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Bridging Algebraic and Computational Thinking: Impacts on Student Development in K–12 Education

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Abstract. Algebraic Thinking (AT) and Computational Thinking (CT) are pivotal competencies in modern education, fostering problem-solving skills and logical reasoning among students. This study presents the initial hypotheses, theoretical framework, and key steps undertaken to explore characterized learning paths and assign practice-relevant tasks. This article investigates the relationship between AT and CT, their parallel development, and the creation of integrated learning paths. Analyses of mathematics and computer science/informatics curricula across six countries (Finland, Hungary, Lithuania, Spain, Sweden, and Türkiye) informed the development of tasks aligned with consolidated national curricula. Curricula were analysed using statistical methods, and content analysis to identify thematic patterns. To validate the effectiveness of the developed tasks for AT and CT, an assessment involving 208 students in K-12 across various grade levels (students aged 9–14) was conducted, with results analysed both statistically and qualitatively. Subsequently, a second quantitative study was carried out among teachers participating in a workshop, providing further insights into the practical applicability of the tasks. The research process was iterative, encompassing cycles of analysis, synthesis, and testing. The study also paid special attention to unplugged activities – tasks that help students learn CT without using computers or digital tools. A local workshop in Hungary, where 26 tasks were tested with students from different grade levels, showed that developing CT and AT effectively requires more time and practice, especially in key topics. The findings underscore the importance of integrating AT and CT through thoughtfully designed learning paths and tasks, including unplugged activities, to enhance students' proficiency in these areas. This study contributes to the development of innovative educational programs that address the evolving digital competencies required in contemporary education.

Keywords: computational thinking, algebraic thinking, learning path, unplugged activities.

1. Introduction

Algebraic Thinking (AT) and Computational Thinking (CT) are foundational competencies in contemporary education, equipping students with the skills to approach problems methodically and develop robust analytical abilities (Stacey & MacGregor, 1999; Hsu *et al.*, 2018; Dagienė, Hromkovic & Lacher, 2021; Sibgatullin *et al.*, 2022; Bocconi *et al.*, 2022; Bilbao *et al.*, 2023; Dagienė *et al.*, 2024). AT involves recognizing patterns, understanding variables, and manipulating symbolic representations, while CT encompasses problem decomposition, algorithmic thinking, and abstraction. Integrating these competencies fosters a cohesive learning experience, particularly within STEM education (Dolgopolovas & Dagienė, 2024).

This study was developed mainly under the Erasmus+ CT&MathABLE project (2025) – *Computational Thinking and Mathematical Problem Solving, an Analytics-Based Learning Environment* – aimed to enhance European educational resilience by leveraging digital transformation tools and pedagogies. The project focuses on developing innovative K-12 school curricula that facilitate the recognition and validation of skills necessary for digital transformation, emphasizing the integration of AT and CT. By providing open, relevant, and localized educational content with novel interaction modes, CT&MathABLE supports students aged 9–14 in developing key competencies for the digital age. The project involves six universities: Ankara University, Eötvös Loránd University, the University of the Basque Country, the University of Turku, Vilnius University, and KTH Royal Institute of Technology, along with two schools: Klaipėda Gedminai Progymnasium from Lithuania, and Mamak Özkent Akbilek Primary School from Türkiye.

A central concept in the project is the "Learning Path", referring to the structured sequence of teaching methods and curriculum topics designed to integrate CT and AT effectively. The initial phase involved clarifying the definitions and applications of CT, AT, and Learning Paths. Subsequently, the mathematics and informatics curricula of six participating countries (Finland, Hungary, Lithuania, Spain, Sweden, and Türkiye) were analysed. This analysis required consolidating diverse national curricula to define core mathematics topics, which were then examined through content and statistical analyses. Based on these analyses, tasks were developed and compiled into a comprehensive task package, with selected samples and assessments presented in this paper.

This study addresses the following research questions:

RQ1: How can learning paths be designed to effectively integrate AT and CT for students aged 9–14?

RQ2: What are the commonalities and differences in national curricula concerning AT and CT across the six participating countries, and how can these inform the development of integrated tasks?

RQ3: What impact do the developed tasks have on students' proficiency in AT and CT, and what adjustments are necessary to optimize learning outcomes?

To address these research questions, a retrospective analysis was conducted, drawing upon the collective experiences, documented communications, and publications of the CT&MathABLE project team. This analysis aimed to synthesize insights from the project's implementation across the six participating countries. The retrospective approach facilitated a comprehensive examination of the project's methodologies, including the design of integrated learning paths, curriculum analyses, task development, and the evaluation of student outcomes. By reflecting on the project's progression and outcomes, the study seeks to inform future educational practices that effectively combine AT and CT for learners aged 9–14.

2. Concepts

2.1. *Learning Path*

The term "learning path" encompasses multiple interpretations that should be clarified. The most frequent usage of this expression is the flexible learning paths within Learning Management Systems (LMS), where learning paths are structured sequences of educational content tailored to individual learner needs. These paths facilitate personalized learning experiences, allowing learners to progress at their own pace and according to their specific goals (Janssen *et al.*, 2008; De Smet *et al.*, 2016). Such flexibility is particularly crucial in lifelong learning contexts, where the comparability and exchangeability of courses, programs, and other learning activities are essential both nationally and internationally.

Another common application of the term arises in the context of special education. Here, the Learning Path refers to individualized educational plans designed to accommodate the unique needs of students with exceptionalities, whether they are gifted or require additional support due to learning challenges. These personalized paths are crafted based on the students' specific skills and areas needing development, ensuring that each learner receives appropriate guidance and resources to achieve their educational objectives (Zabolotskikh *et al.*, 2021).

A third interpretation of the Learning Path relates to curriculum design, focusing on the sequencing and organization of topics within educational programs. This perspective examines which subjects are included in the curriculum, their order, and how educators can effectively structure syllabi to optimize learning outcomes. By analysing the progression of topics, educators can develop coherent instructional strategies that build upon prior knowledge and facilitate deeper understanding (Confrey *et al.*, 2014; Soare, 2017).

In the context of our study, we adopt this third definition of the Learning Path, emphasizing the deliberate arrangement of curriculum topics to enhance the integration of Algebraic Thinking and Computational Thinking. By meticulously designing the sequence and interrelation of subjects, we aim to create a cohesive educational experience that fosters the development of these critical competencies.

2.2. *Computational Thinking*

Computational Thinking (CT) is an educational concept by Seymour Papert (1996), who developed the Logo programming language to support children's learning through exploration and construction. Papert's work emphasized the importance of learners building personal mental models to understand abstract concepts through computational means. The concept of CT was later popularized by Jeannette Wing in her article (2006), where she advocated for CT as a fundamental skill for everyone, not just computer scientists. Wing defined CT as solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science (Wing, 2006).

In our interpretation, CT encompasses a cognitive skill set essential for problem-solving and navigating the complexities of the digital age (Lodi and Martini, 2021). It transcends mere programming proficiency, emphasizing logical reasoning, abstraction, decomposition, and algorithmic thinking. These skills are applicable across various disciplines, enabling individuals to approach problems methodically and develop robust analytical abilities.

There are multiple interpretations and categorizations of the components of CT in existing literature (e.g., Grover & Pea, 2013; Barcelos *et al.*, 2018; Cansu & Cansu, 2019; Bocconi *et al.*, 2022, Su & Yand, 2023; Bilbao *et al.*, 2024). In our study, we employed two hierarchical lists: a major list encompassing broad categories, and a more detailed minor list. The minor list elaborates on specific elements that fall under the overarching themes of the major list, establishing a hierarchical relationship between them. These classifications were derived from an extensive review of relevant literature and curricula during our work (Bilbao *et al.*, 2024; Bocconi *et al.*, 2022; Cansu & Cansu, 2019; Dagienė *et al.*, 2024; Denning & Tedre, 2019; Hsu *et al.*, 2018; Sarmasági *et al.*, 2025; Su & Yand, 2023). The components identified in both lists are presented in Table 1.

2.3. *Algebraic Thinking*

In mathematics education, Algebraic Thinking (AT) is as important as CT is in computer science. AT is also an educational concept, and its origin is not so clear. The history of Algebra is measurable in millennia; however, the education methodology was strengthened only in the 20th century, so the concept of AT appeared in the middle of the last century in published articles (English & Kirschner, 2002). More relevant are the ones published after the 1990s, when AT can be compared with CT (Sarmasági *et al.*, 2023; Bilbao *et al.*, 2023; Bilbao *et al.* 2024; Godino *et al.*, 2017). Based on the works of Lins (1992), Kieran (2004), Kriegler (2008), Stramel (2021), Blanton & Kaput (2011), we understand the components of AT as the following: Relational thinking, which contains equality, and inequality; Pattern recognition, which is part of most learning processes; Generalization, and its base, abstraction; Numbers and operations; Mathematical language, which includes symbols; and Problem-solving (Table 1).

Table 1
Lists of components of CT and AT

Id	Description		
CT1	Decomposition	CT1.1	Decomposition
CT2	Abstraction	CT2.1	Abstraction
CT3	Algorithmic Thinking	CT3.1	Algorithmic modelling
		CT3.2	Logics, and logical thinking
		CT3.3	Logical reasoning
		CT3.4	Pattern recognition
CT4	Data	CT4.1	Data representation and analysis
		CT4.2	Data collection
		CT4.3	Data modelling
		CT4.4	Visualization
CT5	Evaluation	CT5.1	Evaluation
		CT5.2	Adjustment for efficiency
		CT5.3	Optimization
		CT5.4	Simulation
CT6	Generalization	CT6.1	Generalization
		CT6.2	Transferability
		CT6.3	System Thinking
AT1	Relational thinking	AT1.1	Equality
		AT1.2	Inequality
		AT1.3	Relational thinking
AT2	Patterns	AT2.1	Pattern recognition
		AT2.2	Recognition of symbols, numbers
		AT2.3	Expression patterns
AT3	Generalization	AT3.1	Abstraction
		AT3.2	Generalization
AT4	Numbers and operations	AT4.1	Numbers
		AT4.2	Operations
		AT4.3	Variables and unknowns
AT5	Mathematical language	AT5.1	Symbols and numbers
		AT5.2	Concepts and definitions
		AT5.3	Expressions
AT6	Problem-solving	AT6.1	Define and understand
		AT6.2	Plan and implementation
		AT6.3	Evaluation, improvement

AT enables students to address abstract problems and fosters, among other skills, the development of mathematical intuition. By understanding symbolic representations, equations, and algebraic structures, students can develop strong analytical thinking and problem-solving skills, while also understanding and using mathematical language. The combination of CT and AT is especially significant in education.

Similar to the components of CT, there are multiple interpretations and categorizations of AT components in existing literature (Radford, 2000; Kieran, 2004; Kieran, 2022; Kalati *et al.*, 2024). In our study, we utilized two hierarchical lists: a major list encompassing broad categories and a more detailed minor list. The minor list elaborates on specific elements that fall under the overarching themes of the major list, establishing a hierarchical relationship between them.

The sequence of components can be organized in various ways; in this context, we adopt a didactic perspective. Students typically begin their mathematics education by observing simple objects, listing their properties, comparing them, identifying identical items, and exploring differences such as size, shape, and colour. These foundational activities cultivate pattern recognition and the identification of relationships. The first component of AT can be called relational thinking (AT1) which involves equality as well as inequality and it drives to patterns (AT2) and the recognition of patterns. When students practice pattern recognition, a key aspect is the ability to identify general rules or principles from specific examples – this process is known as generalization. (AT3). To represent generalized patterns, we use symbols and special characters. The world of digits represents numbers (AT4), which form number sets, and operations can be performed on them, and they have their own symbolic system (AT5). This structured approach supports the subsequent problem-solving (AT6) and the development of AT by guiding students from concrete observations to abstract reasoning.

Finally, we used six major components each for AT and CT, as shown in Table 2.

Some clear similarities can be observed between the two sets of components, as illustrated in Fig. 1 (Sarmasagi *et al.*, 2025). Both begin with thinking as a cognitive process, grounded in the collection, identification, classification, and sorting of information.

Decomposition helps break a problem into smaller, manageable parts, while abstraction strips away irrelevant details to simplify the issue. Pattern searching and recognition reduce the problem to familiar and previously solved forms. Solutions can often be expressed as a finite sequence of steps, which may then be generalized for application to other problems. Thus, perception, processing, and representation are integral to both thinking skills. In both AT and CT, the use of a specialized language – a defined set of concepts and terms – is also essential.

Given these similarities, the analogous thinking processes and underlying logic of AT and CT reveal further connections between the two.

Table 2

The main components of Computational and Algebraic Thinking

Id	Description
CT1	Decomposition
CT2	Abstraction
CT3	Algorithmic thinking
CT4	Data
CT5	Evaluation
CT6	Generalization

Id	Description
AT1	Relational thinking
AT2	Patterns
AT3	Generalization
AT4	Numbers and operations
AT5	Mathematical language
AT6	Problem-solving

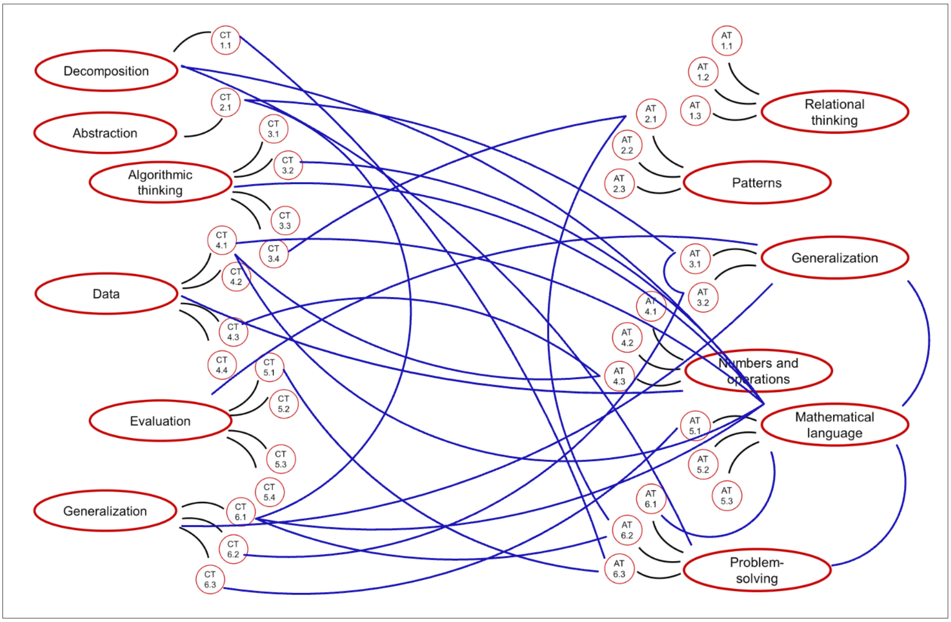

Fig. 1. Key conceptual connections between CT and AT.

3. Methods

This study employed a comprehensive mixed-methods approach to investigate the integration of AT and CT within educational curricula across six European countries: Finland, Hungary, Lithuania, Spain, Sweden, and Türkiye. The research design encompassed qualitative explorations, quantitative analyses, curriculum evaluations, task development, and the implementation of computer science unplugged activities to foster CT and AT skills among students aged 9–14.

Curriculum Analysis. A comprehensive analysis of mathematics and informatics (computer science) curricula from the six participating countries was conducted. This analysis utilized statistical methods, including a concentration measure akin to the Herfindahl-Hirschman Index (HHI), to assess the distribution and emphasis of AT and CT topics within each national curriculum. **Content analysis** further elucidated thematic patterns and instructional approaches across the curricula.

Qualitative Exploration. The initial phase involved exploratory qualitative research through structured, in-depth interviews with mathematics teachers. These interviews, featuring open-ended questions, aimed to gather insights into teachers' perspectives on integrating AT and CT in classroom settings. The qualitative data collected informed the development of a subsequent quantitative instrument.

Task Development and Pilot Testing. Insights from the curriculum analysis and teacher interviews guided the development of targeted learning tasks focusing on key areas such as grouping and classification, basic operations with integers, and unit conversions (e.g., weight, length, perimeter, area, and currency). These tasks were piloted in Hungary with 208 students from grades 7–12, divided into three cohorts: grades 7–8, 9–10, and 11–12 plus first-year university students. Each group worked on foundational tasks designed to foster both Algebraic Thinking (AT) and Computational Thinking (CT) skills. Although our target age group is 9–14, the aim of including higher-grade students in the assessment was to analyze their Algebraic Thinking – whether it is functional and whether they possess this skill.

Integration and Evaluation of Unplugged Activities. Recognizing the pedagogical value of unplugged activities – educational tasks that teach computational concepts without the use of digital devices – the project incorporated such activities into the learning tasks. These activities are particularly beneficial for young learners, offering hands-on, interactive approaches to complex topics, thereby enhancing engagement and comprehension. In mathematics education, unplugged activities help students visualize abstract concepts and develop logical reasoning skills. In computer science education, they introduce fundamental programming concepts such as algorithms and computational thinking without the need for computers. The effectiveness of these activities was evaluated through student performance and feedback during the pilot testing phase.

Iterative Research Design. The research process was iterative, encompassing cycles of analysis, synthesis, and testing. Each phase built upon the previous, ensuring that the development of learning paths and tasks was grounded in empirical evidence and responsive to stakeholder feedback.

This iterative research design ensured that the development of learning paths and tasks was grounded in empirical evidence and responsive to stakeholder feedback, thereby enhancing the integration of AT and CT in educational practices.

4. Curricula analysis

The exploration of Learning Paths began with an analysis of national curricula. The six participating countries provided their detailed mathematics and informatics curricula for processing and in-depth examination. Typically, a curriculum outlines a sequence of topics, each accompanied by specific learning materials and expected outcomes. However, the structure and organization of national curricula varied significantly. To enable meaningful comparison, the curricula had to be consolidated during the analysis.

4.1. *Mathematics – Algebraic Thinking*

When comparing national mathematics curricula, structural and content-based inconsistencies often emerge. Many curricula contain duplications, as certain key topics must be introduced and reinforced at multiple stages – either within the same grade or across several years. Additionally, the level of granularity varies: some countries divide topics into two or three separate entries, while others present them in a single, consolidated row.

To enable cross-country comparison, these differences were addressed through a careful consolidation process. First, duplications were eliminated. Then, Hungary's curriculum – being the most detailed – was chosen as the reference framework. Each entry from the other national curricula was aligned to the corresponding topic in the Hungarian curriculum whenever possible. If no equivalent topic existed, a new one was added to the structure.

Table 3 presents the number of topics analysed and how they changed throughout the consolidation process. In some cases, topics from a given country were duplicated in the final version because they appeared in multiple grade levels. This explains why the final column (Categorized rows) shows more topics than the previous one (Consolidated state).

Ultimately, 31 major mathematics topics were defined, representing a consolidated structure based on the curricula of all six countries. After the major math topics were defined, the typical components of AT and CT were assigned to these topics. Table 4 contains the 31 major topics and the list of components of AT and CT that affect the given major topic.

The relationship is obvious in most cases, as components were defined by the common parts of algebra, math, or computer science. However, there are some not-so-obvious relations, so the next examples explain some assignments. Comparing numbers, shapes, or sets, recognizing the relation among them (less, equal, greater) are the basis of relational thinking (AT1), and these are parts of most topics in math curricula. Concepts, names, and symbols (AT5) help thinking, and to recognize patterns that represent numbers (AT4), expressions (AT2). Arithmetic (AT1, AT4) serves as a foundation for algebra (AT3) and mathematical problem solving (AT6), both of which are essential in science and everyday life. Decomposition (CT1) is important in mathematical problem solving (AT6), as well as numeral systems (AT4). The concept of numeral systems (AT4) involves both abstraction (CT2) and generalization (CT6), the latter of which corresponds to generalization in AT3. This is evident in the place value system, where the same digit represents different values depending on its position. Numbers, shapes, and sets form data (CT4), and every math operation has an algorithm (CT3). Compari-

Table 3

Mathematics curriculum processing progression states

Country	Rows in source	Pre-processed state	Intermediate state	Consolidated state	Categorized rows
Finland	156	156	156	116	141
Hungary	506	207	104	103	104
Lithuania	49	49	49	49	39
Spain	249	201	201	193	138
Sweden	76	76	76	73	67
Türkiye	116	76	76	54	76

Table 4
31 major mathematics topics

Area of Math	Topic ID	Name of topic	Affected components of AT and CT
Mathematics logic / set theory	1	Categorization, classification	AT1, AT2, AT3, AT5, CT1, CT2, CT3, CT4
Algebra	2	Problem solving	AT1, AT2, AT3,AT4, AT5, AT6, CT1, CT2, CT3, CT4
Algebra	3	Comparison, sorting	AT1, AT2, AT3, AT5, CT1, CT2, CT3, CT4
Algebra	4	Counting, approximations	AT1, AT2, AT4, AT5, CT1, CT3, CT4
Number system	5	Digits, numbers, number systems	AT1, AT2, AT3, AT4, AT5, CT1, CT3, CT4, CT6
Measuring	6	Measurements and measurement tools	AT1, AT2, AT3, AT4, AT5, CT1, CT3, CT4
Algebra	7	Equations, operations	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT2, CT3, CT4
Algebra	8	Mental calculations	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT2, CT3, CT4
Geometry	9	Shapes and objects, and their properties	AT1, AT2, AT3, AT5, CT1
Analysis	10	Constructions and translations	AT1, AT2, AT4, AT5, AT6, CT1, CT3
Geometry	11	Orientation in space and on a plane	AT1, AT2, AT4, AT5, AT6, CT1, CT3
Algebra	12	Relationships	AT1, AT2, AT3, AT4, AT5, CT1, CT3
Probability and Statistics	13	Data collection and management	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT2, CT3, CT4
Probability and Statistics	14	Randomness	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Algebra	15	Columnar operations	AT1, AT2, AT4, AT5, CT1, CT3
Algebra	16	Part-Part-Whole relationships	AT1, AT2, AT3, AT4, AT5, CT1, CT3, CT4
Algebra	17	Natural numbers, Integers, and their operations	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Mathematics logic / set theory	18	Sets	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT3, CT4
Mathematics logic / set theory	19	Math and logic in everyday life	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT3, CT4
Algebra	20	Rational numbers, fractions and their operations	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Probability and Statistics	21	Ratios, percentages	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Algebra	22	Problem-solving with equations, proofing	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT2, CT3, CT4
Analysis	23	Functional relationships	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT2, CT3, CT4

Continued on next page

Table 4 – continued from previous page

Area of Math	Topic ID	Name of topic	Affected components of AT and CT
Algebra	24	Series (Sequences)	AT1, AT2, AT3, AT4, AT5, AT6, CT1, CT2, CT3, CT4
Geometry	25	Planar and spatial shapes' constructions, transformations, properties, and classification	AT1, AT2, AT3, AT5, CT1
Measuring	26	Measurements and units	AT1, AT2, AT3, AT4, AT5, CT1, CT3, CT4
Probability and Statistics	27	Descriptive statistics	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Probability and Statistics	28	Probability theory	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Mathematics logic / set theory	29	Mathematical language, reasoning, logic and combinatoric	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Algebra	30	Numbers theory, LCM, GCD, power, root	AT1, AT2, AT3, AT4, AT5, AT6, CT3, CT4
Algebra	31	Pattern usage/recognition	AT2, AT3, AT5, AT6, CT1, CT2, CT3

son and sorting (AT1) require decomposition (CT1) to recognize and select the relevant properties. Decomposition is also important for compound operations or expressions (AT2, AT4, AT6).

The consolidated list of mathematics curriculum topics was examined using both statistical and content analysis methods. However, both types of analysis were conducted with the important limitation that only the presence of topics was considered – information on the instructional time allocated to each topic was not available.

Before presenting the statistical breakdown of each nation's curriculum across the 31 identified categories, it is essential to highlight several key differences among the countries: (a) the total number of curriculum entries varies significantly, ranging from as few as 39 in Lithuania to as many as 141 in Finland; (b) the extent of coverage across categories differs, with Türkiye represented in only 18 categories, while Hungary appears in 30; (c) the distribution of content also varies, as reflected in the average number of entries per category – ranging from 1.95 in Lithuania to 5.11 in Spain; and (d) the relative emphasis placed on each category differs by country, reflecting national educational priorities.

It is also important to note that some structural differences in curriculum design help explain these discrepancies. In Lithuania, several topics related to AT are integrated into the informatics curriculum rather than the mathematics curriculum, which results in fewer entries appearing under mathematics. In contrast, Finland adopts the opposite approach: many informatics and CT topics are embedded within the mathematics curriculum, leading to a higher number of entries classified under mathematics.

Fig. 2 shows the breakdown of each category based on the percentage of a nation's curriculum that the given category comprises. By using percentages rather than the total number of entries, we are able to standardize across nations, regardless of the overall size of their curricula. The figure clearly illustrates that certain categories –

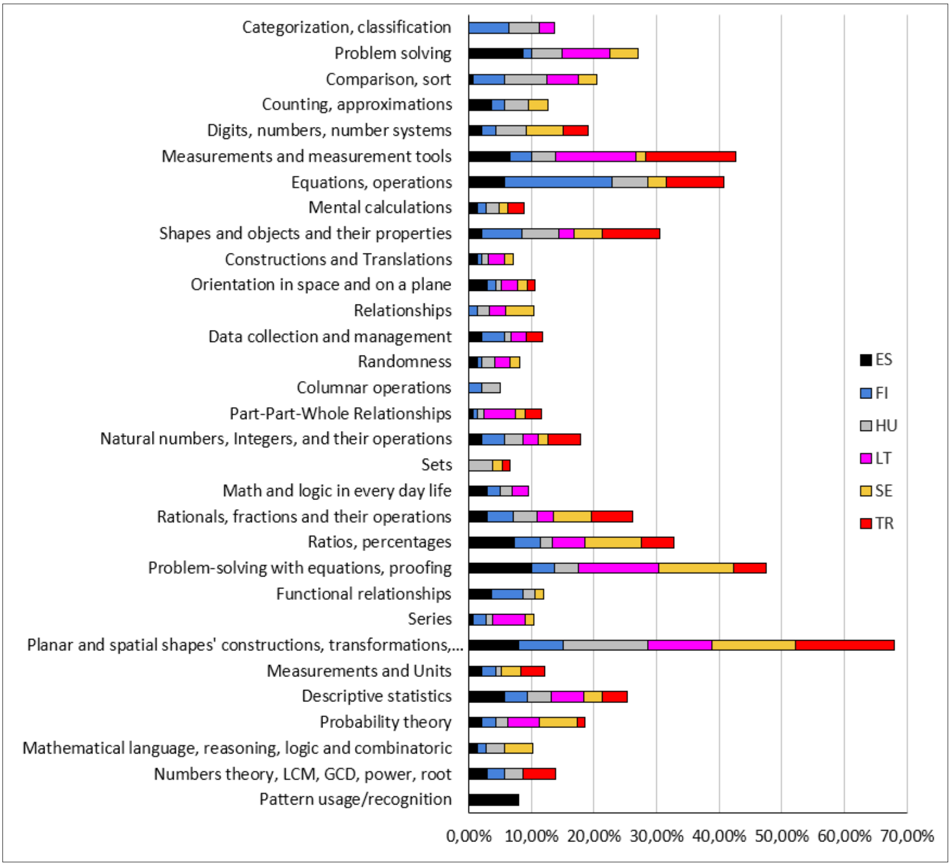

Fig. 2. Breakdown of categories by nation, showing the relative importance of each mathematics category within the national curriculum.

such as Measurements, Equations, Problem-Solving with Equations, and Shape Constructions – are more prominent than others. It also reveals that the relative emphasis placed on each topic varies across countries. For example, Finland places significantly greater emphasis on Equations than on Measurements, whereas Lithuania shows the opposite trend.

While the curricula may appear fragmented, statistical analysis reveals substantial similarities among them. The selection of countries, as all-European countries, may lead to close proximities, and further investigation with Asian, American, South-American or African curricula are work to be done still. Group by group, each nation shares more than 47.5% of its curriculum with at least four other countries, and nearly 80% with at least three. At the same time, each nation maintains its own distinctive focus, emphasizing particular areas within the shared material. Excluding Geometry – used as a catch-all category for spatial topics – the national emphases are as follows: Spain focuses on problem-solving and pattern recognition; Finland emphasizes equations and operations; Hungary highlights comparison, sorting, and equations; Lithuania prioritizes measurements and problem-solving; Sweden focuses on problem-solving and ratios; and Türkiye emphasizes measurements and equations.

We were also interested in examining how concentrated each nation's curriculum is. Due to the differing levels of detail in national core curricula, a direct comparison is not feasible. To address this, we applied a Hirschman-Herfindahl-like concentration index – calculated as the sum of the squares of the relative weights of each category per nation, scaled to a range of 0–10,000. The results are presented in Table 5.

When plotted (Fig. 3), the data reveal that the concentration of a nation's curriculum is strongly influenced by the number of categories represented in that curriculum. This is a crucial consideration: while individual categories may appear disproportionately significant – for instance, more than 17% of the Finnish curriculum falls under the Equations/Operations category, a proportion unmatched by any other country – this does not necessarily indicate an unusually high concentration overall. As seen in Fig. 3, Finland sits only slightly above the regression line, and in fact, its overall concentration value is fairly average when compared to the other five nations.

The conclusion is that none of the national curricula are excessively concentrated in just a few categories. Overall, the mathematics curricula across countries are broadly similar and collectively cover most key components of AT at the primary school level.

Table 5

Concentration of national curricula across mathematics categories

Code	Nation	# entries	# categories present in	Concentration
ES	Spain	138	27	566
FI	Finland	141	29	621
HU	Hungary	104	30	516
LT	Lithuania	39	20	717
SE	Sweden	67	25	657
TR	Türkiye	76	18	855

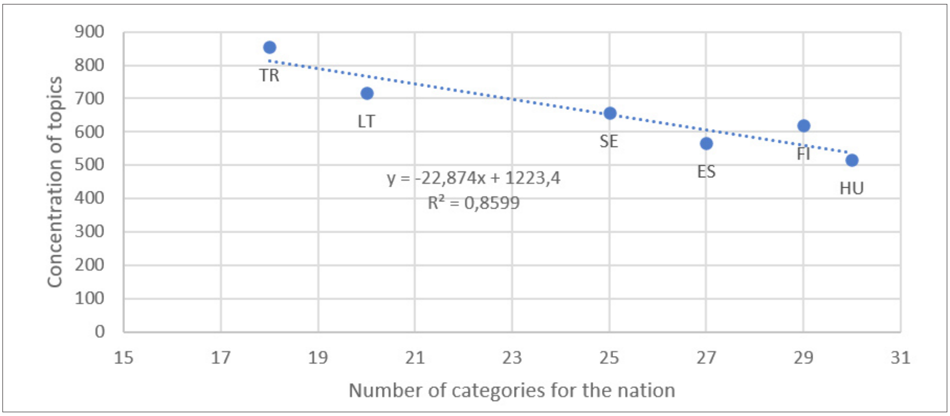

Fig. 3. Concentration of national mathematics curricula based on category distribution.

4.2. *Informatics – Computational Thinking*

Informatics (also referred to as computer science or, in some countries, as part of information technology – IT) knowledge requirements in education are shaped by European Union (EU) directives. The EU developed the Lifelong Learning programme at the community level, involving NGOs and government bodies from Member States (Lifelong Learning, 2002). A key element of this initiative is the definition of key competencies aligned with labour market needs, including digital competence as a distinct area. To address this need and clarify the components of digital competence, the EU introduced the European Digital Competence Framework, known as DigComp (DigComp, 2022). The first version was published in 2013, with the most recent update – DigComp 2.2 – released in 2022. DigComp offers a structured framework to help European citizens understand what it means to be digitally competent, as well as to evaluate and enhance their own digital skills. The main elements of this framework are outlined below, in a slightly reduced form.

- Information and data literacy – Browsing, searching, filtering, evaluating, and managing data, information, and digital content data.
- Communication and collaboration – Interacting, searching information and content, engaging in citizenship, and collaborating through digital technologies; Netiquette; Managing digital identity.
- Digital content creation – Developing, integrating, and elaborating digital content; Copyright and Licenses; Algorithmizing and programming.
- Safety – Protecting devices, personal data and privacy, health and well-being, and the environment.
- Problem-solving – Solving technical problems; identifying needs and technological responses; Creatively using digital technologies; Identifying digital competence gaps.

Based on this description, algorithmizing and programming belong to digital content creation, whereas application development as a classical programming task usually follows the steps of problem-solving. Corresponding to the EU concept, these components define the general requirements of digital literacy. Obviously, these do not cover the professional part of the digital world.

Three of the six countries have stand-alone curricula for informatics. In the remaining countries, the informatics and digital culture content is partially integrated into the mathematics curriculum and partially into other subjects, such as crafts or technology. The project team collected the stand-alone informatics curricula, and for the other countries, extracted informatics-related content (e.g., applications of digital tools, etc.) embedded within the mathematics curriculum. The union of these topics was then categorized similarly to how the mathematics curriculum topics were organized. The volume of material – and consequently the number of topics – is significantly lower than in mathematics, as informatics is taught in fewer grades and with fewer hours per week. Since the project focuses on ages 9 to 14, the curricula from grades 3 to 8 were analysed, yielding a total of 401 topics across the six countries.

The first step in processing was the elimination of pure mathematics topics from the mathematics curricula in countries without a separate informatics curriculum. The subsequent steps followed a process similar to that used for consolidating mathematics topics, though it was simpler due to the smaller number of entries and the absence of significant duplication. The final number of categorized topics was 288, as shown in Table 6.

The categorization of informatics topics presented some challenges. Since the influence of EU directives was evident in every curriculum, the initial categorization was based on the EU suggested digital competencies. Three of the five EU competencies are included in the curricula of all six countries. The remaining two competencies were not covered in the analysed topics for countries without a dedicated informatics-related subject. This gap is expected, as the analysis focused solely on the mathematics curriculum in those countries. However, colleagues from these countries confirmed that informatics-related content appears in other subjects, ensuring that all EU competencies are ultimately addressed. Table 7 illustrates the extent to which EU recommendations are covered in national curricula.

Summarized, the analyses pointed out the national curricula fulfil the expectations of EU digital competence (DigComp, 2022). At the same time, algorithmizing and programming skills are not so emphasized in EU directives, as those focus only on digital literacy and user skills; meanwhile, these are more emphasized in national curricula (Oshanova *et al.*, 2019; Soboleva *et al.*, 2021). One possible reason for the over-rep-

Table 6

Informatics-related curriculum processing progression states

Country	Rows in source	Consolidated state
Finland	106	11
Hungary	132	132
Lithuania	54	54
Spain	38	20
Sweden	20	20
Türkiye	51	51

Table 7

EU suggested digital competencies in CT-related curricula

Country	Communication and collaboration	Digital content creation	Information and data literacy	Problem-solving	Safety
Finland	–	7	3	1	–
Hungary	16	71	16	23	6
Lithuania	6	23	4	9	12
Spain	–	11	2	7	–
Sweden	2	9	2	7	–
Türkiye	12	15	8	10	6

resentation of programming and algorithmization is historical. In the 80's, informatics meant programming, so the first IT-related curricula focused on programming. In the 90's, the MS Office application spread in business, and it initiated the curricula changes. Most curricula preferred applications and user skills, while programming went back, but it has not disappeared, at least in the six countries of this study.

The next major development was the widespread adoption of the internet and mobile communication, which led to the transformation of the informatics subject into Information and Communication Technology (ICT) (Stevenson, 1997). Programming remained part of the curricula in some countries, and its importance began to grow again in the 2010s. During this time, computer science professionals emphasized the significance of algorithmic thinking and, more broadly, computational thinking (Szlávi and Zsakó, 2012).

The curricula analysed in this study reflect this trend. In Finland, digital literacy is viewed as a skill developed naturally through education, as students regularly use digital devices throughout their learning (Finnish Educational System, 2023). In Hungary, the most recent National Curriculum was launched, renaming the subject from informatics to digital culture. According to this new curriculum, digital culture components are integrated across most school subjects (The National Curriculum of Hungary, 2020).

Lithuania updated its latest curriculum in 2023, changing the subject name from IT (information technologies) to informatics, with a clear emphasis on CT and programming skills (The National Curriculum of Lithuania, 2023). Spain updated its curriculum in 2022. Although there is no separate mandatory subject for computer science, several topics related to digital literacy and Computational Thinking are included in the mathematics curriculum. Additionally, some regional curricula offer optional computer science subjects at the pre-university level (Spanish Government, 2022).

Sweden also released its updated national curriculum in 2022. It does not include a dedicated subject for informatics; instead, digital literacy content is incorporated into mathematics and technology subjects (The National Curriculum of Sweden, 2022). Türkiye's curriculum, introduced in 2018, includes a subject titled Information and Communication Technologies and Software (The National Curriculum of Turkey, 2018).

A new categorization has been developed that better aligns with the subject areas of the curricula, the age group, and the educational goals expected in teaching. This curriculum-based, extended categorization defines 12 major categories. The same type of analysis was applied to this categorization as was used for processing the mathematics curriculum with its 31 major topics.

As with the analysis of mathematics topics and categories, a few observations must be made before examining the data. When looking at each nation's curriculum in relation to the 12 identified categories, significant differences emerge among countries: (1) The total number of entries varies widely – from as few as 11 for Finland to as many as 132 for Hungary; (2) The number of categories represented also differs – Finland and Sweden appear in only 4 categories, while Hungary and Türkiye are present in 9; (3) The distribution of content, measured by the average number of entries per category, ranges from 3.75 in Sweden to 14.67 in Hungary; (4) The relative frequency of each category differs across nations.

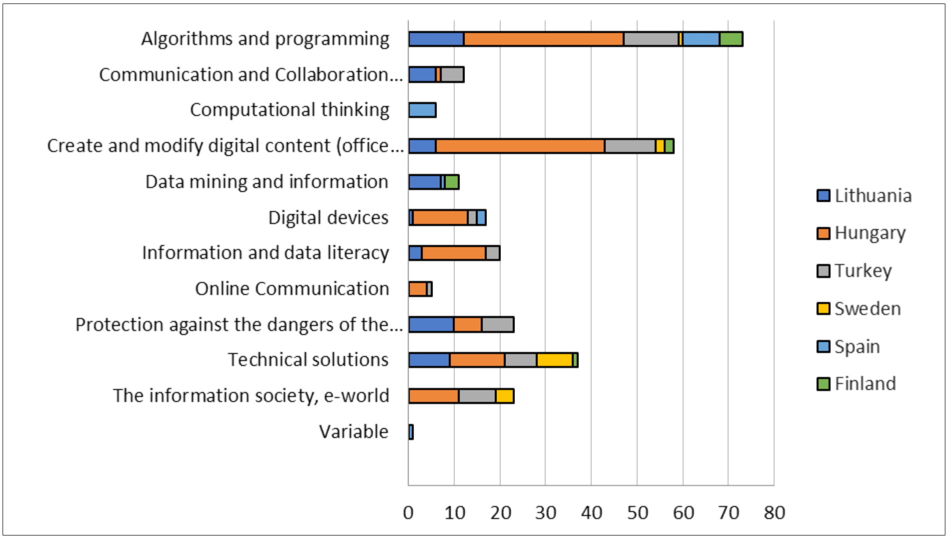

Fig. 4. Proportional distribution of informatics categories by country.

Fig. 4 shows the breakdown of each category, based on what percentage of each nation's curricula the given category makes up. By using percentage instead of total number of entries, we standardize among nations irrespective of the curricula size.

Certain categories – such as *Algorithms and programming*, *Create and modify digital content (office and creative)*, and *Technical solutions* – emerge as notably more dominant than others across national curricula. At the same time, the relative emphasis placed on each topic varies significantly by country. For example, Lithuania gives far greater priority to *Protection against the dangers of the digital world*, while Hungary places more emphasis on *Create and modify digital content (office and creative)*, highlighting distinct national approaches within the broader digital competence framework.

We also investigated how concentrated each nation's curriculum is. Due to the different details of the national core curricula, the Hirshman-Herfindahl-like concentration measure (sum of the square of the relative weight of each category for the nation, scaled up to 0–10,000) was used, which provided the following data:

Plotting the data from Table 8, Fig. 5 illustrates that the concentration of a nation's curriculum is largely influenced by the number of categories it addresses – this trend mirrors what we observed in the mathematics analysis. In general, nations that include a broader range of categories tend to have a more evenly distributed curriculum, while those focusing on fewer categories show a higher concentration in specific areas.

The absence of a stand-alone informatics curriculum in three countries – contrasted with its presence in the other three – helps explain the variation in the number of topics and categories represented. Looking at the data more closely, it becomes evident that some topics carry disproportionate weight in certain countries. These differences stem in part from structural variations in national education systems: while some countries

Table 8
Curriculum concentration of nations

Code	Nation	# entries	# categories present in	Concentration
ES	Spain	18	5	3272
FI	Finland	11	4	3223
HU	Hungary	132	9	1866
LT	Lithuania	54	8	1564
SE	Sweden	15	4	3778
TR	Türkiye	56	9	1486

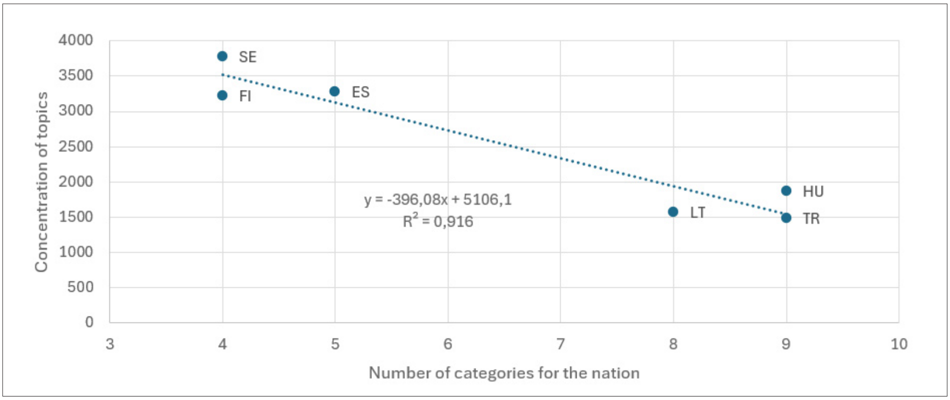

Fig. 5. Informatics-related category concentration by nation.

teach informatics as a dedicated subject, others integrate it into areas like mathematics or technology.

Despite these differences in structure and emphasis, all six countries fall relatively close to the regression line. This indicates that the overall concentration of informatics content is fairly consistent across nations. In other words, no curriculum appears significantly more concentrated or diffuse than the others. This suggests a broadly shared recognition of the need for a balanced and comprehensive approach to digital education, even though its implementation varies by country.

5. Content Analyses

5.1. *Mathematics curricula*

Content analysis in this study refers to the systematic examination of curriculum documents to identify, categorize, and compare the knowledge, skills, and learning goals emphasized in mathematics education across different countries. This approach helps reveal both commonalities and variations in how core mathematical concepts are taught within K–12 education. The analysis was carried out in two major parts.

The first part focused on the examination of the 31 major mathematics topics, aiming to clarify the purpose and expected outcomes of each thematic group. This analysis was supported by insights from interviews conducted with primary school teachers, whose classroom experience helped contextualize and validate the interpretations.

The second part involved the creation of a detailed list of learning outcomes, organized by the main areas of mathematics – such as Algebra, Geometry, and Calculus – and grouped according to age ranges (grades 3–4, 5–6, and 7–8). This structure allows for a clearer understanding of the progression of mathematical skills and concepts across K-12 levels, offering a practical tool for curriculum comparison and alignment across different national systems.

The analysis of curricular topics and content revealed no significant differences among the national curricula regarding the conceptual underpinnings of mathematics, which form the basis of algebraic thinking (AT). Generally, it starts with playing, when the students stack, sort, group and classify simple but distinguishable objects. These playful experiences allow the students to get used to the language of mathematics and to learn the basic concepts. Besides the Categorization and comparison topics the Problem solving and Comparison and sort topics are also parts of the introductory and foundational process, so students also learn the relations and relationships that introduce them to relational thinking and problem-solving. The knowledge of basic concepts, like quantity, less than, and greater than provides a foundation for moving to Counting, approximations and Digits, numbers, and number systems topics, and the next step is the Mental calculations and Equations, operations topics, which focuses on basic operations, like addition at early grades. The topic of measurements and measurement tools is a complex element of the curriculum that draws on several components of algebraic thinking (AT). Relational thinking, problem-solving, patterns, numbers and operators, symbolic representation, and mathematical language are equally important to achieve the learning outcome. Three major topics help students to get basic geometry knowledge. Shapes and objects and their properties, Orientation in space and on a plane, and Constructions and Transformations. These topics also confirm several components of AT. While the additional early-grade topics are not as prominently featured, domains like data collection and management, and mathematics and logic in everyday contexts, play a key role in laying the groundwork for problem-solving and algebraic thinking.

The identified topic groups span several grades, the students are practicing, reinforcing, and extending the knowledge of the topic after the initial introduction. The Columnar operations and Natural numbers, Integers, and their operations topics generalize the number concept and their operations in grades 3–4. In the upper grades, the number range is extended with rational numbers, fraction operations, and the notion of functions. In the pre-secondary grades, only Mathematical –language, reasoning, logic, and combinatorics is a new topic, the further learning materials are the extension of earlier topics.

Some countries include distinctive topics in their curricula. For example, the Lithuanian curriculum covers financial calculations, while the Hungarian and Turkish curricula incorporate set operations and set theory. Finnish and Spanish curricula place a stronger emphasis on the use of mathematical language, whereas in Hungary and Sweden, it is mentioned only as part of certain learning materials.

Despite these differences, the core elements of the curricula are largely aligned. In addition to shared foundational topics, the curricula reflect similar pedagogical principles and instructional sequences. For example, when introducing operations, a common progression can be observed: starting with estimation, followed by (mental) calculation, verification of result, and rounding. This sequence also closely corresponds to key aspects of algorithmic thinking.

After the 31 major topics were defined, each national curriculum topic was assigned to a major topic by age group. This resulted in some duplications of topics at different age groups; however, the detailed descriptions explain the differences. For instance, the columnar operations in grades 3–4 are limited to natural numbers, while these are extended to negative integers in grades 5–6. Taking age groups into account, the result of assigning minor topics to major topics is 231 pieces of learning material, the order of which defines the available learning paths. These were the source of the task collection for practicing the components of algorithmic thinking that needed to be prepared, created and collected by the project team.

Clearly, there are differences in the learning pathways of different national curricula, as well as in the importance and difficulty level of minor learning topics. To explore the critical parts of mathematics curricula and the most relevant learning paths regarding algorithmic thinking, exploratory research was implemented. This helped to identify the components that students should practice and the critical tasks that could hinder their progress. The first stage of the exploratory research involved qualitative analysis and five teacher interviews. Two teachers from lower-primary school, two from higher-primary school and a teacher from secondary school.

Teachers from lower-primary schools reported that students need significantly more time and practice to develop strong arithmetic skills. Once these foundational skills are secure, students are better able to explore relationships, recognize patterns, and begin to generalize. The recommended tasks should encourage approximation and allow for extensive trial and error, guiding students to discover results independently. An emphasis should also be placed on finding *all* possible solutions through systematic exploration – an approach closely related to the logic of backtracking algorithms.

One teacher specifically highlighted subtraction as a particularly challenging operation that demands extra attention. Multiplication, on the other hand, should be introduced through number sequences. For example, multiplying by 7 is often difficult for students, so repetition of the multiplication table – especially at the start of each school year – is essential.

Teachers also emphasized the importance of practicing mathematical logic through playful activities, particularly in understanding true and false statements and using negation. These exercises help students become more comfortable with mathematical language and reasoning.

Another challenge noted was students' lack of experience and conceptual understanding when learning measurement units. Changes in lifestyle – such as children being driven to school rather than walking, or rarely encountering real-life examples like buying a half-kilogram of bread – mean that students often have little intuitive sense of distance, weight, or volume. As a result, this area of the curriculum requires rich visual tools, hands-on experiences, and repeated practice to build understanding.

Additionally, one respondent teacher emphasized the importance of estimating the results of operations – even with columnar algorithms – and recommended using domino-style arrangements of numbers to help students practice quantity recognition. Another teacher pointed out that many students struggle with weak memory skills, which need to be actively developed. They also observed that students often try to avoid the cognitive effort involved in thinking through problems and calculations, preferring instead the simplicity of filling out multiple-choice tests. Finally, the concept of part-whole relationships was highlighted as essential preparation for learning fractions, with particular emphasis on understanding halves, thirds, and quarters.

The teachers from upper-primary schools also highlighted the arithmetical skills. The basic operations should be practiced, subtraction, multiplication table and the division with two digits numbers. During the practicing, the approximation and rounding are also important. The classification by properties can be generalized in upper grades, for numbers, operations, triangles, rectangles, etc. The secondary school teacher in addition emphasized the compound operations with negative numbers.

This exploratory qualitative research identified the most important learning paths and highlighted the key details that practicing reinforce students' knowledge and algebraic thinking skills. This result was confirmed by a small-sample quantitative study (n = 32), in which the respondents were from three of the six participating countries.

5.2. *Informatics curricula*

A detailed content analysis of informatics curricula was not carried out for several reasons. First, informatics curricula generally contain fewer topics, and the variation between national approaches is considerably higher than in other subject areas. Second, the core learning outcomes of informatics – particularly those related to computational thinking – are already well established in the professional community, and many tested tasks and teaching strategies are available from prior work in the field.

Moreover, informatics / computer science is not consistently treated as a standalone subject across countries. In many education systems, informatics content is embedded within other subjects such as mathematics, science, or technology, or it may be largely absent at the primary and lower-secondary levels. Where a separate subject does exist, it often emphasizes digital literacy and the practical use of digital tools (e.g., word processing, spreadsheets), rather than focusing on deeper algorithmic or problem-solving skills.

Given these factors, the compilation of learning outcomes was based on curriculum review and supported by statistical categorization, rather than in-depth content analysis of individual national curricula.

6. Early Evaluation of Key Mathematical Concepts through Sample Tasks

During the development and selection of tasks, we incorporated insights from teacher interviews to focus on three key recurring topics identified as essential in learning trajectories: (1) Grouping and classification (including basic set operations), (2) Basic operations with integers, and (3) Understanding and converting measurement units (e.g., weight, length, perimeter, area, and money).

A mid-phase study was conducted in Hungary prior to the full-scale pilot across six countries. This involved administering 26 fifth-grade tasks in a timed online format. Each task had a time limit of either 30 or 60 seconds, depending on its difficulty.

The tasks were distributed as follows:

- 9 tasks focused on grouping and classification, testing basic set operations such as union and intersection.
- 2 tasks assessed number concepts and the understanding of mathematical symbols.
- 3 tasks involved converting monetary units.
- 10 tasks addressed basic operations with integers.
- 1 task evaluated students' understanding of columnar division.

While many tasks were solved easily by students, those targeting the identified critical areas produced noticeably weaker results. These specific topics are not only foundational for AT, but also crucial for developing CT skills.

The findings validated the concerns raised by teachers – highlighting that certain fundamental topics require significantly more instructional time and practice. The remainder of this section provides detailed descriptions of nine representative tasks from the set of 26, illustrating their role in fostering CT and AT development.

The total number of respondents was 208 students, with their grade-level distribution presented in Table 9. Grades 7–8 correspond to primary school, grades 9–12 to secondary school, and "1^{st}" refers to first-year university students enrolled in a Computer Science program. For the purposes of detailed statistical analysis, three grade groups were created: 7–8, 9–10, and 11–12–1.

Additionally, 116 of the respondents were enrolled in mathematics extended (advanced) classes, and their results were compared with those of students in standard mathematics classes. In general, students in higher grade levels and those in advanced mathematics classes performed significantly better than their peers in lower grades or regular classes; any exceptions to this trend are highlighted in the results. A 5% significance level was used for statistical comparisons ($p < 0.05$).

Table 9

Number of respondent students by grade

Grade	7	8	9	10	11	12	1	Total
Subjects	23	76	10	24	40	18	17	208

The introductory tasks were recognizing even numbers (Q1– it means, it was the first task, question within the questionnaire) and prime numbers (Q2), and most respondents knew the right answer. The next 2 tasks asked about the basic set operations. The items of A set are 2, 4, 6, 8, 10, 12, 14, 16, and the items of B set are 2, 3, 5, 7, 11, 13, 17. The union of A and B sets (Q3) was the first task where the rate of right answers was less than 50% (40.4%). It was observable, after the online application displayed the right answer, students remembered the name and rule of operations, and 68% gave the right answer to the intersection of A and B sets question (Q4).

The fifth question (Q5; HU_56_18_01_05 – it is the identifier of the task in the task collection) is part of our task collection: What is the intersection of the set of even numbers and the set of odd numbers? The options for answer are (a) the set of integers; (b) The set that contains only the number 0; (c) The set that contains only the number 2; (d) The empty set. The correct answer is (d), and the freshman students of the Computer Science program selected it correctly; the students of secondary school gave 72% right answers, and the students of primary school achieved only 28%. The further questions regarding grouping, classification, and sets provided similar results. There was no significant difference between 9–10 and 11–12-1 grades.

The importance of this topic comes from the general learning process. There are several theories of the learning process, common of them the role of experience, which involves collecting information through touching, watching, and listening. The human processes them, grouping, sorting, classifying, and making a link, an association between the new thing and a known object or concept. So, the first steps of mathematics learning in lower grades are the classification, sorting, comparing, and counting of objects and concepts; later, students assign symbols to the concepts and operations. Because these steps repeat later in the case of most new topics in higher grades, the grouping, classification are very important. Some curricula introduce set theory from the 5th grade, where students identify sets by their elements or separate numbers, and items into different sets by classification. Students also learn basic set operations like the union and intersection of two sets, which helps to generalize the mathematics operations to apply them in other parts of life.

These tasks are related to mathematical language (AT5), abstraction (CT2), generalization (AT3, CT6), and problem solving (AT6). The latter is not only mathematically, but also generally meant, which is also extended to computer science.

We selected tasks related to money handling and currency denominations from the broader topic of understanding and converting units of measurement. The first two introductory exercises focus on recognizing and using currency denominations. In the first task (Q12), students calculate the total value of several displayed bills. In the second task (Q13), they must determine how many ten-unit denominations are equivalent to the previously calculated total.

The next highlighted task (Q14; HU_56_17_01_02/a) asked how many five-denomination banknotes correspond to the previously calculated total, while the hardest task (Q15; HU_56_17_01_02/b) from this topic asked about the minimum number of banknotes if the amount is 4.575 EUR and the available denominations are 5, 10, 20, 50, 100, 200, and 500 EUR. The results are relatively weak: in primary school, 62% and

36% of students answered the latter two tasks correctly; in secondary school, the corresponding figures were 84% and 76%. The performance of first-year university students was also thought-provoking, with 76% and 65% answering correctly.

These tasks are built on arithmetic skills (AT4) and decomposition skills (CT1), which are important for both investigated thinking skills, as it is part of problem solving (AT6) and mathematical language (AT5).

The basic operations with integers were tested with simple one-digit integers. Almost every expression contained three numbers and two operators in the exercise, where the numbers were replaced with variables. The values of variables were A = 7, B = -2, C = 5, and D = -3. The difficulty of the tasks increased from task to task. Before the analyzed exercises, there were four introductory tasks, which checked the usage of four basic operators (Q16–Q19). The calculation of A + B + C (Q20; HU_56_17_01_01/a) value was not an issue; 94% gave the right answer, and the weakest grade, the 7th grade, achieved 78%. There were no significant differences by any of the groupings. The right calculation of A - B - C (Q21; HU_56_17_01_01/b) was successful for 59%, confirming the issues regarding subtraction, especially with negative numbers. Although the standard deviation is only 21%, there is a wide difference between the result of the weakest 7th grade (39%) and the best university students' grade (94%). The percentage of students who got D + B - C (Q22; HU_56_17_01_01/c) correct was 53%, and in almost all grade levels, students performed worse on Q22 than on the preceding task. The next subtraction task required the result of D - C - B (Q23; HU_56_17_01_01/d). The total rate of right solutions was 54%, the standard deviation was 26% among grades, the weakest was the 7th grade (26%), while the best was the 11th grade (89%).

The next task (Q24; HU_56_17_01_01/e) was extended with multiplication, asking students to calculate A * (B - C) + D. The overall correct response rate was below 50% (49%). While university students performed very well (94%), and secondary school seniors also showed decent results (67%), primary school students scored significantly lower, with 7th graders at 22% and 8th graders at 32%. This result further confirms that mastering the evaluation of parenthetical expressions and fundamental operations involving signed numbers necessitates additional practice. These skills form the foundation of algebra, which inherently depends on algebraic thinking. Moreover, the sequential application of appropriate steps constitutes an algorithm, a key component of computational thinking.

These tasks – especially the final one involving brackets – play an important role in mathematics by preparing students for solving equations, working with inequalities, and understanding algebraic fractions. In addition to their relevance for AT, they also support the development of CT, as they require and strengthen skills such as decomposition and algorithmic reasoning. Recognizing sub-expressions within brackets and understanding the correct order of operations are essential components in both AT and CT.

A separate task was the assessment of columnar division (Q26). Students were given the wrong solution to a columnar division (63271 : 4 = 15842) and had to find the first wrong step. This was the last task of the questionnaire, and its result was the weakest. The total rate of right solution was 35%, and the standard deviation was only 15%, although the best, 12th grade, achieved 72%, their rate among the respondents is low.

Their success reason is the practice for graduation. The results of students at the university were only 41%, while further grades' results were close to the total rate. The only significant difference was that the 11-12-1 grades group scored better; the number of mathematics lessons did not affect the results.

The importance of the columnar division is reasoned with decomposition skill (CT1), knowledge of numbers and operations (AT4), algorithmic thinking (CT3), and problem-solving skill (AT6). Besides the AT and CT components, it requires students' attention and consideration.

The weak results confirmed, students forgot simple mathematics operations as they always use a calculator, and they have given up thinking. As a teacher mentioned in an interview, students prefer multiple-choice tests, where they do not have to think and calculate, they can tip it. Although this test was also a multiple-choice test, the presented tasks contained calculations that required the implementation of operations.

7. Unplugged exercises to develop AT and CT skills

There are several unplugged initiatives like Graph Paper Programming from code.org; or Barefoot Computing that offers unplugged lessons for Primary, focused on CT (barefootcomputing.org); or the CS Unplugged movement (`www.csunplugged.org`), which promotes the teaching of computing concepts through games, magic tricks, and hands-on activities, has brought a more dynamic and engaging approach to computing education. This CS Unplugged initiative was established in the late 1990s by professors Tim Bell, Ian H. Witten and Mike Fellows (Bell *et al.*, 1998), and has since gained international recognition, influencing curriculum design in many countries (Cortina, 2015).

Unplugged activities play a significant role in both mathematics and informatics (computer science) education by fostering critical thinking, problem-solving abilities, and a deeper understanding of fundamental concepts – without relying on digital technology (Bell *et al.*, 2009; Resnick & Rosenbaum, 2013; Pluhár, 2021). These activities are particularly effective for younger learners, offering a tangible, interactive way to engage with complex ideas, making learning more accessible and enjoyable.

In mathematics education, unplugged activities help students visualize abstract concepts and strengthen logical reasoning skills (Rumbus, 2023). For example, tasks involving sorting, pattern recognition, or geometric construction allow students to explore mathematical ideas in a hands-on manner. This not only improves comprehension but also promotes collaboration and communication among peers.

In informatics, unplugged activities introduce key programming concepts – such as algorithms, data structures, and computational thinking – without the need for computers (Vöcking *et al.*, 2011; Bende, 2020; CS Unplugged, 2025). These activities encourage students to break down problems into smaller, manageable parts, thereby fostering early algorithmic thinking (Duncan & Bell, 2015). Furthermore, they help address the digital divide by providing meaningful learning experiences even in settings where access to technology is limited.

Thus, unplugged activities are a powerful tool in laying a strong foundation in both mathematics and computer science. They not only prepare students for more advanced study but also help develop transferable skills that are valuable in real-world problem-solving contexts (Mohamad Noor & Hassan, 2018; Lénárd, 2019).

The learning process and the tasks of the project contain unplugged activities in each topic as a start "step". The tasks were developed based on the results of a study of curricula and support the development of both algebraic thinking and computational thinking.

The tasks are age-appropriate, designed to align with the cognitive development of each age group. The target groups were divided into three categories: pupils in grades 3–4, 5–6, and 7–8. A total of 23 fourth graders, 23 sixth graders, and 26 seventh graders participated in the testing. Most of the activities were adapted across the age groups, maintaining the same basic rules while increasing either the complexity of the rules or the difficulty of the components used.

We would like to highlight and present two selected activities from our collection.

7.1. *Learning fractions with a hands-on puzzle activity*

An activity was designed to introduce and reinforce pupils' understanding and practical application of fractions. In this task, learners are given a variety of pre-mixed puzzle pieces, each depicting a part of a whole through coloured segments. The goal is to identify and match pairs of pieces that together complete a whole. This hands-on approach supports the development of a conceptual understanding of fractions, strengthens analytical thinking, and promotes recognition of part-whole relationships.

The mathematical content becomes progressively more complex through increasing levels of difficulty. Tasks incorporate a range of ratios, diverse visual representations, and more abstract relationships. This progression allows students to explore fractions beyond basic forms, including comparisons, identification of equivalent fractions, and the construction of composite wholes.

When introducing fractions, it is crucial to consider learners' cognitive readiness to assimilate a new number system, which becomes essential when understanding division. The awareness that the outcome of a division is not always a whole number is fundamental to grasping the concept of fractions meaningfully.

Understanding the part-part relation is key to developing concepts of rational numbers from the lower grades onwards. In the early stages of the didactic process, it is useful to use visual, playful tools in which pupils are not yet exposed to the formal notation of fractional numbers. In these tasks, a whole is broken down into two parts (sometimes of different sizes) and the aim is for pupils to fit the puzzle elements together in such a way that they complement each other visually and in terms of content to form a complete whole. In later stages, formal notation of rational numbers, including ordinary fractions, can be gradually introduced, according to age-specific needs. The task type can be differentiated accordingly to support conceptual consolidation in the upper grades. Pupils then assemble the whole using fractions, thus developing their

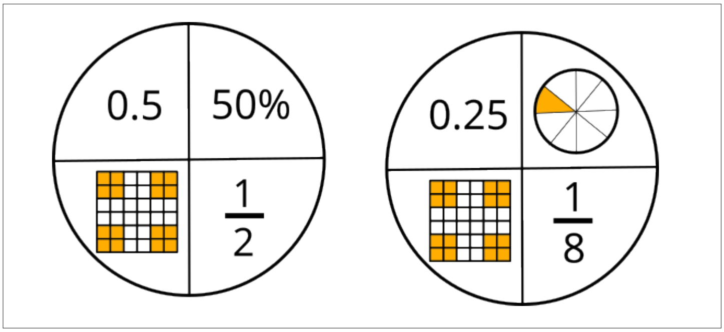

Fig. 6. Fraction puzzles at a higher difficulty level – "Find equivalent values" and "Match the pairs to form a complete whole".

number concepts and their ability to work with fractions. An improved version of the method can also be used effectively to introduce and visualise the concept of percentage. In this case, the pupils do not only work with the colouring of the whole parts, but the rational number is displayed on the surface in the form of a common fraction, a decimal fraction and a percentage at the same time (Fig. 6). This simultaneous representation of multiple representations contributes to the development of transferability between different number representations and helps to develop a deeper understanding of the concept of percentage.

The presented tasks were designed to develop multiple components of algebraic reasoning, including relational thinking (AT1), pattern recognition (AT2), generalisation (AT3), and numerical operations (AT4). Simultaneously, they also strengthened core elements of computational thinking, such as decomposition (CT1), abstraction (CT2), and data representation and analysis (CT4).

7.2. *Developing AT and CT skills through a spatial-visual task: tangram*

We selected a geometry-based task using the tangram – an ancient Chinese puzzle designed to strengthen spatial reasoning and visual perception. A standard tangram set consists of seven geometric pieces: two small triangles, one medium triangle, two large triangles, one square, and one parallelogram.

In this activity, pupils were challenged to arrange all pieces so that they touched edge-to-edge without overlapping. The task was introduced in two phases. In the first phase, students replicated a coloured figure using visual cues. The second phase presented a more demanding challenge: reconstructing a shape from a black-and-white silhouette, requiring higher-level spatial-visual skills and abstract thinking.

Age-appropriate versions of the tangram, such as the "Columbus' Egg" variation (Fig. 7), were used for different grade levels. Students were also encouraged to design their own tangram puzzles, create visual or verbal clues, and collaborate on solving each other's challenges. Instead of using printed templates, learners could create pieces using salt dough or 3D printing, further fostering creativity and hands-on engagement.

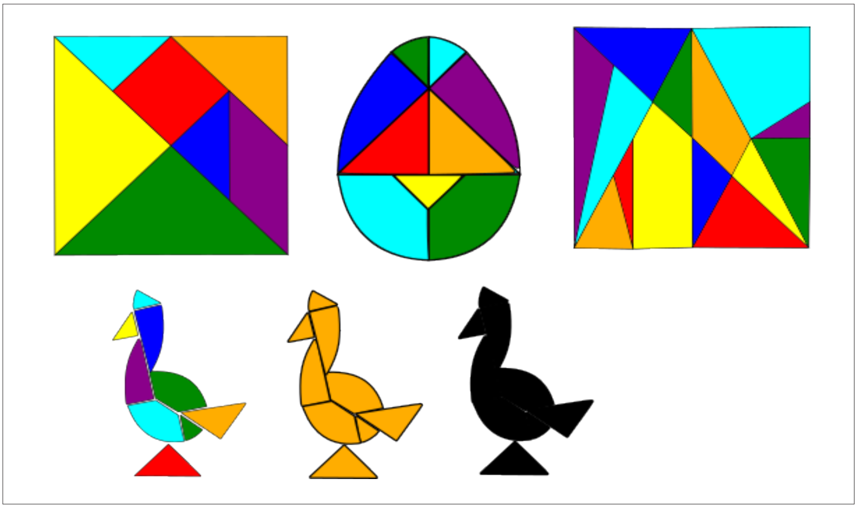

Fig. 7. The tangram puzzles and the clues in the different age and difficulty levels.

The task aimed to develop key aspects of spatial thinking, geometric intuition, problem-solving abilities, and strategic planning. Furthermore, it supported the development of several components of algebraic reasoning, particularly Relational Thinking (AT1) and Problem Solving (AT6). In parallel, it fostered components of computational reasoning, including Algorithmic Thinking (CT3) and Generalization (CT6).

8. Conclusion

This study examined how Algebraic Thinking (AT) and Computational Thinking (CT) can be meaningfully integrated into mathematics (and/or informatics) education for students aged 9–14. The research was guided by three questions, addressing how learning paths can support both forms of thinking, how national curricula compare in their treatment of these competencies, and how developed tasks affect student outcomes.

The study demonstrated that well-structured learning paths – starting with foundational tasks in grouping, classification, and set operations – can effectively support the development of both AT and CT. The progression was designed with increasing complexity across three learner groups (grades 3–4, 5–6, and 7–8), using familiar mathematical content as a foundation for abstract reasoning, algorithmic thinking, and decomposition. Visual puzzles, numerical patterning, and logic-based exercises (such as tangram configurations or fraction matching) were adapted to each level to reinforce the same core principles through age-appropriate means.

These paths show that CT can be naturally introduced through mathematical processes like classification, comparison, and basic operations, while AT is enhanced by tasks involving abstraction, patterns, and symbolic manipulation. The learning paths also illustrate how interdisciplinary tasks can be embedded into existing curricula with minimal structural disruption.

A comparative analysis of the curricula revealed broad agreement on the importance of logical reasoning, problem-solving, and basic mathematical operations, although the timing, depth, and framing of AT and CT varied across countries. While CT is not always explicitly named, its underlying skills (such as algorithmic thinking and decomposition) are often addressed through mathematics standards.

These findings informed the development of adaptable tasks that can be used in multiple national contexts. Tasks were designed to align with shared curriculum goals – such as developing number sense, introducing set theory, or understanding measurement systems – while also accommodating country-specific learning expectations. This adaptability is crucial for widespread implementation and sustainable use across diverse educational systems.

Empirical findings, based on testing with 208 students across three educational levels, revealed recurring difficulties with foundational concepts – particularly set operations, addition and subtraction of negative numbers, and multiplication with parentheses. In many cases, fewer than 50% of students correctly answered tasks involving operations with brackets or more complex symbolic representations.

The results indicate that students often rely heavily on calculators and multiple-choice formats, limiting their capacity for independent reasoning and deep conceptual understanding. Set theory and basic integer operations, which reappear at higher educational levels, were especially weak points, highlighting the importance of reinforcing these early and consistently.

Crucially, teacher feedback gathered during the project strongly supported the introduction of unplugged, hands-on activities to address these weaknesses. Practical tasks – such as puzzles, classification challenges, or tangram-based spatial reasoning – were identified as effective tools for promoting CT and AT simultaneously. Teachers emphasized that such activities support exploratory and collaborative learning, helping students to internalize abstract mathematical ideas through tangible, engaging experiences. These tasks can be easily integrated into both mathematics and informatics lessons, creating synergy between the subjects. As demonstrated by the sample tasks included in the project (Sarmasági *et al.*, 2024), unplugged approaches not only help build conceptual understanding but also reduce overdependence on digital tools.

Together, these findings underscore the need for a more intensive, structured, and practical approach to teaching fundamental mathematical concepts in a way that naturally develops CT and AT. Learning paths that combine gradual conceptual development with hands-on, unplugged activities have strong potential to improve student engagement, retention, and long-term proficiency.

Future work should continue to refine these tasks, test their effectiveness in diverse classroom environments, and provide educators with targeted professional development. Ultimately, fostering CT and AT through mathematics instruction equips students not only for success in school but also for the challenges of a digital and data-driven world.

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