Eszterházy Károly Catholic University

Doctoral School of Educational Sciences

Zoltán Csernai

The development of Computational Thinking among upper primary school teachers

Theses of doctoral (PhD) dissertation

Supervisors:

Réka Racsko, senior lecturer, PhD.

Lajos Kis-Tóth, retired senior lecturer, PhD, Dr. habil.

Head of the Doctoral School:

Prof. Zoltán Szűts, full professor, dean, PhD, Dr. habil.

Programme Director:

Enikő Szőke-Milinte, senior lecturer, PhD.

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1. The Topic and Structure of the Dissertation

In the 21st century, as a result of the 4th Industrial Revolution, the skills expected of citizens keep changing. The focus is to shift from knowledge to competencies, and new expectations to be performed emerged in the labour market. One of today's dominant trends is the development of STEM fields. STEM is an acronym for science, technology, engineering, and mathematics, whose interdisciplinary and cross-currical education is of particular importance.

Computational Thinking (CT) is an overarching concept in STEM fields. It encompasses the formulation and representation of problems, the development of solution strategies, the application of various design systems, and, in some cases, the understanding of human behavior (Kovácsné, 2016).

In my research, I explore the concept of Computational Thinking. I believe it is important for teachers in Hungarian upper primary schools to become familiar with the various interpretations of Computational Thinking and to learn the methods for its development in an e-learning environment. I I have a personal motivation for this topic, as I hold a Master's degree in computer science. I lead courses and special interest groups on LEGO® robot programming, am actively involved in teacher training, and have experience in developing distance learning curricula.

My doctoral (PhD) dissertation is consists of three parts. The theoretical background provides a detailed examination of the conceptual framework of Computational Thinking and its application in developing teachers' Computational Thinking skills. The dissertation presents the research objectives, questions, and hypotheses, as well as the phases, methods, and tools employed in the research. Additionally, it describes the e-learning environment and the online course that I have developed. The input questionnaires available on the e-learning portal assess prior knowledge about the concept of Computational Thinking, while the output questionnaires evaluate changes in attitudes and knowledge. The online course will be monitored using Big Data analytics methods based on learner activities. In the results and conclusions section, I compare the results of the questionnaire studies, as well as the data on activities during the course and in user interactions, with my preliminary hypotheses. In the chapter describing the limitations and vision for the future, I outline the difficulties encountered and possible directions for continuing my research.

In the words of Jeannette M. Wing (Professor of Computer Science at Columbia University and former Director of the Data Science Institute): "Anyone who graduates knowing computational thinking or with the skills of a computer scientist will have an advantage over those who don't and they will be more competitive in the job market" (NSW Department of Education, 2019).

2. Theoretical Background to the Research

The digital transformation of today's society (Racsko et al., 2023) has created new challenges for public education (Prantner et al., 2023), with the teaching of Computational Thinking being a priority among them.

In the Hungarian language context, the terms Computational Thinking and computer-related thinking are often used synonymously. However, the difference between these two terms may not be only linguistic but also conceptual. While computer-related thinking primarily emphasizes skills tied to technical tools, Computational Thinking explains the interdisciplinary and abstract aspects of the concept in a broader sense. Both terms are valid, as they refer to a fundamental functional thinking skill that is not synonymous with programming.

MIT professor Seymour Papert, a pioneer in Computational Thinking, did outstanding work in the 1970s developing the LOGO programming language and using the computer as a learning tool. Papert's work was based on constructivist pedagogy, which argues that learning is most effective when learners are actively engaged in constructing their knowledge. The concept of constructionism, which he introduced, refers to the use of external, interactive tools, such as the LOGO programming language, to facilitate learners' construction of knowledge. LOGO helped children acquire not only formal thinking but also its practical applications, which included pattern recognition, abstraction, and algorithmic approaches (Papert, 1980; Komenczi, 2014).

Jeanette Wing, a significant figure in Computational Thinking, published her paper "Computational Thinking" in 2006. According to Wing, "Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33). Later, in 2010, she refined her definition of Computational Thinking as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Cuny et al., 2010, p. 1).

In 2022, an attempt was made to create our own definition based on the definitions published in specialized literature, which reads as follows: "Computational Thinking is a cognitive process of problem solving using the tools of the digital ecosystem, through the decomposition from the problem into elementary parts, pattern recognition, understanding of abstractions, and the creation and use of algorithms" (Csernai & Racsko, 2022).

Based on a detailed analysis of the definitions in specialized literature, we developed our current working definition: "Computational Thinking is a problem-solving mental process and an associated set of cross-curricular competencies that use the principles of computer science and the tools of the digital ecosystem to solve problems effectively. It is a mental process because it "enables the understanding of the interrelationships of reality, the acquisition of new knowledge and the solving of problems through the creation of concepts and thought processes (Keményné, 2006, p. 114)", which include elementary decomposition, pattern recognition, abstraction, and the use of algorithms, which together help solve problems effectively and creatively, not only in the digital world but also in everyday life. It is a set of competencies, because it includes and integrates in a cross-curricular way the following key competencies: mathematical abilities and thinking competencies; learning competencies; competencies for creativity, creative work, self-expression and cultural awareness; competencies for work, innovation and entrepreneurship" (Csernai & Racsko, 2024, p. 9).

Computational Thinking encompasses several skills (decomposition, pattern recognition, abstraction, creation, and use of algorithms) that are essential for effective problem solving, especially in a digital society. These skills enable us to understand complex problems, solve them in a structured way, and use IT tools effectively.

Although the term Computational Thinking is not explicitly used in all educational guidance documents (e.g., National Curriculum, Curriculum and Qualifications Requirements), there are several concepts closely related to it, such as algorithmic thinking, problem-solving, and programming.

International and national best practices (e.g., Barefoot Computing, Bebras competition, LEGO® Education kits) provide numerous examples that demonstrate how to integrate Computational Thinking into education.

The development of Computational Thinking is not limited to digital or science subjects; its conscious integration into disciplines that do not traditionally use digital tools also offers outstanding pedagogical potential.

There are several frameworks (e.g., the CT Integration Framework) to support the teaching of Computational Thinking, which help educators integrate it effectively, emphasizing the importance of school vision and cross-curricular links (Sherwood et al., 2025).

Teachers often have a narrow understanding of the concept of Computational Thinking, an excessive focus on algorithms, and limited teaching approaches. This situation creates an urgent need for continuous training and to fill gaps in pedagogical and didactical knowledge.

3. Research Objectives, Questions, and Hypotheses

The primary objective of my research was to develop and implement a technical online learning environment that supports Computational Thinking, along with an accompanying online course.

I thought it was important for educational actors and researchers to use a Hungarian translation of the definition of Computational Thinking (CT) based on a consistent set of concepts. A further aim was to create a Hungarian equivalent term that expresses the developmental potential of the concept.

My long-term goal is that the results of my research will contribute to the establishment of STEM education in Hungary and to the broader application of the concept of Computational Thinking in education.

In order to answer the scientific problems that arose during my research, I formulated the following research questions:

- Q_1: How does the literature describe the conceptual framework of Computational Thinking, how has the concept changed over time, and what different approaches exist in the literature?
    - Q_{1A}: Where does the concept of Computational Thinking appear in educational governance documents?
    - Q_{1B}: What is the relationship between digital competence, algorithmic thinking, and Computational Thinking?
    - Q_{1C}: What are the national and international practices in developing e-learning environments?
- Q_2: How familiar are teachers with the concept of Computational Thinking and its development, and what factors influence their knowledge?

- Q_3: What are the content nodes along which Computational Thinking can be developed for teachers in upper primary schools, and what methodological approaches can be used to develop this skill among teachers effectively?
    - Q_{3A}: What are the criteria for building an e-learning curriculum that effectively develops Computational Thinking among teachers in upper primary schools? What multimedia elements should be included in the e-learning material? How can interactivity and user activity be ensured? What methodological approaches can be used to convey the principles of Computational Thinking effectively?
- Q_4: What tools, methods, and software can be used to develop Computational Thinking in a pedagogical context, how can they be applied in teacher education, and what impact do they have on teachers' knowledge and attitudes?
- Q_5: How effective is an online course in developing Computational Thinking among teachers in upper primary schools? What factors influence the effectiveness of the online course? How can the effectiveness of an online course be measured? What Big Data analytics methods can be used to assess the effectiveness of the online course?
- Q_6: How can e-learning and online courses be further developed based on user feedback and recent research findings?
- Q_7: What is the role of teacher-student interaction in the development of Computational Thinking online, and how can this interaction be effectively supported in the digital learning environment?
- Q_8: What possibilities are there to integrate an online course for developing Computational Thinking into the formal framework of teacher training (e.g., accredited CPD)?

Based on the theoretical background of the research, my hypotheses are as follows:

- H_1: A significant proportion of current and prospective teachers are unaware of the precise relationship between the concepts of Computational Thinking and algorithmic thinking.
- H_2: Almost half of current and prospective teachers have limited or no knowledge of the concept of Computational Thinking.

- H_3: Current and prospective teachers are open to the possibilities for developing Computational Thinking.
- H_4: Current and prospective teachers, after completing the online course, will positively evaluate the course and find it useful to learn and deepen their understanding of the concept of Computational Thinking.
- H_5: There is a relationship between participation in the course and the effectiveness of developing Computational Thinking.
- H_6: Analysis of data obtained using Big Data analytics tools can predict the learning behavior and course outcomes of current and prospective teachers.
- H_7: Based on the clustering results of Big Data analytics methods, the learning activities of current and prospective teachers can be clustered.
- H_8: Based on the analysis of the activity data collected in the online course, the activity of current and prospective teachers differs in each subject area of the course.
- H_9: Based on the analysis of student progress and time spent on the course, the progress and time spent on the course interface by current and prospective teachers vary.

4. Research Phases, Methods, and Tools

My research was structured in three phases (R&D&M):

1. Research: The theoretical grounding involved a review of the international literature on Computational Thinking and its adaptation to the domestic context, as well as the delineation and synthesis of relevant concepts (e.g., digital competence, algorithmic thinking). In addition, a survey was conducted to assess the perceptions of computer science education students, and the experiences with online learning platforms were analyzed, which were then incorporated into the development of the online course.
2. Development: In this phase, I developed an online course for the development of Computational Thinking and an online learning portal as an e-learning environment.

3. Measurement: During the practical implementation of the short-cycle course, I used the following measurement tools and methods: input measurement (a questionnaire survey on prior knowledge and beliefs about the concept of Computational Thinking), output measurement (a questionnaire survey on attitude and knowledge change about Computational Thinking after the short-cycle training), and Big Data analytics (quantitative analysis of the activities and user-activity interactions during the course).

In my research, sampling was done using the easily accessible subject method, i.e., convenience sampling (Lampek & Kívés, 2015). The choice of convenience sampling was motivated by the short time frame available, the purpose of testing the questionnaire and the research method, and the easy accessibility during my teaching activities at the university.

During the data collection process, the survey was conducted using a quantitative method with an online, self-developed questionnaire. The input questionnaire was designed using Google Forms and was divided into several groups of questions (demographic, work history, ICT use, familiarity with Computational Thinking, logical tasks, and self-evaluation). The output questionnaire was also designed using Google Forms and included questions on course evaluation and self-evaluation, as well as logical tasks.

The other method of data collection was the use of an online learning portal as an e-learning environment, and the analysis of the online course available there using Big Data analytics methods.

Data from the online self-developed questionnaire were examined using interrelationship analysis. I analyzed the teachers' responses and learning outcomes before and after they were introduced to the electronic learning material for the course "Developing Computational Thinking among teachers in upper primary schools". The statistical analysis of the questionnaire data was performed using descriptive statistical methods, considering the measurement scales of the variables (nominal, ordinal, interval, and ratio), with a focus on hypothesis testing.

I also used methods and techniques (e.g., clustering), tools, and platforms of educational data mining and learning analytics to analyze learner activities and interactions in Big Data analytics (Csernai, 2024).

5. Theses

Thesis 1: Awareness of the relationship between Computational Thinking and algorithmic thinking among teachers.

The results of this research suggest that a significant proportion of current and prospective teachers are not aware of the exact relationship between Computational Thinking and algorithmic thinking. More than half of the respondents (54.55%) had no in-depth knowledge of the two concepts, and a minority (3.41%) considered them synonymous.

It is an important observation that no one claimed that there is no relationship between the two concepts. However, clarification of their exact relationship is essential in professional discourse and education. The proportion of respondents who considered algorithmic thinking as a skill category or a necessary skill for Computational Thinking was also low (28.41% and 13.64% respectively).

Thesis 2: Awareness of the definition of Computational Thinking.

The survey revealed that almost half of current and prospective teachers (48.87%) have no or only a superficial understanding of the concept of Computational Thinking. 19.32% of respondents indicated that they had never heard of it, while a further 29.55% had heard of it but were unsure of its content. The most significant proportion of respondents (39.77%) had a superficial knowledge.

Only 11.36% claimed to know the exact definition. This shortcoming indicates a significant need for improvement in teacher training, underlining the importance of a deeper understanding of the concept of Computational Thinking.

Thesis 3: Teachers' openness to developing Computational Thinking.

The research confirmed that current and prospective teachers are open to the possibility of developing Computational Thinking. A significant majority of respondents (54.55% fully agreed, another 30.68% strongly agreed) that the practical application of Computational Thinking develops creative, social, emotional, cognitive, and physical skills.

A similarly high proportion (50% fully agreed, 36.36% strongly agreed) of teachers in upper primary schools considered it important to learn about Computational Thinking. The data suggest a strong interest and positive attitude among teachers towards the role of Computational Thinking in education.

Thesis 4: Evaluation and impact of the online course.

Following the completion of the online course, the vast majority of current and prospective teachers evaluated the course positively. 46.59% of the respondents fully agreed, and a further 42.05% strongly agreed, that the course provided sufficient professional material to learn and master Computational Thinking.

The electronic course material received very positive feedback from both technical (63.64% fully adequate, 26.14% highly adequate) and ergonomic (65.91% fully adequate, 27.27% highly adequate) perspectives. Based on the opinions expressed in the output questionnaire, 93% of the participants had a positive attitude towards the training, and 42.05% of them had become explicitly interested in the subject, confirming the positive impact of the course in teaching Computational Thinking.

Thesis 5: Impact of training on the development of Computational Thinking.

There is a correlation between participation in the training and the effectiveness of developing Computational Thinking. The results of the input questionnaires showed an average logical problem-solving rate of 34.09%, which increased to 52.56% in the output questionnaires, representing an average improvement of 0.73864 points in the sample studied.

However, the improvement was not uniform: 27 participants showed no improvement, while 9 experienced a decrease of 1 point and two a decrease of 2 points in the output questionnaire. The effectiveness of the training was not significantly affected by the difficulty of the tasks, but the course had an overall positive impact on the participants' Computational Thinking.

Thesis 6: Predictability of learning behavior using Big Data analytics.

Based on the analysis of data obtained using Big Data analytics tools, the learning behavior of current and prospective teachers, as well as their achievements in the course, can be predicted. According to the clustering results of the Behaviour Analytics plugin, learning activities can be grouped; in relation to the results of the Analytics Graphs plugin, the participants' activity in each topic of the course is different; and according to the results of the Edwiser Reports plugin, the participants' progress and time spent on the course interface are different.

Together, these data enable predictions of learning behavior and achievement, which can help educators support them more effectively, particularly in identifying those at risk of dropping out.

Thesis 7: The clustering of learning activities based on Big Data analytics methods.

Based on the results of Big Data analytics methods, particularly clustering, the learning activities of current and prospective teachers can be clustered. Analysis of data from 103 active course users revealed the formation of 5 clusters, reflecting distinct learning behaviors.

The largest cluster, comprising 67.96% of the participants (70 participants), exhibited the highest activity during the course. The smallest cluster was represented by only 2 participants (1.94%). This clustering effectively identifies the different learner profiles based on the data obtained by the Behaviour Analytics plugin.

Thesis 8: Variations in participants' activity by topic based on analysis of data collected in the online course.

Analysis of the activity data collected in the online course shows that the activity of current and prospective teachers varies across the course topics. The Analytics Graphs plugin's graphs indicate that the frequency of access to the different content elements of the course varies among participants.

The most visited topics were "General Section" and Topic 1 ("Introduction to Computational Thinking"), while activity related to Topic 8, concerning the course completion certificate, was the lowest. This discrepancy indicates differences in participants' preferences for each topic. It highlights the varying attractiveness of the course elements, as well as the fact that activity not only varies over time but also depends on the course content.

Thesis 9: Differences in participant progress and time spent on the online course.

The analysis of participant progress and time spent data shows that the progress and time spent on the course interface by current and prospective teachers differ. 80.36% of registered users (90 users) have completed the course, while 19.64% (22 users) have not yet completed it.

In terms of time spent on the course interface, the majority of participants made 50 or fewer visits per session, and a significant proportion spent less than 2 hours on the interface. However, some users showed a higher time commitment, spending up to 6-8 hours on the course material, showing the diversity of individual learning habits.

6. Limitations of the Research, Directions for Further Research

During my research, I encountered some limitations that may have affected the interpretation and applicability of the results. First, the sample was not representative of the entire Hungarian teacher population, so the results may not be generalizable to the entire population. Second, the motivation of the teachers participating in the research to develop Computational Thinking may have influenced the responses. Thirdly, the research was primarily based on a quantitative study, which prevented me from a deeper understanding of teachers' experiences and motivation due to the lack of qualitative methods. These limitations may have affected the generalizability of the research; however, the focused target population allowed for a deeper level of research and internal coherence. The results provide valuable insights for developing Computational Thinking in teachers in upper primary schools.

A key direction for future research is the longitudinal monitoring of teachers' digital competencies and Computational Thinking. Such a comprehensive, long run study aims to provide deeper insights into changes in teachers' attitudes and the development of their practical use. The methodological approach can be mixed, combining qualitative (e.g., repeated interviews, classroom observations, analysis of professional portfolios) and quantitative (e.g., multi-wave data collection with 3-5 measurement points, survey tests, teacher self-efficacy scales) methods to develop the most comprehensive picture possible. To deepen self-reflection and integrate Computational Thinking in the long term, the use of structured digital self-reflection tools (e.g., digital portfolios), peer feedback mechanisms, professional learning communities (PLCs), mentoring programs, and gamification strategies are recommended in teacher education to ensure practical and continuous professional development.

The popularity of the course "Developing Computational Thinking among teachers in upper primary schools" confirmed the necessity of exploring further ways to develop teachers' Computational Thinking. In the future, I will focus on creating a knowledge base that includes the following content: teaching materials, curricula, lesson plans, methodological recommendations, and interactive learning games. The content available in the knowledge base aims to provide teachers with practical support for developing Computational Thinking in the classroom. As a complementary AI-based tool, integrating ChatGPT would enable teachers to explore the potential applications of AI in education. The knowledge base could be a valuable resource for teacher educators (e.g., subject methodologists), pre-service teachers (students), practising teachers, practitioners, and researchers involved in the development of the teaching profession.

7. Summary

My research has yielded results in several areas. In terms of educational technology, I explored the user expectations of new types of learning environments (e.g., MOOC courses). In the disciplinary field, I compared terminological variations in Computational Thinking and created a unified set of concepts. Methodologically, I developed electronic courseware for the development of Computational Thinking and created an electronic learning environment to deliver the courseware. In the area of measurement methodology, I presented the results of the course investigation, utilizing various measurement tools and methods.

The practical utility of this research is also demonstrated in the following. I created a free online learning resource for teachers of upper primary schools, which contains state-of-the-art methodological solutions. Additionally, I developed a detailed work plan for a 15-week robot programming course, which can serve as a methodological recommendation for teachers in upper primary education.

Today, Computational Thinking has become a generally accepted concept and a widely researched field (both theoretically and empirically) within educational informatics. Due to its complexity, the development of Computational Thinking leads to the development of core 21st-century competencies. It should therefore be more prominently reflected in nationwide research, development, and practice in public education.

In conclusion, I believe that my research, the e-learning environment I have created, and the course "Developing Computational Thinking among teachers in upper primary schools" will help teacher educators, pre-service teachers (students), practising teachers, as well as professionals and researchers involved in the development of the teaching profession.

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