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

White Paper #4: CT and AT Competence: Understanding Pupil's Development through COMATH

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Executive Summary

It has been concluded in EU policy that computational thinking is essential in education because it fosters problem-solving skills, critical thinking, and creativity. In the digital age, computational thinking is not just a technical skill, but a type of thinking that can transform the way we approach the challenges and opportunities the modern world presents us with every day. While these skills are widely acknowledged as crucial, assessing computational thinking skills in school-level learners is a challenge that is currently being addressed in several contexts. Assessing computational thinking is a complex process that requires a combination of qualitative and quantitative methods. Analytical rubrics, portfolio analysis, and standardized tests are essential tools that help provide a comprehensive and accurate assessment of student skill in this field. In this White Paper we explore further the assessment instrument, COMATH, a research-based instrument with two rounds of piloting in six counties with subject-matter experts and over 6400 students and 100 teachers. Building on White Paper 3 we describe how we have developed tasks related to computational thinking, and present some of the most recent results.

1 Introduction

Educational assessment has traditionally relied on standardized tests, surveys, and qualitative observations. While these methods provide valuable insights, they are often limited in their ability to capture the complexity and diversity of educational processes especially in the era of generative AI [Rudolph et al.(2023)]. Analytics in education offers a solution to these limitations by enabling deeper, more detailed analysis of educational data to evaluate learning outcomes. By using advanced data analysis techniques, educators and policymakers can gain a more complete and accurate understanding of student performance and needs [van de Vijver et al.(2021), Cook et al.(2016)]. Additionally, analytics in education enables more personalized and adaptive assessment. Rather than applying a one-size-fits-all approach, educators can use analytics data to develop teaching and assessment strategies that are tailored to each student's individual needs. This not only improves teaching effectiveness, but also promotes a more inclusive and equitable learning experience [Raj and Renumol(2022)].

To address some of these challenges the project developed the COMATH instruments in order to provide methods with which to reliably benchmark the performance of the educational components of the CT&MathABLE project. However, they serve a broader purpose as a way to quantify individual learner development in CT and AT skill-sets appropriate to three age groups.

Six countries, Finland, Hungary, Lithuania, Spain, Sweden and Türkiye, are participating in the project, funded by the Erasmus+ program of the European Union. Through this project, it is intended to provide teachers with new approaches to develop students' both Algebraic Thinking (AT) and CT competencies in a way that is individually tailored to the learner.

2 Method

The COMATH items in the Computational Thinking (CT) Dimension of the scale are derived from items developed for the 2022 International Bebras Challenge [Dagiene and Stupuriene(2016), Kaarto et al.(2025)]. These items are chosen as their use in the Bebras Challenge gives us access anonymised population response answer data for thousands of pupils in each age group. A sample test item which tests ability to analyse sequences of operations linked to the computational concept of a "stack" is shown in Figure 3[1].

Algebraic Thinking (AT) items were developed at University of Turku by staff in the Turku Research Centre for Learning Analytics during Autumn of 2023 and Spring of 2024. The data analysis resulting from a full scale data collection also facilitates the continuous improvement of teaching and assessment methods in the learning pathways developed in the earlier stages of the project. It is clear from our results that by monitoring and analysing data over time, educators can identify which strategies are most effective and make adjustments to improve learning outcomes. Furthermore, data can help develop new tools and resources for teaching computational thinking. This white paper presents some results deriving from the application of assessment instrument, Comath, a research-based instrument with two rounds of piloting in six counties with subject-matter experts, over 6400 students, and educational assessments of 100 teachers.

Three interactive assessment tools for CT and AT were developed, specifically designed to evaluate the proficiency of students in CT and AT across different age groups: COMATH1 for ages 9 to 10, COMATH2 for ages 11 to 12, and COMATH3 for ages 13 to 14. These tools are developed from two pilot tests that provide us with valuable data that help us improve in the assessment of these two competencies, computational thinking and algebraic thinking. The pilot test developed so far consists of 18 items for the computational thinking part and between 20 and 23 items (depending on the age level of the students) for the algebraic thinking part. Both parts are carried out separately, with the students having 45 minutes to complete each of them. However, in some cases, teachers extended the session to a little over 60 minutes, for organizational reasons at their school.

3 Results

Several results have been collected that can help improve our understanding of the validity of these tests. One of the variables that has been measured has been the time that the students have spent completing the tests (see Figures 1 and 2).

Approximately two thirds of the students who completed the pilot tests took between 20 and 40 minutes. The average duration was longer for higher level students, the main reason

[1]This task was initially developed as Bebras Task 2022-CA-06 copyright Troy Vasiga, licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

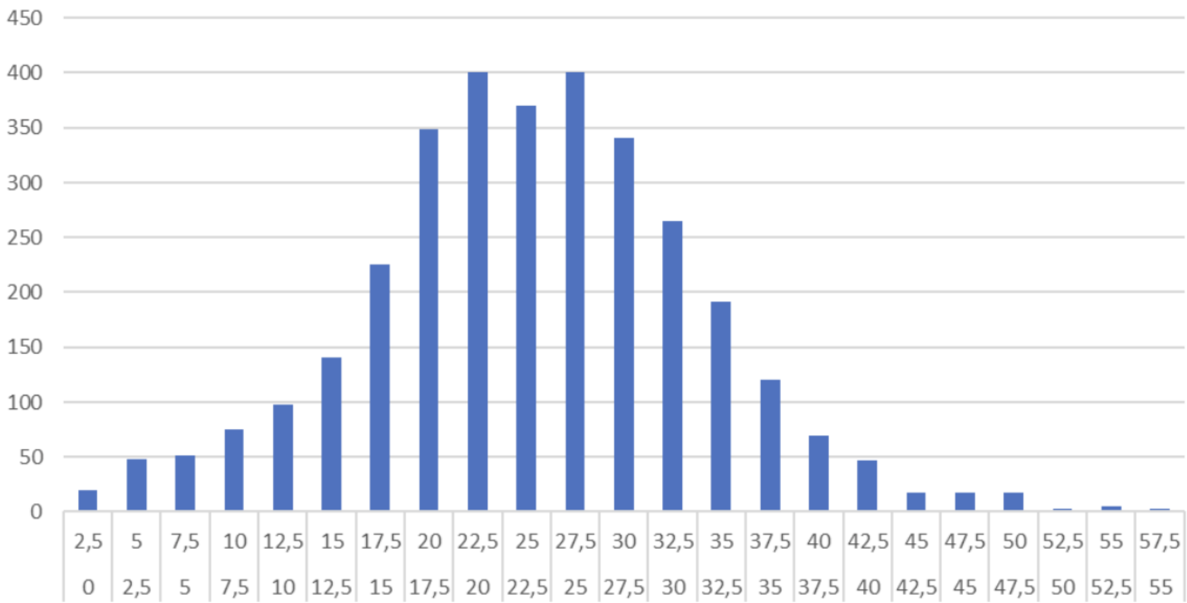

Figure 1: CT assessment task time, time intervals X-axis, number of students Y-axis

being the greater difficulty of the test exercises, although, checking the difference with the first two levels (COMATH 1 and 2), this is not significant.

	COMATH 1	*COMATH 2*	*COMATH 3*	*COMATH 1-3*
Average duration (min)	23.51	23.35	26.01	24.13
SD duration (min)	9.80	7.95	8.29	8.75
Max duration (min)	61.37	53.33	58.88	61.37

Figure 2: CT assessment task time, mean and SD per Age Group

In the case of algebraic thinking, an Item Response Theory (IRT) analysis of the pilot test allows us to determine what relationship exists between the empirical scores obtained by a subject (or several subjects, which in our case are the students) in a test, and a non- observable characteristic or trait that is being studied in that subject (or subjects), and which in our case we have broken down into six AT skills: Generalised arithmetic, Equations and inequalities, Functional thinking, Representation, Transformation, and Transversal skills for AT. Thus, IRT allows us to build measurement instruments (tests) with properties that do not vary between populations; in this way, if two people have the same level of the trait measured, both will have the same probability of giving the same answer, and this is independent of the population to which they belong. Six skills are analysed for AT tests, with two different sets: the first three on the one hand (advanced), and the last three on the other (basic). The second set can be considered as the base (necessary) for the first set. As you can see, the difference between these two sets is noticeable at any level. It is striking that the average duration to perform the exercises corresponding to the skills of the advanced set remains high even for 14-year-old students (See Figure 3).

Average duration (min)	*COMATH 1*	*COMATH 2*	*COMATH 3*	*COMATH 1-3*
Generalised arithmetic	5.94	7.43	6.69	6.72
Equations and inequalities	8.59	8.16	6.97	7.99
Functional thinking	7.23	10.47	7.36	8.53
Representation	1.24	0.98	1.66	1.25
Transformation	1.95	3.10	2.54	2.56
Transversal skills for AT	3.20	3.31	2.66	3.10
Total	28.16	33.44	27.89	30.16

Figure 3: AT assessment task completion time per Age Group and Skill

4 Conclusions

Educational assessment analytics harness the power of data to enhance the quality and effectiveness of teaching and learning. By leveraging advanced analytical techniques, educators and policymakers can make evidence-based decisions that drive meaningful improvements across the education system.

Computational thinking is a powerful problem-solving framework that involves breaking down complex challenges into manageable steps using principles from computer science. Far beyond programming, it applies across disciplines and everyday life, cultivating essential skills such as abstraction, pattern recognition, algorithmic thinking, and automation. These capabilities are increasingly vital in a world shaped by technology and data-driven innovation.

Critical competencies in the CT domain like logical reasoning, creativity, and collaborative problem-solving can be both measured and enhanced. Integration of exercises that foster these skills into educational curricula equips students with the tools needed to thrive in the dynamic, fast-paced environment of the 21st century.

Our international research initiative, employing data analytics to assess computational and algebraic thinking, revealed three key insights.

A Persistent challenges: Students consistently struggle with certain algebraic concepts, highlighting the need for innovative teaching strategies.

B Strong interconnection: Computational and algebraic thinking are deeply linked—strengthening one supports the development of the other.

C Transformative potential: Teaching computational thinking significantly improves students' ability to grasp algebraic ideas, offering a promising pathway to enhance mathematics education.

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