbl, 2011). Taking this into account, this work also tries to address these concerns about the use of data. Therefore, the data from colour codes were stored in a database only for a certain period of time and then automatically deleted, and for the purposes of data processing, it was mostly encrypted using student IDs instead of their first and last names. Nowhere in the research publications personal information of students is used, only group data.

Data analysis in the field of education is an important and promising way to gain knowledge about the student learning process, create successful course materials, student satisfaction, and knowledge creation. Today, with a growing focus on ICT tools and solutions and their use in education, the amount of available educational data is growing tremendously, and the opportunity to use data to improve the quality of management decisions is emerging. This is especially true for e-learning and blended learning. Quality requirements in the higher education institutions make it necessary to offer services that meet the needs of students, academic staff and other participants of the education system as much as possible. Data mining can help students and higher education institutions make more effective decisions about how to improve the quality of instruction and services (Al-Twijri, 2015).

Current LMS data analysis approaches must evolve and adapt to the new challenges that higher education institutions are facing. The recommended solution is to use big data in e-learning as a new discipline. Big data offers the opportunity to achieve a higher level of LMS usage, gaining increased benefits from the student experience and making decisions based on strategic answers obtained from the results of big data. Thus, it is possible to transform complex, unstructured data into usable information, thereby promoting the identification and transformation of useful data into valuable information for higher education institutions (Ducange, 2016; Cantabell, 2019; Daniel, 2015).

Educational data mining (EDM) is the application of data mining techniques to educational data. The purpose of EDM is to analyse this data and solve educational research problems. EDM uses emerging new methods to study educational data and better understand student learning environments using data mining techniques. In the EDM process, the output (raw) data from the educational system is transformed into useful information that could potentially have a major impact on educational research and practice. Predicting and analysing student performance are important cornerstones of an educational environment (Kaur, 2015). The main field of application of EDM predictions is the prediction of student educational outcomes (Asif, 2017). Analysing student behaviour in online learning and finding interaction characteristics in LMS are important topics for educational data mining (EDM) and study analytics research groups (Juhaňák, 2019).

Process mining, which is another type of data mining, was mentioned in the first Handbook of Educational Data Mining (Romero, 2010) as one of the EDM techniques. Process mining in education, however, attracts increasing attention of researchers. Process mining and its potential use in education, among others, are discussed in Reimann's works (Reimann, 2013, 2014) that have devoted their articles to the perspective of methodological challenges of process mining in data-intensive research methods (Juhaňák, 2019). The colour code method is an example of a process mining approach in which real-time learning process data is captured and analysed.

Taking into account the quality aspects and criteria related to the colour code method, it can be concluded that this method refers to 1) the personal aspect, allowing the student to look into and better understand their individual learning process; 2) course aspect, allowing to better evaluate the pros and cons of the course and to react and make changes in the course in time, according to the student feedback obtained with the help of the colour code method; 3) and the system aspect, considering that the colour code method is being integrated into an existing system, an existing Learning Management System (LMS) and its technical performance, visual appearance, button response and user interface must be integrated into the existing system, which, of course, means that the effectiveness of the colour code method could also be affected depending on the LMS chosen. It would be important to take this into account when choosing the LMS in which to test the method, as well as in the future – it means for system builders that the colour code method should be adapted to the specific LMS technically as well. Complementing this in relation to the quality criteria mentioned by Chen, Barker and Rabai (Chen, 2009; Barker, 2007; Rabai, 2011), the colour code method covers the aspect of infrastructure quality (due to the already mentioned choice of LMS and the need for system integration), teaching methods (to be evaluated, whether the methods and objectives of the training course are in line with the possibilities provided by the colour code method (CCM) and whether it will make sense), evaluation and feedback (the ways in which the course creators already receive data about the course, as well as the types of data – maybe introducing CCM means that some of the existing methods can be discarded or modified) and human resources, teachers (at the early stage of implementation, the instructor must familiarize himself with the nature and meaning of the method, learn to use it; as well as the technical staff of the course must be able to add the method to the course system, connect it to the database and provide technical support in data processing and analysis. Along with the creation of a professional user interface for the CCM, this need for technical personnel will decrease).

There are several online tools available for obtaining feedback for e-learning. Some of them are listed in *Litmos Author's review* (Litmosauthor, 2016), which offers the possibility to create reviews through collaboration; *Review my learning* (Reviewmylearning, 2016), created to get feedback in the form of comments visible to other users; *Trivantis* (Trivantis, 2016), which provides the ability to write down comments that are sent to course creators who can then respond accordingly and make changes to the course, while the user can then rate the teacher's response to the comment as "good" or "not good". However, these tools do not provide the possibility of continuous observation of the learning process and rely on the willingness of students to be involved in defining and reporting the identified problems. These types of tools are likely to add cognitive load, as they require the learner to jump to another window/environment and then back again, creating a disruption in the learning process.

Among the widely used methods of getting feedback, a nice example is voting systems that express the likes and dislikes with a help of on-screen buttons, which are a common way to rate photos, videos, texts, and more in social media platforms. For example, the *Coursera* learning platform offers the opportunity to rate each learning item with a "like" (thumbs up pictogram) and a "dislike" (thumbs down pictogram), as well as to report a problem (flag pictogram) visually presented as a dark outline without filling. In such voting systems, students have to decide whether or not they like the learning item, and this decision-making process can be associated with additional cognitive strain, and only two choices are possible without choices between these extremes. In this respect, CCM has great advantages, as it does not require evaluation but only reporting on the actual state of the learning process. *Moodle* learning platforms provide a block of code that allows faculty and students to track progress through a colourful *Progress Bar* tool that shows how much course material has already been viewed or completed and identifies students at risk of not completing the course (Attwell, 2006).

Identifying and modelling different types of student behaviour in learning environments is one of the basic research areas in educational data mining EDM research. Peña-Ayala (Peña-Ayala, 2014) states in her review that modelling student behaviour is included in 21 % of EDM studies and general student modelling is included in 82 % of studies. Current research models different types of behaviour, such as guessing behaviour, sleeping behaviour, playing the system, seeking help behaviour, inadequate or too little use of help, willingness to cooperate, and so on (Baker, 2014; Peña-Ayala, 2014). In terms of methodology, clustering and classification are the methods most commonly used to study student behaviour (Juhaňák, 2019; Bousbia, 2014; Dutt, 2017; Jovanović, 2017).

2.4. Colour code method (CCM) for solving the challenges of the digital age

This chapter discusses in more detail the concept and essence of the colour code method as well as analyses the methodology used for validation and the conclusions drawn in this process and provides a general evaluation of the method. The types of data that can be obtained using this method are described in more detail, it is justified why these data types are important and how they differ from the existing solutions and the types of data to be obtained.

To validate the operation of the method and to obtain information and data on whether and how the method works, it was decided to validate the system in several iterations, starting with the simplest and least resource-intensive prototype, in order to get feedback from users as soon as possible. This approach was chosen based on the *Lean Startup* product development methodology for rapid and efficient prototype validation and knowledge acquisition from the user, thus gaining the opportunity to continuously make improvements and assess their importance in the user's eyes. As the first validation method for the colour code method, a test at a school environment was chosen. After obtaining data from field experiments, conclusions were drawn and based on them, an ideological framework for the digital version of the colour code tool was developed.

Many online data analysis tools are available for course evaluation, usually with user interface features (e.g., student assumptions and perception surveys), and facilities are available to record and analyse user behaviour by determining login duration and frequency, addresses visited, user profile, and so on. But available assessment and evaluation methodologies do not provide enough information on the causes of user behaviour, many of these tools have a sufficiently sophisticated design and are ingeniously designed but lack guidelines for interpretation and analysis (Attwell, 2006).

The new colour code method (CCM) is proposed for the continuous data collection to improve the learning process and teaching in both the classroom and e-environment. The method will be available to a wide range of students, from pre-school to adults, as the method is easy to understand and use and does not require specific skills or knowledge. The success and effectiveness of the method largely depends on the teacher (and/or the person analysing the data obtained from the method).

Figure 1 shows a schematic image of the proposed cardboard tool: each of the three prism faces represents one of the three codes. The students show the corresponding colour to the teacher representing the learning process flow at every given moment. The colour codes are defined as follows:

- "Red" is used to show that the task is not clear, or difficulties have appeared during the process and an assistance is needed (in the form of teacher or some extra learning materials);
- "Yellow" is used whenever the task is being done and everything is clear – no need for assistance;
- "Green" is used when the task is done, or a break is taken.

Colours are chosen based on traffic lights because almost anyone recognizes these colours, which allows to intuitively guess the meaning of colour – red as something that slows down or stops, green as something that allows you to go to the next place and is connected with pleasant associations and yellow as something that lies between the two above.

A colour-code tool (see Fig. 6) is offered to use in a real classroom, in this case – cardboard. This tool is in the shape of a prism with the triangular faces empty, while the other three quadrangular faces are each a different colour and represent one of the colour codes. In a virtual learning environment, the codes must be visible on the screen for the student to click on the relevant colour conveniently and at any point in the learning process.

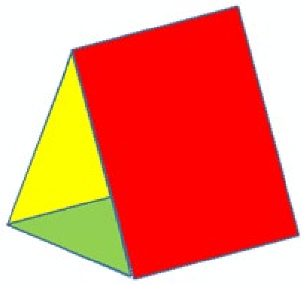

Fig. 6. Example of a cardboard colour code tool.

Based on these considerations, which are also presented in the author's publications (Dzelzkalēja, 2016; 2017; 2018) a model can be created that supports the learner at each stage of the course (see Fig. 7). When there are no problems, the learner finishes the learning item and can continue learning. At each stage of the course when the learner has difficulties (red screen button), he/she receives learning support and can continue learning.

The web and related network technologies offer great solutions for teaching, publishing and sharing learning content and information. Usually, special software is used for this purpose – the Learning Management System (LMS) already mentioned in the previous chapters. Nowadays, various LMSs are used as a support tool in e-studies. A large number of LMSs, both commercial and open, are widely used for education and training purposes. Most universities combine forms of learning using one of the commercial or open LMS (Balogh, 2013).

The large open online courses at MOOC have been one of the most significant technological innovations in higher education over the last decade. During this transdisciplinary research, the next step was taken to introduce the method in the digital environment – in the Learning Management System (LMS). For the implementation of CCM, the edX learning platform, which is a MOOC platform, was chosen and as an open online platform is suitable for the development of the new colour tool and code block as well as for sharing this code with other stakeholders. More about the reasons for choosing the edX platform and the analysis of edX in comparison with Moodle can be found in the study of V. Zagorskis and A. Kapenieks (Zagorskis, 2018), which states that the edX platform attracts young people more than Moodle.

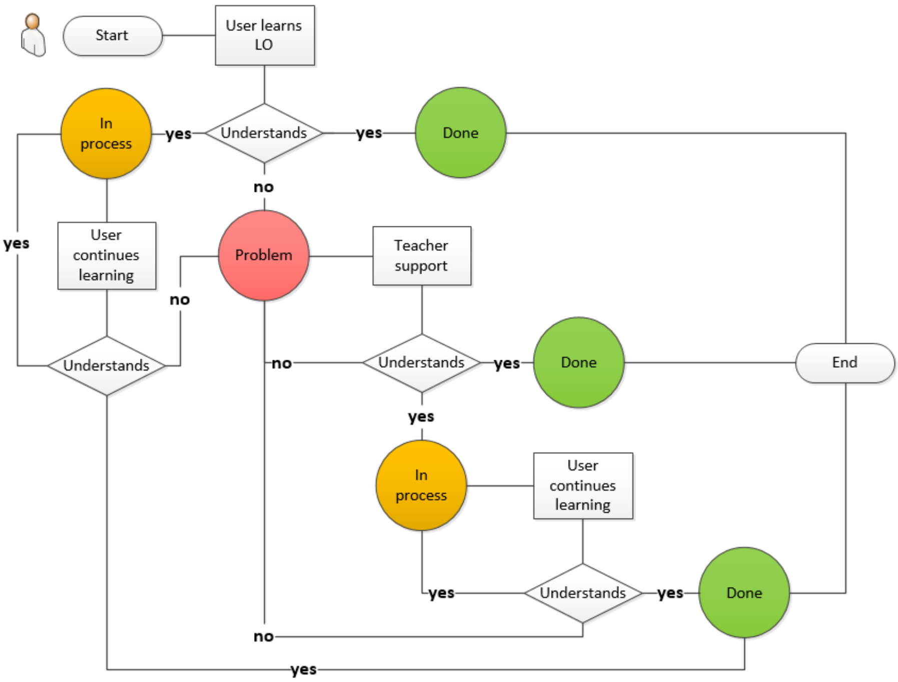

Fig. 7. Simplified algorithmic solution using the colour code method (Gorbunovs, 2018).

Next, an overview of the edX learning platform and e-learning course evaluation methods and strategies, as well as a description of the new method and the implementation process is given. The colour code method works in a similar way to voting systems, allowing the user to report on their status in the learning process by pressing the appropriate button, and valuable data is collected in the database with each press.

The edX platform was released in the spring of 2012 by the Massachusetts Institute of Technology (MIT) and Harvard University with the support of Google. At the end of 2020, it already had 35 million users (edX, 2021). By comparison, Moodle, the largest LMS, has about 253 million users (Moodle, 2021), and the Coursera training platform, which has the largest number of training courses among MOOC providers, has 70 million registered users (Coursera, 2020). So, edX enters the market as a powerful player. edX offers a university-level course on topics mostly related to science. In 2015, Riga Technical University (Distance Studies Centre) also created its first course on the edX learning platform.

The strengths of edX, according to Fenton (Fenton, 2015), are the large catalogue of online courses in higher education; the opportunity to join either self-paced or timed courses lasting between four and 12 weeks; students can join the courses as free listeners or receive Honor Certificates both free of charge and for a fee; video text transcripts or transcripts are available. The open platform (Open edX) allows course developers and programmers to build and share assessment modules and make changes to the look of the learning platform and add additional functionality with xBlocks, which are components of the edX architecture and connect different sources (Open edX, 2017). edX encourages developers to contribute to the open edX initiative, and the combined efforts of the edX platform have increased the number of new features and functions.

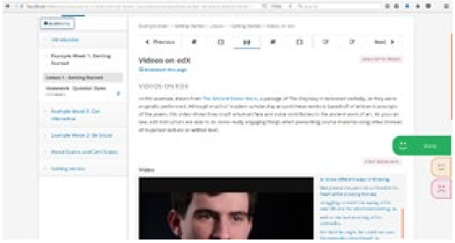

Fig. 8. Screenshot of edX learning platform with CCM buttons.

The set of the colour code buttons was placed in a fixed position on the screen (Fig. 8) and was displayed continuously in the lower right corner, regardless of which learning item is open. When the corresponding button was pressed, information about it was registered and sent to the database where all the data was collected.

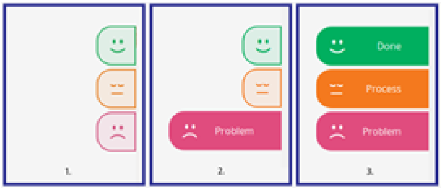

Fig. 9. Appearance of virtual buttons.

The visual interactive button design is based on key user interaction and experience design guidelines, so appropriate colours and playful animations have been introduced to encourage more frequent interaction with the button tool (Fig. 9). The on-screen buttons are equipped with spam protection, as well as initially with a message to notify the user that the on-screen button press has been successfully registered. It was then concluded that the message pop-up was becoming quite cumbersome and distracting quite quickly, therefore this response was discarded.

As mentioned above, data collection using this method takes place in addition to edX's built-in data collection system. The pressed screen button indicates the process at the current time (completed, process or problem (Fig. 9)). With every press several parameters are captured: 1) the colour of the button pressed; 2) precise time stamp (hh:mm:ss); 3) name of the user (id); 4) course title; 5) course identification number; 6) course section name that was viewed; 7) page URL.

Scripting languages such as Javascript, HTML and CSS, and programming languages such as Python have been used to create the colour button plug-in. A prototype has now been created. An industrial end product can be created as edX xBlock which would be available to anyone as an open-source block. The current setup requires an injection of jQuery code into the edX document object model (DOM), which then renders the screen buttons and communicates with the database. The Python programming language was used to set up the database server.

edX has a built-in data analysis tool, but it is not complete, therefore it was supplemented with the colour code method for the reasons mentioned above. A study by Schumacher and Ifenthaler (Schumacher, 2018) shows that one of the most desirable things a student expects from learning analytics is the generation of a personalized analysis of learning activities. And one of the goals of the colour code method is just that.

As shown in Fig. 10, two separate databases have been created to collect data on student behaviour from the learning platform. The databases are separate so as not to interfere with the basic settings of edX. Both edX and colour buttons are adapted to a MySQL database so that all data can be exported to various formats and analysed with the chosen data analysis tool.

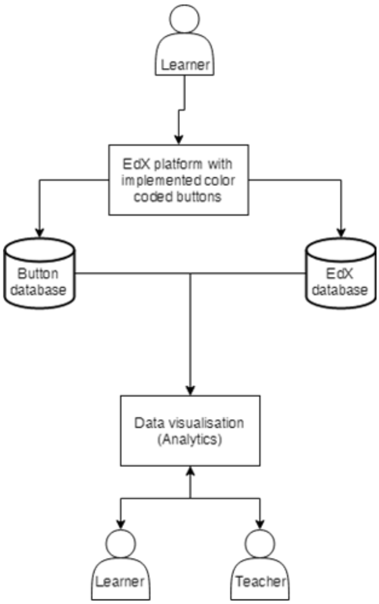

Fig. 10. System diagram. (Dzelzkalēja, 2018)

The raw data was initially converted to be fed in *MS Excel* and *IBM SPSS Modeler* using Notepad ++, which replaced the incorrectly converted symbols with easier-to-understand ones, and each record was placed on its own line using the “new line” function in Notepad ++, because the records raw data were recorded in one long row. A data file of students registered in the course was obtained from the Riga Technical University internal system, as well as data on examination results, which formed two more data sets.

When the data was prepared for input into the data processing system*, IBM SPSS Modeler* software was used for the initial processing. The data files processed in it –student register, marks and CCM module entries – were subjected to various data manipulations to find possible relationships between members, as well as to obtain quantitative information about the dimensions of certain data sets according to predefined parameters. For example, the gender distribution in the data set, the distribution of exam marks, as well as the “caught” invalid data points, such as students who appear as registered in the course but no longer appear in the exam mark register. *MS Excel* was used for data processing and comparison as a tool for validation of results and for data visualization. Using two different tools provides more reliable results and less chance of error. Some data, such as the use of colour buttons by training type, were processed in *MS Excel* because the author was not familiar with *IBM SPSS Modeler* at the beginning and some data seemed more convenient to process in *MS Excel*, as it is easier to review and manipulate the entered data set. *SPSS Modeler*, on the other hand, seemed more useful for comparing different data sets and obtaining correlations.

2.5. Performance research and approbation of the colour code method (CCM)

This concluding chapter describes the results and conclusions of the colour code method approbation on-site and in a digital environment. This is a continuation of Chapter 4, which described the methodological approach to method validation. This section further describes the specific experimental sample set, experimental process, results, and conclusions.

The main on-site approbation of the method took place in primary school in two classes, while the virtual colour codes were tested sequentially in two different university courses. From the beginning, the results were summarized and conclusions were drawn about the operation of the first virtual solution, improvements were made and then a test was performed in the second group. Virtual experiments were performed using the edX learning management system.

The results present observations in the classroom – the use of codes, user reactions and teacher comments. The results from the code approbation in the virtual environment are divided into three groups – the results on the use of screen buttons, the results from the student survey, and the comparison of the use of screen buttons with the results of the student exam.

The analysis of the results confirms the hypothesis that the utilisation of the colour codes and analysis of the obtained real-time data improve the possibility to evaluate learning process and to perfect the content and teaching methods.

Table 2

Main Characteristics and Observations of the On-site Experiment

Characteristics	1st grade	4th grade
Number of students in the class	23	24
Type of the class	Individual written test	Individual written test
Biggest number of "reds" simultaneously	8	6
Minutes after the beginning of the lesson, when most "reds" were observed (1–40 min)	15–20 min and 30–32 min	25–28 min
Biggest number of "greens" simultaneously	6	7
Minutes after the beginning of the lesson, when most "greens" were observed (1–40 min)	35–37 min	30–36 min
Number of pupils that raised hand at least once	6	2
Number of raised hands	12	2

The main on-site experiment took place with the first grade (7–8 years old children) and fourth grade (10–11 years old children) students. Since the possible target group is very wide – from children to adults, and from the classroom to the e-learning environment, it was decided to narrow down the target group at the beginning and to try and test the method first in the primary school. This target group was chosen to find out if the CCM is formulated in a simple and understandable way that even young children can use. It was assumed that if small children understand the essence of the method and can start using it in the intended way shortly after getting acquainted to it, then the method is also suitable for use at other age groups (adolescents, adults). The experiment was conducted in November and December 2016 in Cēsis, Latvia.

When comparing the results of the first and fourth grade students, differences can be observed (Table 2). The first grade students changed the colour code more often because they needed the help of a teacher more often. The fourth graders used the colour code to get the teacher's attention and barely raised their hands, but some of the first graders forgot to use the code tool and raised their hand for one of two reasons: 1) because of the lack of patience, because the teacher didn't react as fast as they wanted, being worried that the teacher had not noticed the colour at all, 2) the student had forgotten about the code tool at all and, when he remembered, quickly lowered his hand and showed the chosen colour to the teacher. Most fourth graders did not need the help of the teacher, so the red code was elatively little used, and most code tool activity was observed in the third part of the lesson, when students started completing tasks and showing the green code. In the first grade, on the other hand, red was actively used throughout the lesson. Some students in the first grade did not need help throughout the lesson, but those were few, and they were also the ones who completed the work the fastest (showing the green code). In general, it was observed that younger children had more questions and confusion about tasks and the help of teacher was needed more, which is understandable, and younger children had more issues when using colour codes.

Colour codes were also put to the test in an elementary school computer lesson by placing the colour codes next to the computers to test whether and to what extent the computer screens interfered with the teacher seeing the colour codes and the children using them. It was concluded that when students use computers in the classroom, it is more difficult for the teacher to see the colour codes on the desks because the screens blocked the view. In this case it is better to use virtual codes on the screen This is not a problem for a small class. The tactile colour code was also tested in high school classrooms: it was observed that the students had low motivation to learn during the lessons and the students were reluctant to keep up with the work. This also probably explains why the colour codes were used more as a toy than for their intended purpose. The last phase of the face-to-face observations was in a teacher training. Teachers were observed to use colour codes only when reminded or prompted by the lecturer. Observations suggest that as a person grows up, the need to be accepted by peers and colleagues increases, so the fear of looking foolish or standing out from the crowd tends to be a barrier to innovations and their use.

All lesson leaders (teachers) were included in expert interviews. In total, three face-to-face lesson teachers were interviewed – experts who have worked for several years both as teaching staff at a school and also in research at a university. Expert interviews were conducted orally, listening to experts' opinions on the ease of implementation and use of the method, observations on the students' interest and attitude towards the use of the method, opinions on the usefulness and possibilities of using the method, comments on the weaknesses and disadvantages of the method, as well as suggestions for improvements and possibilities for future use.

On-site observations and analysis of the results confirm the hypothesis that the utilisation of the Colour codes and analysis of the obtained real-time data improve the possibility to evaluate learning process and to perfect the content and teaching methods, as it gives the teacher the opportunity to immediately objectively see what is happening in the classroom and react, without the need to mention or use the professional intuition.

In the next stage of the research, the CCM plugin for the digital environment learning management system (LMS) was developed. The edX learning platform was chosen (more on this in Chapter 4). The button module for the edX platform was created in the summer of 2017. The edX platform was chosen because of its open source, the ability to add modules, and its growing popularity and prestige.

Students of Riga Technical University were selected as a sample for the virtual environment experiments that took part in the 2017/18 and 2018/19 academic years. The first group (2017/18) were 1st year bachelor students, the learning subject was Entrepreneurship, the number of registered students was 104, but the number of (valid) students considered in the study was 94. Of these, 66 (70 %) were men and 28 (30 %) were women. The second group (2018/19) was RTU 1st year masters, the learning subject was Natural Science Modelling (a course that was partly developed and implemented by the author of this dissertation). There were 22 people registered for the course, five of them were considered to have dropped out and were not taken into account in the further data analysis. The remaining 17 students were female, so it was not possible to perform a gender-specific comparative analysis.

The learning form for the virtual environment experiment was blended, i.e., part of the course material had to be learned through the edX platform but face-to-face classes also took place. The online learning took place on the edX learning platform that students encountered for the first time. At the beginning of the course, students were introduced to the edX learning platform and the colour code method and were asked to use colour buttons on a voluntary basis to aid the research. The students involved in this experiment did not have access to a personalized visualization of their activity data, and the aim of the experiment was to check the overall operation of the system, debug it and observe data entry into the database, as well as to receive student feedback afterwards (Dzelzkalēja, 2018).

Oral interviews were conducted with two teachers and using virtual environment who were asked to give their expert opinions on the ease of implementation and use of the method, observations on learners' interest and attitude towards the method, views on the usefulness and possibilities of the method, comments on weaknesses and shortcomings, as well as recommendations for improvements and future uses.

The implementation of the virtual technological solution of the colour code method and the result of the performance research also confirms the hypothesis that the utilisation of the colour codes and analysis of the obtained real-time data improve the possibility to evaluate learning process and to perfect the content and teaching methods. The data clearly shows the correlation between exam results and the use of the tool and provides information about the learning objects in which students have more problems or need help.

3. CONCLUSIONS

3.1. Method SWOT analysis

SWOT analysis was performed for the colour code method, which briefly mentions the strengths and weaknesses, opportunities and possible threats or risks of the method. This analysis can be seen in Table 3.

Table 3

SWOT Analysis of the Colour Code Method

Strengths	**Weaknesses**
• Can be used both in person and in a virtual environment. • The method is quick to understand and easy to use for the user, it does not require much additional investment. • The method can be used by people of different ages, genders, educational levels, and other parameter users. • The method delivers real-time data. • The method does not require decision-making by the user; therefore, it does not create additional cognitive load. • The method helps the user to become more aware of his learning process. • The method allows the teacher/course creator to quickly identify problematic parts of the e-course content and students. • The method helps to evaluate the quality of the e-course.	• The implementation of the method and the usefulness of its use in person completely depends on the teaching staff. • In order for the student to be motivated to use the method in the virtual environment, the student must see the point of doing it – most likely, without a good user interface of the method and data visualization, as well as a quick reaction of the teaching staff to the problem situations, the method will not be used. • A technical employee is needed who will at least initially create and/or adapt the method plugin to the required learning environment and course, as well as take care of the connection of the database data analysis tools.
Opportunities	**Threats**
• To integrate the colour code method into the existing e-study infrastructure. • To create an attractive user interface that will provide students with the opportunity to receive feedback on the flow of their learning process and make their learning process more efficient. • To reduce “drop out” cases in e-courses, allowing early identification of students' difficulties. • To reveal in time elements of the curriculum that are difficult for students to understand and change the approach in teaching the curriculum and/or provide additional information/more time for learning the element. • To commercialize the method and create a profitable business.	• Users will misuse the method by providing false data about their learning process (a greater risk in the virtual environment than in person). • The user will not use the method – great importance for the teaching staff in person and reminders in the virtual environment. • The method will be difficult to adapt or adjust with learning management systems that are not based on open-source code. • E-course creators and managers will not have the resources to implement the method and maintain it. • Legislation and such changes in various countries and regions related to the registration, storage and protection of user data. • Using the method will disrupt the learning process.

3.2. Conclusions from the literature review

1. Although factual assessments show the level of students' knowledge, they do not reflect the full spectrum of the learning process, the quality of learning materials and their perceptibility, as well as students' learning habits. Consequently, the need for personalised knowledge transfer and the need for analytics of the learning process appears that could allow providing real-time information about the students' individual learning process and its nuances. This is especially important in the online learning process when interaction between students and teaching staff are limited. This aspect gave an inspiration and desire to create the new methodology described in this Doctoral Thesis.

2. The new colour code method and its performance research are in line with the UNESCO values, paying a lot of attention to the feasibility study of the situation, helping to map the development of the field, and offering a new technological solution that is innovative, scalable, and easy to transfer. The research and analysis of the policy and planning documents and the mapping of the current situation with recommendations and forecasts for the future make this doctoral research also politically significant and potentially significant for a more sustainable development of education and society. Thus, this transdisciplinary Doctoral Thesis is also a contribution to the creation of a richer common information, methods and knowledge base using the opportunities provided by ICT to promote understanding-based decision-making in the education sector.

3. The international planning documents and the vision for the future mark the direction towards a knowledge society in its highest sense – opportunities for education and learning basic skills for all, regardless of gender, age or social affiliation, and providing the opportunity for lifelong learning. That is why the technological method developed in this Thesis is universal – applicable to all age groups, from children to adults, learners of different educational levels, learners of different ages, cultural backgrounds, nationalities and financial opportunities.

4. Blended learning already has a big role, and it is predicted that it will play an even bigger role, the method should be usable both in person and in digital format.

5. It is concluded that the method should be equally well understood and usable by both genders. Observations and results showed only slight differences in the use of the method between the genders, so it can be concluded that the method is equally suitable for both genders (students' gender fluidity and personal awareness of their gender were not specifically identified).

6. The colour code method developed in this research helps the student to get acquainted with his own learning, allowing him to more consciously observe his learning process in the background of learning without additional effort to accumulate experience about theirhis learning process, from which knowledge and understanding of the dynamics of the learning process are later formed. This approach would be most closely related to the constructionist learning theory, as it emphasizes self-reflection, a better understanding of one's individual experience through observation and self-knowledge, thus allowing a more conscious and effective approach to the process of acquiring knowledge.

7. There are several barriers to the introduction of online education. The colour code method developed in this Thesis helps to contribute to overcoming the barrier of study activities and study materials, providing students with a tool that helps create a more conscious learning

process, and at the same time provides the instructor with feedback on the learning process and allows conclusions to be drawn about the quality of learning materials.

8. Individual subsystems of the global system can be distinguished, which can be identified and separated based on environmental differences and actor differences. However, unlike biological ecosystems, the e-learning ecosystem is quite homogeneous throughout the global system because the "abiotic environment" in this case is very similar and the technological solutions that provide this environment are similar and in similar availability around the world. And yet, there is an opportunity to distinguish different subsystems of the global e-learning ecosystem, considering geographical regions, types of institutions, types of knowledge flows, types of content creation and transfer techniques, and types of behaviour and personal characteristics of participants.

9. The following predictable successions can be distinguished in the e-studies ecosystem: 1) participants unknowingly and without clearly defined selection criteria choose or encounter (because perhaps there is no choice) learning materials with e-studies elements; 2) participants start using e-study environments and LMS and develop personal criteria and quality standards; 3) participants begin to look for learning opportunities more actively to learn more effectively on the web, starting to independently learn the material of their interest, independent of formal educational institutions, beginning to look for answers and solutions to problems on the web and discussion forums (e.g., with the help of experts who are difficult to meet in person), and are able to critically evaluate the quality and reliability of information and knowledge channels; 4) participants become active creators of knowledge – the participants feel so confident and comfortable in the new system that they are able to answer questions and provide information to other participants, perhaps even participating in the creation of learning objects with educational content.

10. LMS mainly does not contain in-depth data mining tools, while external data mining tools are too complex for teachers and extend beyond what a teacher would need. Therefore, it is necessary to create new simple and sufficiently detailed analytics and data mining tools for teachers to observe student behaviour and interaction during online activities (Juhaňák, 2019). This Thesis is an attempt to move towards meeting this need by offering a new method of real-time feedback analytics that would provide valuable information to the teaching staff in a straightforward way and would not burden the student too much.

11. The colour code method developed in this Thesis will potentially contribute to the evaluation of the didactic quality of the courses thanks to the possibility for the instructor to quickly and conveniently see the learning objects or topics in which students note the most problems during the learning process; those parts of the course where problems occur the least; and those parts of the course where students spend the longest time studying. The method provides the opportunity to adjust and more objectively assess the time needed for studying and responds to problems in a timely manner and faster and easier identifies the course learning objects that require changes.

12. The colour code method developed in this Thesis differs from most analytical tools and approaches in that its direct target audience is also the student or user, but the teacher will also be able to receive feedback.

13. The colour code method developed in this Thesis indirectly motivates thanks to the opportunity for students to become more aware of their learning process, and as a result,

students acquire skills to better control their learning process, plan time and achieve learning goals.

14. Considering the classification created by Krumm and his colleagues, the colour code method can be classified as an analytical methodology that directly provides information to students.

15. The colour code method can be classified as belonging to the User Behaviour Analytics classification. This fact was emphasized when developing and testing the colour code method. The Colour code method is an example of a process mining approach in which real-time learning process data is captured and analysed.

16. The colour code method (CCM) developed in this Doctoral Thesis will allow to better understand and evaluate student behaviour and interaction with learning resources and LMS, as well as to obtain course data and new artifacts from learning sessions, which, according to the list given in the work of Dinevski and colleagues, are among the elements that should be taken into account when evaluating a training course.

17. Considering the system and quality aspects and criteria related to the colour code method, it can be concluded that this method refers to the personal aspect, allowing the student to look into and better understand his individual learning process; aspect of the course, allowing to better evaluate the pros and cons of the course and to react and make changes in the course in time according to the student feedback obtained with the help of the Colour code method; and the system aspect, considering that the colour code method is being integrated into an existing system, an existing Learning Management System (LMS) and its technical performance, visual appearance, button response and user interface must be integrated into the existing system, which of course means that the effectiveness of the colour code method could also be affected depending on the LMS chosen. It would be important to take this into account when choosing the LMS in which to test the method, as well as in the future – for system builders it means that the colour code method should be adapted to the specific LMS technically as well. In addition to this, in relation to the quality criteria mentioned by Chen, Barker, and Rabai, the colour code method is subject to the aspect of infrastructure quality (due to the already mentioned LMS choice and the need for system integration), teaching methods (it is necessary to evaluate whether the methods and objectives of the training course are consistent with the colour code method (CCM) and whether it will make sense), assessment and feedback (the ways in which the course creators already receive data about the course, as well as the types of data – perhaps, when implementing the colour code method, some of the existing methods can be discarded or modified), and human resources, teachers (at the early stage of implementation, the instructor must familiarize themselves with the nature and meaning of the method, learn to use it; as well as the course technical staff must be able to add the method to the course system, connect it to the database and provide technical support in data processing and analysis. Along with a creation of a professional user interface for the CCM, the need for technical personnel will decrease).

18. In the context of this research, there is no concern about the issue of students' "materialization", that is, treating them as objects rather than subjects, because the experimental groups were partly face-to-face, and the students' involvement in the use of the code system was completely voluntary, based on the basic principles of design thinking.

19. When developing the method, the growing data protection concerns should also be considered, thus the data from the use of colour codes was only stored in the database for a

certain period of time and then automatically deleted, and for data processing purposes it was mostly encrypted using student ids instead of names and surnames. Nowhere in the research publications personal information of students is used, only group data.

20. There are many online data collection tools for course evaluation, typically they are features of the user interface software (e.g., surveys on student perceptions and assumptions) and secondarily devices that record and analyse usage duration, number of logins, addresses visited, etc. The next logical question is – why do we need another evaluation method in the e-study platform? The reason is that available assessment and evaluation methodologies do not offer enough information about the reasons for user behaviour in the real-time continuously, many of them have very complex design and are ingeniously created, but they lack interpretation and analysis guidelines. Therefore, the creation of a new method that would allow the evaluation of real-time processes in a simple and easy-to-understand way is justified and necessary, and the colour code method is a step towards the creation of such a method.

21. When studying the available tools and approaches, it was concluded that it is difficult to find learning process analytics mechanisms, tools and examples that would not be based only on formal assessment, namely, grades and the amount of completed tasks, and would have settled well in learning platforms, gaining wide recognition. This suggests that either such tools tend to have an unfortunate and unwieldy design that does not facilitate their use; that they have an unclear intended use and purpose; or that no need for such tools has been identified in the online learning process. Presumably, it is a combination of all the above-mentioned aspects, but most of all, this sphere is affected by the fact that e-learning analytics and the possibility of collecting big data related to it and its processing and analytics is still a fairly new field of research and practical solutions, which is starting to develop more rapidly only in recent years.

22. Literature analysis shows that learning analytics is a very promising and present field in the context of modern education. However, with the rapid entry of big data into the education sector, an ever-increasing amount of data and information, it is becoming increasingly challenging to extract knowledge from learning data that is useful and contributes to improvements in the learning process.

23. Much is being done and more research is being done in the field of learning process analytics. This field is specific in that it requires a transdisciplinary approach to data and data processing in research, as it requires both data processing and analysis competence, as well as pedagogical competence, which allows obtaining data important for the learning process and interpreting them accordingly. This Doctoral Thesis is an attempt to contribute to this transdisciplinary field by giving a holistic view of the education, especially higher education, sector in Latvia and the world, as well as offering and testing in a real learning environment an analytics tool that allows to quickly and simply get feedback from students in a simple way, which does not require a lot of time, attention and effort on the part of learners, as a result of which time is not taken away from the learning process and there is no great resistance to using the tool.

24. This Thesis offers a method that can be easily integrated into the online learning process and provides the teacher or instructor with information about the student's learning process at every moment in real time, helping to identify problematic learning objects and learning content for each student, the time the student spends solving problems, compared to others (indicating persistence and/or slow work pace), as well as the spaced learning approach, learning how often breaks are taken during the learning process, in which learning topics, and which topics are

completed faster. The proposed tool is currently still in the development stage and has been tested as a real physical tool in schools, as well as the first prototype version in a digital environment in a university within the framework of this Thesis.

3.3. Conclusions from the experimental analysis

1. The effectiveness of using colour codes depends on the teacher who implements this method, analyses the data and reacts to it.

2. From students' perspective, the use of the colour code method (CCM) must be connected with a personal benefit in its use – the student must see its meaning.

3. The results of the face-to-face experiment suggest that there are low barriers to the implementation of the method in primary school age groups, children are happy to use the new colour tool and they are mostly not disturbed by the additional burden imposed by the need to remember to use the cardboard colour code tools. It is bigger challenge for the teachers – they have to adapt the flow of the learning process and start to use the colour codes at a more advanced level for data collection.

4. CCM is more useful to be implemented in the field of non-formal education, as well as for teachers and trainers who work with changing groups of participants. Teachers and learners would also benefit from CCM because it serves as a useful tool for translating teachers' intrinsic knowledge into verbal knowledge that can facilitate knowledge sharing and operationalization. This approach is especially important in knowledge-intensive processes, and the processes in the education system should be considered as such.

5. The colour tool should be supplemented with graphic or other colour-independent elements so that the tool is also suitable for people with colour vision impairment.

6. Based on the results of literature research, experience, and experiments, it can be concluded that the method can be applied to a wide range of learners – from children in kindergartens to adults to students in the virtual environment, because the method is simple and does not require special knowledge or skills to use it.

7. Children with more learning difficulties also need more time to get used to the colour code tool.

8. The big difference between the number of students who used online colour buttons in the 2017/18 and 2018/19 year groups could have arisen due to one of the following reasons: 1) the assessment results and overall involvement in the learning process of the first-year bachelors who studied Economics were lower than those of the first-year masters who studied Natural Science Modelling, and thus the bachelors also had a lower interest in learning process and online learning materials with greater interest on test scores and course completion; 2) master's students seemed generally more motivated than undergraduates because fewer people choose to study for a master's degree and the choice of direction is more internally motivated, thus the motivation to study is greater; 3) undergraduate program of the 2017/18 group of consisted of more technical subjects, while the master's program consisted of more transdisciplinary subjects that had a connection to creativity and humanities elements along with technical elements, so people who chose this curriculum had different personalities and interests compared to the group of undergraduate students involved in the experiment.

9. The relationship of 7 % that was found in the use of the "red" code in both virtual experiment groups is statistically significant and could indicate a baseline to be used to quickly

identify the proportion of students who have presses "red" significantly differs from this 7 % and to pay special attention to clarifying the causes of this situation and finding solutions to reduce the risk of dropping out and increasing the effectiveness of learning. By paying attention to these "red" situations, problematic learning objects (where the 7 % barrier is well exceeded) can be identified, or if the average number of "red" presses of a particular student is well above 7 %, this student is identified as a student with learning difficulties and may need a different learning style or additional support.

10. Graduate students were observed to be more focused on the learning process itself compared to undergraduate students who were more focused on results and completion of course materials. Some of the differences could also be explained by minor changes and improvements in button design based on the survey results of the 2017/18 group. Also, the explanation of the meaning of buttons seemed to be more clearly understood by the 2nd virtual experiment group thanks to the improvements and development of the idea based on previous studies.

11. It is not possible to accurately determine the influence of each different student parameter on the results in both virtual experimental groups, but it was observed that the biggest contribution to a higher proportion of button users in the 2018 student group could be the students' personal characteristics and learning motivation, thus increasing the overall activity and engagement in learning process.

12. It is not clear from the red code what type of problem the student faced – technical, contextual, cognitive or other. And this fact further reinforces the need for a personalized user interface, so that the faculty member can detect problematic parts in real time or very soon after they occur and through discussion forums or private messages, find out more about the nature of the problem and suggest solutions or solve the problem themselves as quickly as possible. This challenge is one of the next directions of CCM research and implementation.

13. On-site observations and analysis of the results confirm the hypothesis that the utilisation of the colour codes and analysis of the obtained real-time data improve the possibility to evaluate learning process and to perfect the content and teaching methods because it gives the teacher the opportunity to immediately objectively see what is happening in the classroom and react, without the need to guess or use professional intuition.

14. The implementation of the virtual technological solution of the colour code method and the result of the performance research also confirms the hypothesis because the data clearly shows the correlation between exam results and the use of the tool and provides information about the learning objects in which students have more problems or need help.

3.4. Future plans and afterword

The colour code method, although still incompletely developed, is nevertheless very versatile. In order to offer this method to a wider number of edX users, it still needs to go through a serious testing and verification process, improving it visually, technically and conceptually. It is also possible that the current data collection approach may not be adequate and more advanced content creation approaches are needed.

In the future, it is planned to improve the button design by making the buttons to turn on like light bulbs when pressed, showing which process state the student is in (proposed in the 2019 survey: the button design should reflect which button is active or was pressed last). When the button is pressed, it would light up; when another button is pressed, the previous one would automatically go out and the last button pressed would stay light up. The only difference would be in the case of the green button, since completing a task or learning session is an event, not a process. Therefore, the green button might automatically turn itself off after a few moments. In this way, a place would appear for the fourth element: inactive screen buttons, which would mean that the student has taken a break and is not actively using the learning platform at that moment, even if he has not logged out of the platform. This idea is slightly different from the original one, where there were only three options and the green also meant a break. But the usefulness of this idea should be tested experimentally in the future because it may be that the three process states used so far are also enough and the introduction of the fourth state will not bring additional benefits and will worsen the user experience, as the method would become more complicated.

The recommendation found in the research will be taken into account when developing the user interface for the colour code method in the future, as it should be in principle consistent with the basic principles of the e-study course interface, taking into account that the CCM user interface should be quite simple and easy to integrate into e-courses. Based on the results and recommendations of other studies, it was also important for the author to get the students' opinion and feedback about the graphical design solution of the Colour code method on the screen. In the future user interface great importance needs to be given to easy-to-understand and personalized visualisations that reveal of the most important aspects of the real-time data.

It was concluded that in the future it is necessary to carry out additional research in order to understand the relationship between the use of the learning platform and colour codes –do students always use the codes when they are logged into the platform, or only partially, and what are the reasons for this and whether a certain relationship has been observed between a type of students and their platform/colour code usage habits. Another interesting question arises – does the course design correlate with the codes used for different types of learning materials, for example, if 70 % of the learning materials on the platform are videos, will the proportion of the use of colour codes in the videos also be 70 % and the remaining 30 % will be divided accordingly among other types of learning materials. Already after the first experimental results, it can be said with certainty that the proportion will not be maintained; however, it would be important to find out if any relationship can be observed in this regard. This information would provide further insight into the effectiveness of the method and the possibilities of the application spectrum.

The student is increasingly perceived as a customer in the traditional business sense, thus the customer's needs come to the fore, and course creators and teaching staff are forced to rearrange their thinking in this direction of customer needs or, in other words, design thinking where the customer is at the centre. This approach is also encouraged by the increasing competition among courses. This situation is unique because it reduces the opportunity for teaching staff to usurp power, provide poor-quality service or allow subjective segregation of students on the basis of personal likes or dislikes. Thus, education in general has the potential to become more objective, that is, the possibility of global benchmarks and comparisons for different countries and types of students appears, since online courses are globally available and all students have the same evaluation criteria in each course. This situation also means a much higher quality and more efficient education process in the future because education has become a business, and all businesses are focused on making a profit, which in the case of the education sector means more and more quality and affordable products and services entering the market.

Online learning tools and solutions give us as a society unprecedented opportunity for everyone to become creators and distributors of knowledge, bringing this niche historically available only to a handful of academics and scientists into our global society and into our homes. Consequently, scientific authority and academic degrees increasingly lose their meaning if they do not have purpose, real knowledge and real usefulness underneath. It is thought that in the future people will be judged much more by what they have done, achieved and by their skills, not so much by the achievements of the formal education.

A unique situation has arisen, when the baggage of the global knowledge, unlike in all other historical periods, is formed in a global society and not only in the scientific or academic circles. It is a risk, but it also gives an unprecedented freedom to each individual. And I think this risk is worth it because finally, everyone has the opportunity to contribute into our common path and make it truly common.

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