Computational Thinking and Mathematical Problem Solving, an Analytics Based Learning Environment

White Paper

Erasmus+ KA220-SCH project CT&MathABLE: "Computational Thinking and Mathematical Problem Solving, an Analytics Based Learning Environment", #2022-1-LT01-KA220-SCH-000088736. https://www.fsf.vu.lt/en/ct-math-able

Executive Summary

Integrating Computational Thinking (CT) into the K-12 school curricula has emerged as a 21st century imperative. Rapid transformation of digital technologies provides educators with new approaches to developing CT skills in a way that is individually tailored to the learner. The Erasmus+ project[1] "Computational Thinking and Mathematical Problem Solving, an Analytics Based Learning Environment", (CT&MathABLE), develops a novel architecture to support individualized development paths and seamless integration of CT with Mathematical problem solving and assessment frameworks. The first phase of the CT&MathABLE framework explores national curricula analysing the mathematics and computing/informatics curricula from the perspective of future integration of CT and Algebraic Thinking. Key outcomes include a complete mapping of the K-9 curricula in eight countries, Finland, Lithuania, Turkey, Sweden,

1 Introduction

European curricula reforms already include elements of Computational Thinking (CT) skills in compulsory schooling [Bocconi et al.(2022), Niemelä et al.(2022)]. CT can be understood as a way of thinking used to develop solutions in a form that ultimately allows those solutions to be executed. Thinking computationally is being able to approach and solve problems efficiently based on the principles and methods of computing [Arfé et al.(2020)]. CT is a type of analytical thinking that employs mathematical and engineering thinking to understand and solve complex problems within the constraints of the computational world. Denning and Tedre [Denning and Tedre(2021)] elaborate on these ideas, and link the concept to many already pre-existing ideas of abstraction, decomposition, data representation, and algorithms and their design.
We adapt three guiding principles from earlier work of Dagiené [Dagiene et al.(2022)]:

- Teaching CT as integrated into science and technology, offering a deep contextual view;
- Teach the genesis of fundamental concepts and improve them step by step;
- Teach to control computers by programming and automate well-understood activities to make society more efficient.

CT&MathABLE integrates CT with Mathematical problem solving, and combines learning resources and learning analytics drawing on expertise from leading research groups. Partners

[1]This work funded through the Erasmus+ KA220-SCH project CT&MathABLE: "Computational Thinking and Mathematical Problem Solving, an Analytics Based Learning Environment", #2022-1-LT01-KA220-SCH-000088736. https://www.fsf.vu.lt/en/ct-math-able.

Figure 1: CT&MathABLE classes engage pupils in individualised learning

prior track record in competency frameworks and innovative pedagogy provides a unique position from which to develop learning paths and assessment instruments. The system combines learning analytics and competency frameworks to support individualized learning trajectories for a CT and Maths ABLE society.

2 An integrated approach to CT and Mathematics

Algebraic Thinking is the ability to generalize, represent, justify, and reason with abstract mathematical structures and relationships. Thus the shared skills of CT and Algebraic Thinking, most importantly algorithmic thinking and problem-solving skills, can be utilized to develop the CT&MathABLE assessment system. CT and Algebraic Thinking (AT) are both considered elements of mathematics education, and our view is that intertwining them benefits the development of both [Bråting and Kilhamn(2021)].
Implementing CT education has largely been achieved by changing school curricula, integrating in CS or other similar courses. For example, Finland integrated CT into the curricula of mathematics, which provides a theoretical basis for the concept. CT is also introduced into art and craft allowing pupils to apply their CT skills creatively. We are developing a learning-analytics based framework to support individualized learning trajectories for students in the age range 9-14 to strengthen their computational and algebraic thinking skills. These skills are among the key competencies of the 21st century, providing ability to engage in computer science and problem solving tasks. The ability to think computationally is conceptualised as a combination of higher-order cognitive skills, including (a) analytical thinking and decomposition (analyze a problem and break it into parts); (b) algorithmic thinking (plan and identify action sequences to get to its solution); (c) hypotheses testing and debugging (monitoring and correcting errors); and (d) abstraction.

2.1 Learning Paths for CT and Assessment

Since 2006, CT has emerged as a powerful concept underpinning digital transformation. CT refers to the type of thinking involved in formulating a problem and expressing its solution in a way that can be executed by a computer. Key CT competences include the ability to break down a problem into smaller manageable parts, to analyze data, to recognize patterns, to extract basic principles behind patterns and to design algorithms.

The development of pedagogy in CS education lags behind that of other subjects. In contrast to CS, Mathematics has been taught at schools for centuries, and there is broad consensus about teaching key concepts at different year levels. Through an increased focus on computing and computational concepts in the school curriculum new approaches to integrating CT topics and skills, as well as elements of programming and digital literacy, are deployed into school curricula.

CT&MathABLE develops innovative educational approaches to classroom education and supports transdisciplinary and holistic learning. We promote a pragmatic approach to CT integrated with Algebraic thinking. The resulting personalized learning architecture integrates digital transformation of learning process and assessment frameworks. CT&MathABLE focuses on delivering learning paths with activities for CT with algebraic Thinking for students aged 9-14. Three assessment instruments of CT and AT are under development targeting the evaluation of CT and AT for pupils from ages 9 to 10 years old (COMATH1), 11 to 12 years old (COMATH2) and 13-14 years old (COMATH3).

2.2 Interactive Bebras-like tasks

Leveraging prior experience with running the internationally acclaimed Bebras challenge (www.bebras.org) we both promote CS and CT education and integrate these topics into the classroom. We utilise an existing database of tasks developed in a consortium spanning more than 70 countries and languages.

CT&MathABLE provides new learning resources and techniques through the development of a tool for the creation of interactive tasks, and the integration of these tasks with learning analytics [Dagiene et al.(2017)] customised to the learning domain. The project also develops a library of suitable tasks. Anticipated results include:

- A set of classified interactive tasks according to the concepts of computer science / CT integrated with algebraic thinking;
- A framework of interactive tasks - it can serve for creating new interactive tasks on CT;
- A tool for creating interactive tasks based on templates for type of interactivity and criteria for creating interactive tasks;
- Integrate the tool into an analytics based learning ecosystem.

3 Conclusions

Including Computational Thinking into school curricula is a matter of necessity. Countries that do not start developing childhood skill in computational thinking will rapidly fall behind educationally and economically. Unlike Algebraic Thinking, which is already a pillar of nearly all modern mathematics education systems, CT is still making its way, finding its place in subjects like CS, mathematics, technology and design.

CT&MathABLE delivers: (1) personalized learning paths in CT and Mathematical problem solving which combine a learning architecture with cutting edge learning analytics technologies to enable interactive CT learning; (2) competency frameworks for integrated and automated assessment of learning in CT and Algebraic Thinking; (3) large scale libraries of interactive tasks designed explicitly to hone CT and AT skills in many languages.

This work funded through the Erasmus+ KA220-SCH project CT&MathABLE: "Computational Thinking and Mathematical Problem Solving, an Analytics Based Learning Environment", #2022-1-LT01-KA220-SCH-000088736. https://www.fsf.vu.lt/en/ct-math-able.

References

[Arfé et al.(2020)] Barbara Arfé, Tullio Vardanega, and Lucia Ronconi. 2020. The effects of coding on children's planning and inhibition skills. *Computers & Education* 148 (April 2020), 103807. https://doi.org/10.1016/j.compedu.2020.103807

[Bocconi et al.(2022)] Stefania Bocconi, Augusto Chioccariello, Panagiotis Kampylis, Valentina Dagienė, Patricia Wastiau, Katja Engelhardt, Jeffrey Earp, Milena Horvath, Eglė Jasutė, Chiara Malagoli, Vaida Masiulionytė-Dagienė, Gabrielė Stupurienė, Nikoleta Giannoutsou, Andreia Inamorato dos Santos, Yves Punie, and Romina Cachia. 2022. *Reviewing computational thinking in compulsory education: state of play and practices from computing education*. Publications Office of the European Union, LU. https://data.europa.eu/doi/10.2760/126955

[Bråting and Kilhamn(2021)] Kajsa Bråting and Cecilia Kilhamn. 2021. Exploring the intersection of algebraic and computational thinking. *Mathematical Thinking and Learning* 23, 2 (April 2021), 170–185. https://doi.org/10.1080/10986065.2020.1779012

[Dagiene et al.(2022)] Valentina Dagiene, Juraj Hromkovic, and Regula Lacher. 2022. Designing informatics curriculum for K-12 education: From Concepts to Implementations. *Informatics in Education* 20, 3 (Aug. 2022), 333–360. https://doi.org/10.15388/infedu.2021.22 Publisher: Vilnius University Institute of Data Science and Digital Technologies.

[Dagiene et al.(2017)] Valentina Dagiene, Gabrielė Stupurienė, and Lina Vinikiene. 2017. Implementation of Dynamic Tasks on Informatics and Computational Thinking. *Baltic Journal of Modern Computing* 5 (Jan. 2017), 306–316. https://doi.org/10.22364/bjmc.2017.5.3.05

[Denning and Tedre(2021)] Peter J. Denning and Matti Tedre. 2021. Computational Thinking: A Disciplinary Perspective. *Informatics in Education* 20, 3 (July 2021), 361–390. https://doi.org/10.15388/infedu.2021.21 Publisher: Vilnius University Institute of Data Science and Digital Technologies.

[Niemelä et al.(2022)] Pia Niemelä, Arnold Pears, Valentina Dagienė, and Mart Laanpere. 2022. Computational Thinking – Forces Shaping Curriculum and Policy in Finland, Sweden and the Baltic Countries. In *Digital Transformation of Education and Learning - Past, Present and Future (IFIP Advances in Information and Communication Technology)*, Don

Passey, Denise Leahy, Lawrence Williams, Jaana Holvikivi, and Mikko Ruohonen (Eds.). Springer International Publishing, Cham, 131–143. https://doi.org/10.1007/978-3-030-97986-7_11