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

White Paper #3: Evaluating CT and AT Competence: Introducing COMATH

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Executive Summary

Phase 3 of the CT&MathABLE project focusses on benchmarking Computational and Algebraic thinking skills in school systems in the project partner countries[1]. The COMATH suite of test items are designed to evaluate Computational and Algebraic Thinking competence in three age groups of pupils (COMATH 1 [9-10 years], COMATH 2 [11-12 years], COMATH 3 [13-14 years]) in the compulsory school systems of the participating countries. Forty one items have been assigned in two categories, and stratified into three dificulty levels based on summaries of expert evaluations. The result is a robust instrument that is currently under final evaluation in test populations in all partner countries.

1 Introduction

The COMATH instruments are developed to benchmark the performance of the educational components of the CT&MathABLE project. The other work packages develop theoretical and pedagogical guidelines for the development of learning pathways and principles for using AI-based learning analytical methods to tailor interaction with tasks to support individual learner development in CT and AT skill-sets appropriate to the different age groups involved.

One of the major aims of the project in the long term is to be able to assess learning gains in student populations and also the compare student performance levels across countries. This will enable us to establish hypotheses linking student performance to AI supported learning support and differences in national curricular structure. We are especially interested in exploring the potential impact of curricular innovations associated with the introduction of computational thinking and programming competencies into school curricula, as well as potential links between algebraic thinking capability and computational thinking skills.

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 1[2].

[1] Finland, Hungary, Lithuania, Spain, Sweden, and Türkiye.

[2] 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.

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 and are currently undergoing a final pilot phase. Development of the AT items involved an initial development and translation effort, since the items needed to be piloted in seven languages, Finnish, Hungarian, Lithuanian, Spanish and Catalan, Turkish, and Swedish. Once the items were translated an initial pilot data collection was conducted resulting in several thousand item responses from the partner countries. Analysis of the discriminatory ability of the individual items was performed through statistical analysis and item response theory to arrive at a smaller number of items that constitute the current pilot.

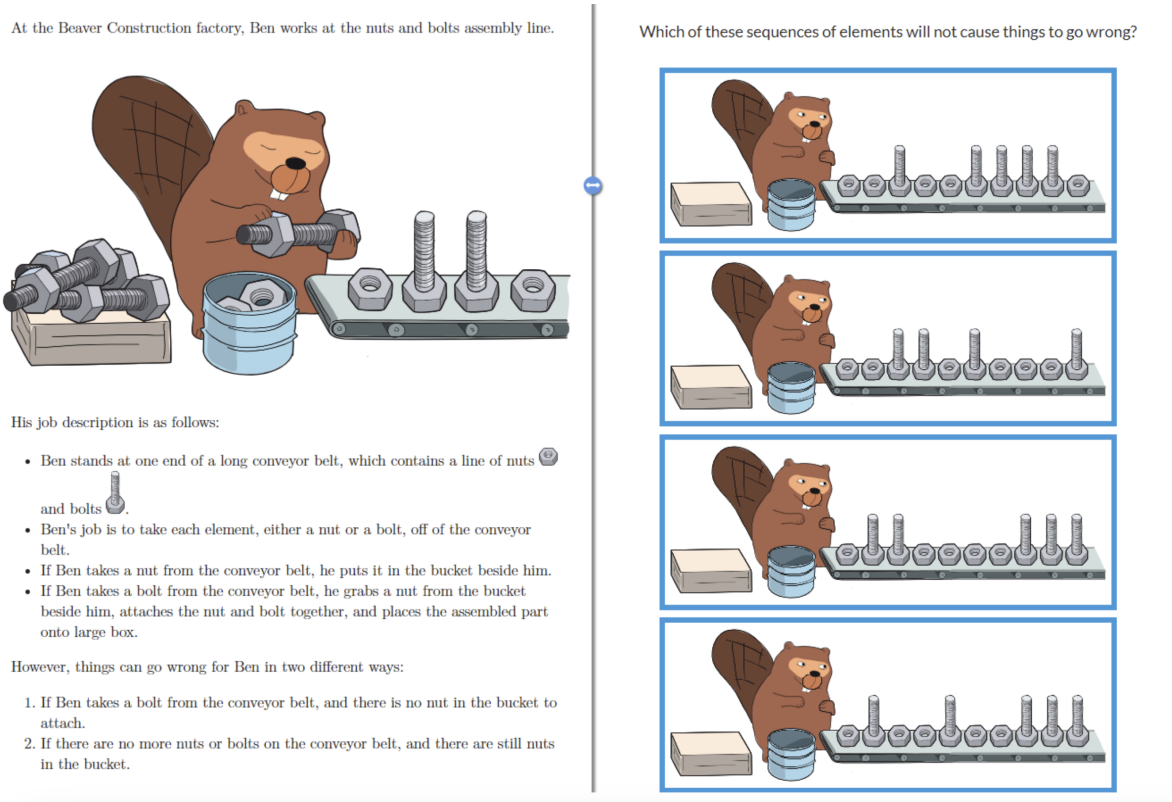

Figure 1: Nuts and Bolts: A sample CT assessment task

3 Project Progress to Date

CT&MathABLE is expected to deliver: (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.

We have analysed the mathematics education literature in detail in order to derive a definition of the cognitive development areas defined as Algebraic Thinking in the research literature.

We have applied this definition, together with a higher order definition of Computational Thinking to the coding of statements in the mathematics curricula of six European nations. We find considerable similarity, but also interesting differences when we perform a statistical analysis of the frequency of reference to certain codes.

Learning pathways have been identified based on the curriculum analysis and test items and interactive tasks have been developed to exercise thinking skills in the necessary areas. These items have also formed a part of the basis of the CT and AT assessment suite COMATH described in this white paper.

The text suite is in the final stages of validation and we expect to conduct our first measurements of AT and CT in chosen learner demographics across the consortium during the Spring of 2025. Results of these assessments will be a part of the CT&MathABLE Learning Summit event at KTH Royal Institute of Technology in Stockholm, June 2nd to 4th 2025.

References

[Dagiene and Stupuriene(2016)] Valentina Dagiene and Gabriele Stupuriene. 2016. Bebras-A sustainable community building model for the concept based learning of informatics and computational thinking. *Informatics in Education* 15, 1 (2016), 25–44. https://doi.org/10.15388/infedu.2016.02

[Kaarto et al.(2025)] Heidi Kaarto, Javier Bilbao, Arnold Pears, Valentina Dagienė, Janica Kilpi, Marika Parviainen, Zsuzsa Pluhár, Yasemin Gülbahar, and Mikko-Jussi Laakso. 2025. BeLLE: Detecting National Differences in Computational Thinking and Computer Science Through an International Challenge. In *Creative Mathematical Sciences Communication*, Henning Fernau, Inge Schwank, and Jacqueline Staub (Eds.). Springer Nature Switzerland, Cham, 168–182. https://doi.org/10.1007/978-3-031-73257-7_14