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Abstract

The study focuses on the identification of relationships and/or rules between computational thinking (CT) concepts among the undergraduate students of Applied Informatics due to their attitudes towards mathematics. We analyze three CT concepts - decomposition, pattern recognition, and algorithmic thinking. We assume that students who have a closer relationship with mathematics, a positive attitude towards mathematics, have better developed CT. We conducted the experiment during the 2022/2023 academic year on the Information Coding and Displaying subject. The results indicate that those students who have no relationship to mathematics, negative attitude towards mathematics, have no problem with decomposition and pattern recognition, but without significant algorithmic thinking. On the other hand, students who have a close relationship with mathematics are also able to decompose or recognize patterns, but moreover they have shown algorithmic thinking. The contribution of the study comprises the identification of relationships and/or patterns of computational thinking concepts among students who have a relationship to mathematics, who cannot assess their relationship to mathematics, as well as among students who have no relationship to mathematics. Our results indicate a different occurrence of computational thinking concepts as well as links and/or relationships between them.

Introduction

In information society, learning and teaching methodologies are constantly changing as a result of ICT (Information and Communication Technology) tools use. Digital technologies have a significant impact on people's everyday life, for example, on entertainment, spending leisure time, information acquisition and transmission (Fülöp, Udvaros, Gubán, & Sándor, 2022; Llorens-Largo, 2015). The process of teaching undergraduate computer science students is set up in such a way that they develop their computational thinking during their time studying computer science. The acquired knowledge and skills can then be applied not only in computer science itself, but also in solving mathematical and other logical problems in practical life.

Deng, Benckendorff, and Gannaway (2020) confirmed that students' attitudes during the learning process can determine their academic achievement. A positive attitude stimulates students' interest and enthusiasm which promote their acquisition of knowledge and skills (Sun, Hu, & Zhou, 2022; Song, Hong, & Oh, 2021). Nowadays, the trend is to have a negative attitude towards mathematics rather than a positive one. The attitude plays a fundamental role in students' academic achievement, especially in mathematics (Stipek & Granlinski, 1991).

The term attitude is not a new concept in mathematics education (Wakhata, Muta-rutinya, & Balimuttajjo, 2022). The attitude towards mathematics is shaped by cognitive and behavioral components, which influence not only the learning itself, but also the student's performance (De-la-Peña, Fernádez-Cézar, & Solano-Pinto, 2021). Attitude towards mathematics refers to beliefs about the interest of students in performing mathematical tasks (Rodríguez, Regueiro, Piñeiro, Estévez, & Valle, 2020). Students with a positive attitude towards mathematics tend to understand the mathematical principles, rules and relationships among the variables (Kiwanuka, Van Damme, Van den Noortgate, & Reynolds, 2020). They perceive mathematics as a valuable subject and feel confident in math (Fishbein, Martin, Mullis, & Foy, 2018). Students' attitude towards mathematics positively impacts their performance and achievement in mathematics (Chen et al., 2018; Dowker, Cheriton, Horton, & Mark, 2019).

Several studies e.g. (Aboelmagd, 2018; Wakhata, Mutarutinya, & Balimuttajjo, 2023; Davadas & Lay, 2020; Primi, Bacherini, Beccari, & Donati, 2020) have investigated the relationship between attitude towards mathematics and achievement in mathematics in different contexts, but not in relation to computational thinking. The computational thinking term has been used since the 1950s and involves the use of structured, i.e. algorithmic thinking to produce the correct output for a given input (Denning, 2017). Computational thinking regained its popularity in the early third millennium. In 2006, Wing began to study this term and defined computational thinking as a process that involves problem solving, system design, and human behavior understanding, building on the basic concepts of computer science (Wing, 2006).

Since researchers have not yet achieved a unified definition of computational thinking, there are several definitions of the term. In order to understand the concept in its essence, we need to consider two aspects. From the first point of view, we look at computational thinking in the context of specific scientific disciplines. This aspect includes the views of experts who consider computational thinking to be, among other things, the application of computational tools and techniques to understand natural and artificial information systems (Csizmadia et al., 2015). Another group of researchers considers computational thinking as a mental process that results in the solution of computational problems, and we can imagine the mental process as algorithm design, analysis, data representation and collection, simulation, parallelization, generalization, and pattern recognition (Chunhua, Feiming, & Pingfei, 2022). The second aspect includes the skills and qualities of a person such as confidence, perseverance, or everyday problem-solving skills that a person can apply to solve informatics problems (Selby & Woolard, 2013). However, a growing number of researchers believe that computational thinking is a way of thinking that is related to everyday problem-solving skills and it is a fundamental skill that can be a typical for anyone (Wing, 2006).

Computational thinking is a universally applicable tool and set of skills that everyone, not just computer scientists, would like to learn and use (Wing, 2006). Wing's view is that this new competency should be added to every child's analytical skills as an important component of learning science, technology, engineering and mathematics. Wing (2006) specified 4 key concepts of computational thinking: decomposition, pattern recognition, abstraction and algorithms. Sanz (2015) believes that computational thinking helps to decompose problems into smaller parts called subproblems. It can be applied not only in programming, but also in understanding the components of a problem and the way to deal with them, in pattern recognition, in extrapolations solution, and also in other disciplines such as mathematics when solving verbal problems or more complex assignments where students have to use more different computational techniques to reach the correct result.

According to Wing (2006), computational thinking has the following characteristics:

- Computational thinking is a concept based on computer science concepts with a high degree of abstraction, not only on programming.
- It provides pupils with the basic skills for life in a society with permanent development, and not with skills that are characterized by monotony and lack of adaptation to development.
- It simulates the way humans think when solving problems; its goal is not to make humans think and solve problems the same way a machine does; humans are intelligent and are able to innovate and adapt to problems.
- It combines mathematical and engineering thinking, and is applied to building systems that are intelligent and interact with people.
- Computational thinking can be applied by all members of society, of all ages, of all specializations, as long as they have the desire to learn. It is the current reality and the new human philosophy in the twenty-first century.

A number of surveys have investigated the impact of CT, but one interesting survey has tracked the evolution of interest in CT, specifically the number of papers published on CT over a selected time period. Subramaniam, Mahmud, and Maat (2022) conducted a survey during which he performed a search of the Scopus and WoS databases for publications related to CT as they meet the criteria for quality and nature of publications, especially in the field of education. He used CT related keywords in the field of mathematical education for the search. He did a screening, which he then limited to items published between 2016 and 2022; the author decided to examine only empirical research papers written in English. Through the research, he found that the number of articles on CT in mathematics education increased slightly between 2016 and 2017. From 2018 onwards, there was a downward trend until 2019, at which point there began to be a much more pronounced increase in interest until 2022.

A number of research studies are tracking the use of CT in primary and secondary schools. One of them is research on the application of computational thinking during the teaching of algorithms and programming (Angeli & Giannakos, 2020). It focuses on the skills that children develop when practicing algorithms and programming and allows for the development of characteristics (all 4 concepts of CT) such as abstract thinking, problem solving, pattern recognition, and logical reasoning. Other well-known research studies covering different aspects of CT learning focus on, e.g., the use of metaphors during the teaching of introductory programming Marín, Neira, Bacelo, and Pizarro-Romero (2020), the development of CT skills in young children during coding instruction Papavlasopoulou, Sharma, and Giannakos (2020), and using scaffolding strategies and educational robotics (Angeli & Valanides, 2020). They were implemented with K-12 students. Chalmers (2018) reports how, during the study, teachers integrated coding and robotics into lessons during which pupils were introduced to LEGO and WeDO 2.0 robotic kits, and how this influenced pupils' computational thinking. It reported that these methods contributed to the development of CT and suggested using robotic building blocks to develop students' CT skills in primary school (Chalmers, 2018; Balcombe & De Leo, 2022; Sanchez et al, 2021).

Kang, Liu, Zhu, Li, and Zeng (2022) developed a test (assessment) apparatus for computational thinking of university students. Computational thinking must be decomposed into a set of well-defined and measurable skills, concepts, or practices (Weintrop & Wilensky, 2015). Based on this, they isolated five basic skills elements of computational thinking, which are abstraction, decomposition, algorithm, evaluation, and generalization. In all absurdity, it is assumed that these five elements are disentangling for understanding, analyzing and solving problems. The test is based on solving practical life situations. After applying it to students, it was found that students showed considerable differences in the five dimensions depending on their field of study. The best results were achieved by students of mathematics and computer science, the worst by students of psychology and languages. Thus, the research confirmed the apparent link between mathematical thinking and CT. The application of mathematics is necessary for mathematical thinking to solve mathematical problems such as equations and functions (Sneider, Stephenson, Schafer, & Flick, 2014). Both computational thinking and mathematical thinking are necessary for problem-solving processes (Wing, 2006). The application of both computational and mathematical thinking in the teaching of computer science students has been addressed in research conducted during several programming classes aimed at solving the Knight's Tour Problem, a chess problem (Gonda, Ďuriš, Tirpáková, & Pavlovičová, 2020). The improvement in CT was also demonstrated during research conducted during several mathematics lessons aimed at solving problems on the topic of graphs of functions and their properties using graphing and computing software (Országhová, 2022). Fülöp et al. (2022) investigated the results of exams over the last 5 years in the object-oriented programming course at Budapest Business School. The results showed that the level of concrete computational thinking could be measured using the exam results and the teacher's experience and their application in teaching improved the level of concrete computational thinking. The author further states that the introduction of microcontroller programming is considered as a suitable way to develop concrete computational thinking. The four important key techniques of computational thinking defined by the author Wing (2006), namely decomposition, pattern recognition, abstraction and algorithms, can be suitably applied in teaching programming with microcontrollers.

Computational thinking can be applied in many fields of natural and technical sciences that use modelling, simulation, data mining, machine learning and Big Data Analysis. Using computational thinking skills in education does not necessarily mean using devices. Rather, it means using the best problem-solving strategies alongside mathematical and algorithmic thinking to teach students to solve problems in innovative ways based on a scientific approach (Gonda, Ďuriš, Pavlovičová, & Tirpáková, 2020).Shute, Sun, and Asbell-Clarke (2017) discussed the differences between computational thinking and other types of thinking. They compared computational thinking with mathematical, engineering, design, and systems thinking. In their paper, they described the relationship between computational thinking, computer science and programming. Mathematical thinking has also been explored in research conducted during online teaching of undergraduate and graduate students Gonda, Ďuriš, Pavlovičová, and Tirpáková (2020) and it has been used during the teaching of combinatorics in high school (Ďuriš, Pavlovičová, Gonda, & Tirpáková, 2021).

Methods

Information Coding and Displaying Subject is taught at the Department of Informatics, Faculty of Natural Sciences and Informatics, Constantine the Philosopher University in Nitra, Slovakia, for 1st year bachelor students of the Applied Informatics study program and the Informatics teaching study program in the winter semester. This year, about 114 students registered for this subject. The subject is taught in the form of lectures (two hours per week) and exercises (two hours per week). The subject is mostly theoretical, it provides mathematical fundamentals necessary to study informatics subjects. As Wing (2006) states, computational thinking consists of four concepts: decomposition, pattern recognition, abstraction, and algorithmic thinking. Decomposition means breaking down a complex problem into smaller simpler problems. Pattern recognition describes the search for similarities between parts of a complex problem. Abstraction means focusing only on the main information. Algorithmic thinking describes the method of individual smaller problems solving (Selby & Woolard, 2020).

To investigate the rate of students' application of computational thinking during the Information Coding and Displaying Subject teaching, we selected a task from propositional logic.

> Task: *There are three machines A, B, C in the workshop, which work according to the following conditions:*
>
> *a) If machine A is working, so is machine B.*
>
> *b) Machine B is working or machine C is working.*
>
> *c) When machine A is not working, neither is machine C.*
>
> *What are the possibilities for running the workshop?*

There were given 3 statements, so called assumptions, and the task was to express the conclusions arising from them, i.e. to find the propositional formula which is the semantic consequence of the given statements. The solution was to consist of several steps, which we classified as computational thinking concepts. The first step of the solution was to identify simple assertions in the given statements, name them using propositional variables, and rewrite the given statements using these variables into propositional formulas (decomposition D). The next step was to construct a truth table to evaluate these propositional formulas, as well as to evaluate conjunction of these formulas (pattern recognition PR). The third step was evaluation, marking the solutions and expressing the semantic consequence of the given statements (algorithmic thinking AT).

Research Question and Objective

The aim of the study is to identify relationships and rules between CT concepts among the undergraduate students of Applied Informatics. For this purpose, we distributed a questionnaire among students at the beginning of the semester, in which we investigated their relationship to mathematics (from none to very close) using a 5-point Likert scale. We examined students´ CT concepts and their use when solving a task of propositional logic. We assumed that students who have a closer relationship with mathematics have better developed CT.

We formulate the following questions:

- To what extent can students of applied informatics apply CT concepts when solving a mathematical problem?
- Do students with a positive attitude towards mathematics use the same CT concepts as students who have no relationship to mathematics?
- Does a positive attitude towards mathematics predict computational thinking?

We conducted the experiment during the 2022/2023 academic year on Information Coding and Displaying subject. This subject is precisely focused on the development of CT, as students become familiar with the principles of natural language coding, with logical and arithmetic operations of coded text, and/or the display of coded information and subsequent decoding in natural language. During lectures and exercises, students develop all four basic CT concepts, i.e. decomposition (D), pattern recognition (PR), abstraction (A) and algorithmic thinking (AT) as mentioned above.

In the presented study, we analyze three concepts of CT - decomposition (process of breaking down problems into smaller), pattern recognition (connections and similarities among the different parts) and algorithmic thinking (problem-solving process). We specifically focus on their application, and/or use by students in the task of propositional and predicate logic. Within the provided student solutions, we identified the application of individual CT concepts. Two teachers coded their solutions into three concepts of computational thinking to guarantee objectivity.

As part of the decomposition concept, we recorded whether students correctly encoded natural language into logic statements, i.e. whether they correctly encoded the statements into the variables (D1) and subsequently whether they correctly created the assumption and conclusion using the variables (D2). As part of pattern recognition, we distinguished whether the students correctly selected the rules of propositional and predicate logic (PR1) and subsequently whether they correctly determined the truth values (PR2). In the last concept of algorithmic thinking, we focused our attention on labelling solutions within the truth table (AT1) and expressing conclusions (AT2).

Participants

In total, 114 students of the first year of Applied Informatics took apart (see Table 1). Of 114, 10 students had no relation to mathematics, 25 students rather no relation, 44 students neither, 30 students rather a close relation and 5 students have a very close relation to mathematics (see Table 1). These findings are in accordance with Kalder and Lesik (2011), who found three types of relationships, and/or profiles of attitude towards mathematics -

negative, neutral, and positive - and also with Berger, Mackenzie, and Holmes (2020), who found four types of relationships, and/or attitudes towards mathematics - negative, neutral, positive, and very positive.

Table 1. Descriptive Statistics 5-point Scale – Frequency

RtoM	Count	Cumulative Count	Percent	Cumulative Percent
1	10	10	8.77	8.77
2	25	35	21.93	30.70
3	44	79	38.60	69.30
4	30	109	26.32	95.61
5	5	114	4.39	100.00
		114	0.00	100.00

Considering the uneven representation for individual categories, we allowed ourselves to transform the 5-point scale into a threepoint scale, the result of which is the division of students into three equally represented categories - students who have a relationship with mathematics, students who cannot express themselves whether they are or are not related to mathematics and students who are not related to mathematics (see Table 2).

Table 2. Descriptive Statistics 3-point Scale – Frequency

RtoM	Count	Cumulative Count	Percent	Cumulative Percent
none	35	35	30.70	30.70
neither	44	79	38.60	69.30
none	35	114	30.70	100.00
		114	0.00	100.00

Method

Association rules analysis is a technique which helps us to discover the relationships between the examined items – CT concepts, i.e. to find frequent patterns, associations, or correlations among examined CT concepts (D1, D2, PR1, PR2, AT1, and AT2). In our study to find frequent patterns during a problem-solving task (similar to Market Basket Analysis, a basket = a task).

There are three main measures of rule interest, which represent the strength of the rule:

1. *Support* - how frequently a CT concept A is used:
   support $(CT\ concept\ A) = \frac{frequency\ of\ (CT\ conceptA)}{number\ of\ transactions\ in\ the\ dataset} * 100$,
2. *Confidence* - how likely a CT concept A is used when a CT concept B is used in task solving:
   $confidence\ (if\ CT\ concept\ A\ then\ B) = \frac{support\ (if\ CT\ concept\ A\ then\ B)}{support\ (CT\ concept\ in\ the\ dataset)} * 100$,
3. *Lift or Interest or Correlation* - how likely CT concept A is used when CT concept B is used, while checking for how frequently CT concept B is used
   $lift\ (if\ CT\ concept\ A\ then\ B) = \frac{confidence\ (if\ A\ then\ B)}{support\ (\mathrm{B})}$.

Results

We used association rules to analyze the frequency of occurrence of individual CT concepts and to determine their mutual relationships given the support. We sorted the association rules created by students who have no relation to mathematics according to the probability of occurrence (see Table 3). Out of 35 students in the task focused on propositional and predicative logic, 30 students correctly decomposed the statements into variables, but only 26 students could correctly choose the rule (recognize the pattern) and 23 correctly evaluated the truth statements, with support greater than 65%.

From the point of view of pairs of CT concepts, i.e. associations, students who knew how to break down statements into variables were also able to correctly choose or use rules to determine the truth value (with the support of more than 65%). And on the other hand, students who do not have a well-established algorithmic thinking, not only did not know how to correctly determine the solution, but also did not know how to draw a conclusion for the given task, despite the fact that they knew how to correctly decompose into variables (support of approx. 51%). An interesting finding shows that, despite the fact that the students have no relation to mathematics, up to 23 students had no problem with decomposition and recognizing patterns, i.e. the rules of predicative logic (support of about 65%), but without significant algorithmic thinking.

Table 3. Frequency of Occurrence of CT Concepts and their Combinations - no Relation to Mathematics, with the Support of min. 50%

Frequent itemsets	Length	Frequency	Support (%)
D1 == 1	1	30	85.71
PR1 == 1	1	26	74.29
AT2 == 0	1	26	74.29
PR2 == 1	1	23	65.71
AT1 == 0	1	23	65.71
D2 == 0	1	19	54.29
D1 == 1, PR1 == 1	2	25	71.43
D1 == 1, PR2 == 1	2	23	65.71
PR1 == 1, PR2 == 1	2	23	65.71
AT1 == 0, AT2 == 0	2	22	62.86
D1 == 1, AT2 == 0	2	21	60.00
D1 == 1, AT1 == 0	2	18	51.43
PR1 == 1, AT2 == 0	2	18	51.43
D1 == 1, PR1 == 1, PR2 == 1	3	23	65.71

Despite the fact that the students have neither a close nor any relationship with mathematics (see Table 4), up to 36 out of 44 students correctly divided the statements into variables (with the support of approx. 81%) and 33 students also recognized the correct patterns, and/or rules (with 75% support). However, only 27 students (with the support of 61%) knew how to use them correctly. If we look at the results from the point of view of associations, interesting relationships are shown, such as between the decomposition into variables and the recognition of patterns, and/or rules.

Table 4. Frequency of Occurrence of CT Concepts and their Combinations – neither Positive nor Negative Relation to Mathematics, with the Support of min. 50%

Frequent itemsets	Length	Frequency	Support (%)
D1 == 1	1	36	81.82
AT2 == 0	1	35	79.55
PR1 == 1	1	33	75.00
AT1 == 0	1	28	63.64
D2 == 1	1	27	61.36
PR2 == 1	1	27	61.36
D1 == 1, PR1 == 1	2	33	75.00
D1 == 1, D2 == 1	2	27	61.36
D1 == 1, PR2 == 1	2	27	61.36
D1 == 1, AT2 == 0	2	27	61.36
PR1 == 1, PR2 == 1	2	27	61.36
AT1 == 0, AT2 == 0	2	27	61.36
D2 == 1, PR1 == 1	2	26	59.09
PR1 == 1, AT2 == 0	2	24	54.55
D1 == 1, PR1 == 1, PR2 == 1	3	27	61.36
D1 == 1, D2 == 1, PR1 == 1	3	26	59.09
D1 == 1, PR1 == 1, AT2 == 0	3	24	54.55

Also on the other hand, the relationship between these two concepts and algorithmic thinking is not shown in students who cannot characterize their relationship to mathematics. Students who have a close relationship with mathematics within CT (see Table 5) do not have a problem with decomposition or recognizing patterns, in our case propositional rules (with the support of more than 57%) and they even show algorithmic thinking when solving tasks aimed at propositional and predicate logic (with the support of more than 51%).

If we compare the most frequently occurring triplet of CT concepts (with at least 50% support), then for students with no relation to mathematics, the most frequent and only triplet was (D1, PR1, PR2), i.e. decomposition into variables, subsequent selection of suitable logical rules, their entry into the table of truth values and its evaluation (see Table 3). For students who could not express their relationship to mathematics (with the support of at least 50%), three triplets (D1, PR1, PR2), (D1, D2, PR1), and (D1, PR1, AT2) with the support of more than 54% (see Table 4) occurred. The difference between the previous students and these students is that these students could also identify relationships between variables (in decomposition), but they still did not demonstrate sufficient algorithmic thinking when solving the tasks.

The greatest variety of triplets and even foursomes of CT concepts was shown among students who have a relationship with mathematics (see Table 5). We identified up to seven different triplets and two different foursomes of CT concepts with more than 50% support (see Table 5). The results indicate that, in addition to the decomposition into variables, the students also know how to correctly determine the relationships between them, subsequently they can correctly recognize the pattern, or rule of propositional and predicate logic and apply it correctly. In addition, students can correctly calculate the entire algorithm for solving the task, but the result of algorithmic thinking cannot be fully decoded in natural language, i.e. draw a conclusion of propositional and predicate logic in natural language.

Table 5. Frequency of Occurrence of CT Concepts and their Combinations - Close Relationship to Mathematics, with the Support of min. 50%

Frequent itemsets	Length	Frequency	Support (%)
D1 == 1	1	27	77.14
PR1 == 1	1	25	71.43
D2 == 1	1	23	65.71
PR2 == 1	1	21	60.00
AT2 == 0	1	21	60.00
AT1 == 1	1	18	51.43
D1 == 1, PR1 == 1	2	25	71.43
D1 == 1, D2 == 1	2	23	65.71
D2 == 1, PR1 == 1	2	22	62.86
D1 == 1, PR2 == 1	2	21	60.00
PR1 == 1, PR2 == 1	2	21	60.00
D2 == 1, PR2 == 1	2	20	57.14
D1 == 1, AT1 == 1	2	18	51.43
D2 == 1, AT1 == 1	2	18	51.43
PR1 == 1, AT1 == 1	2	18	51.43
D1 == 1, D2 == 1, PR1 == 1	3	22	62.86
D1 == 1, PR1 == 1, PR2 == 1	3	21	60.00
D1 == 1, D2 == 1, PR2 == 1	3	20	57.14
D2 == 1, PR1 == 1, PR2 == 1	3	20	57.14
D1 == 1, D2 == 1, AT1 == 1	3	18	51.43
D1 == 1, PR1 == 1, AT1 == 1	3	18	51.43
D2 == 1, PR1 == 1, AT1 == 1	3	18	51.43
D1 == 1, D2 == 1, PR1 == 1, PR2 == 1	4	20	57.14
D1 == 1, D2 == 1, PR1 == 1, AT1 == 1	4	18	51.43

The web graph (see Figure 1) depicts the discovered association rules among students who have no relationship to mathematics. The size of the node represents the support of incidence of the CT concept, the thickness of the line represents the support of rule – pairs of the CT concepts (probability of occurrence in pair) and the darkness of the line color presents a lift of the rule. Association rules represent not only the power of the occurrence of either one concept or a pair, or triplets (the bigger the node, the higher the occurrence), but also the link between them (the darker the link of the nodes, the stronger the link).

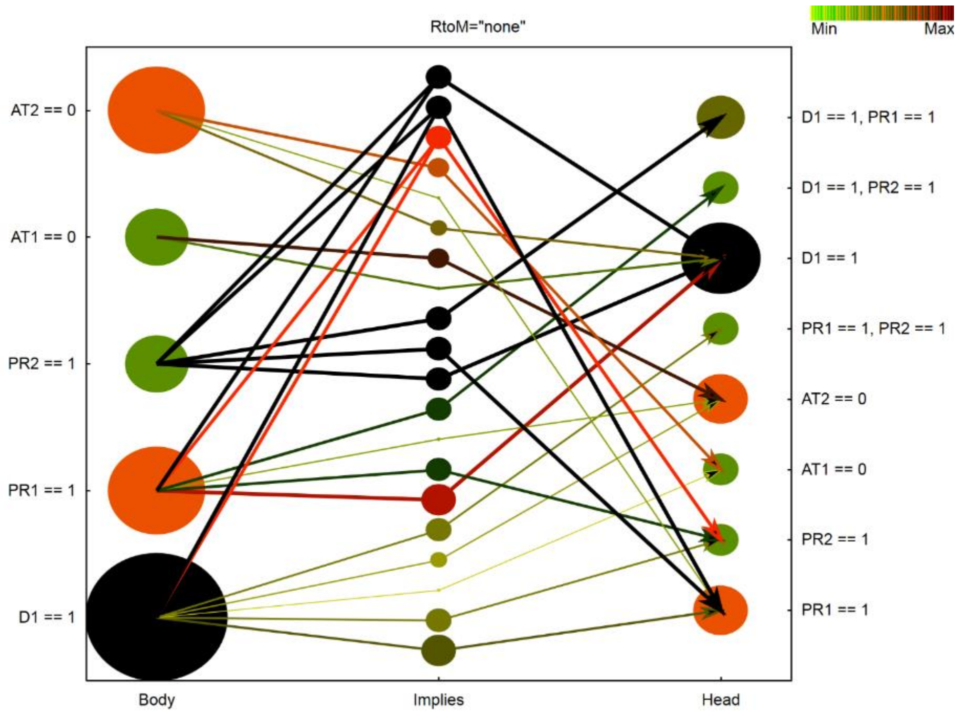

Figure 1. Association Rules Found among Students – no Relation to Mathematics

For students with no relation to mathematics, several strong relationships emerged with support greater than 50% (see Figure 1). With a probability of p = 1, it was shown that if the students were able to correctly decompose into variables (D1) and recognize the correct rule (PR1), they could also correctly apply it to the given variables (PR2). Conversely, the least likely relationship was between algorithmic thinking and decomposition or pattern recognition. In other words, only with a probability of 0.6, there is a link between correctly decomposing and variables and not showing (expressing) algorithmic thinking. The fact that a student correctly decomposes a task of propositional and predicate logic into variables and determines the correct rules does not guarantee that she/he has algorithmic thinking. Our results even indicate that the first two concepts are not related, or only very slightly with the algorithmic thinking of students who have no relation to mathematics. Moreover, the variability and connection between frequent concepts is low (see Figure 1).

Other association rules were found among students who stated that they have neither any nor a close relationship with mathematics (see Figure 2). Students show greater variability in the use of concepts as well as their combination compared to students with no relation to mathematics. An interesting finding is the concept of decomposition, but in the sense of determining relationships between variables. While students who had no relation to mathematics skipped this step when solving task of propositional and predicate logic, i.e. they did not make a note of the assumptions, students with unexpressed relation to mathematics expressed the relationships in the assumptions. If they correctly wrote the relationships in the assumptions, then they correctly decomposed them into variables and recognized the rules of propositional and predicate logic with probability p = 0.96. However, just like the previous students, the relationship between their algorithmic thinking and decomposition, or pattern recognition, was not proven. If they did not demonstrate algorithmic thinking in the task, then at 68.57% they were still able to correctly decompose into variables and determine the rule.

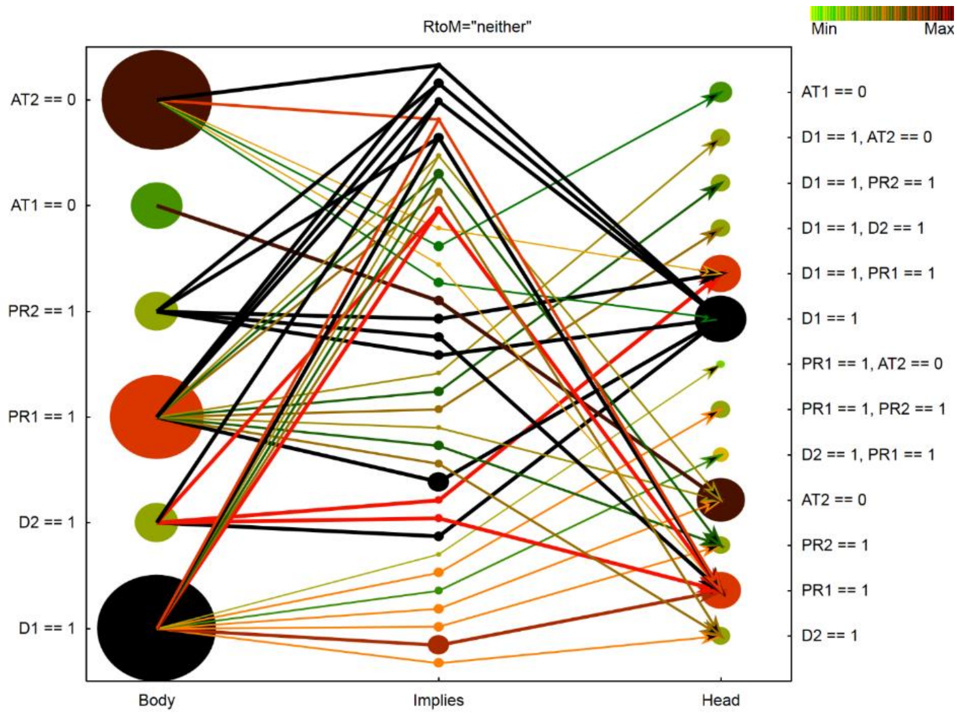

Figure 2. Association Rules Found among Students – Unexpressed Relation to Mathematics

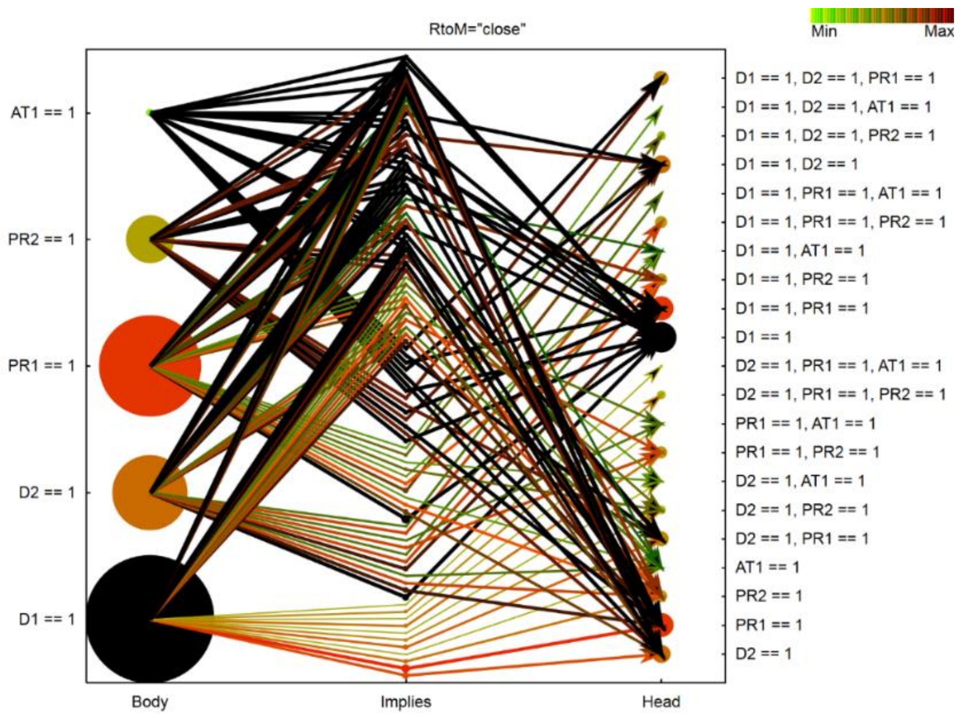

Figure 3. Association Rules Found among Students – Close Relation to Mathematics

As assumed, different rules were found among students who have a close relationship with mathematics (see

Figure 3). Not only is there a more diverse connection between individual CT concepts, but also their pairs and triplets. If they demonstrated algorithmic thinking, then with a probability of $p = 1$, they correctly determined the relationships in the assumptions and recognized the patterns according to which they applied the rules of propositional and predicate logic. And on the other hand, with only a probability of $p = 0.8182$, if they correctly determined the relationships in the assumption and recognized the pattern, they were able to think algorithmically and draw a conclusion, and/or consequence and with only a probability of $p = 0.7826$ based only on the determination of the relations in the assumption.

Discussion

The analysis of the studies shows a high and a currently increasing interest of teachers in the use of computational thinking in teaching Subramaniam et al. (2022). The researches described in the paper were mainly focused on investigating the links between mathematical thinking and computational thinking; in our case, we focused more closely on the association between interest in mathematics and selected computational thinking concepts individually. In all of the studies described, the research focused on all the concepts of computational thinking as a whole, but in none of these studies was the research focused on a particular concept of computational thinking.

The research described above has examined the development of all 4 concepts of computational thinking as a whole during primary and secondary school teaching. Mostly it was about teaching algorithmization and programming (Angeli & Giannakos, 2020). Specifically, it was about incorporating different activities and strategies into the programming teaching, e.g. coding teaching, learning through play, using scaffolding strategies, working with robot kits, etc. (Marín et al., 2020; Papavlasopoulou et al., 2020; Angeli & Valanides, 2020; Chalmers, 2018; Balcombe & De Leo, 2022; Sanchez et al., 2021).

Since we conducted our research at a university, we focused more on studies conducted at universities. One focused on testing the use of computational thinking in the context of a student's field of study. The results of students of many disciplines were compared. The best results were achieved by students of mathematics and computer science, while students of psychology and languages achieved the worst results (Fülöp et al., 2022). Not only this research, but also many others, showed an obvious link between computational thinking and mathematical thinking. Similar results have been found by research realized during several programming lessons aimed at solving a chess problem Gonda, Ďuriš, Tirpáková, and Pavlovičová (2020), during several mathematics lessons focused on solving problems from the graphs of functions topic Országhová (2022), during teaching programming using microcontrollers Fülöp et al. (2022), etc. All of these investigations have demonstrated the improvement in the level of computational thinking by applying the solution of the problems mentioned above. All above mentioned researches conducted in primary, secondary and higher education institutions have investigated the impact of applying the solutions of the problems described above during the teaching of different subjects on computational thinking as a whole, i.e. on all of its 4 concepts. In contrast, we have focused our research on the impact of mathematical thinking, specifically on interest in mathematics and on specific computational thinking concepts individually, which we consider to be an important contribution to the exploration of this issue.

Conclusion

Computational thinking is often regarded as a crucial soft skill, providing a “soft start” for later involvement with artificial intelligence (Nordby, Bjerke, & Mifsud, 2022). The present research was aimed at investigating the relationship between students' attitude towards mathematics and at the application of 3 computational thinking concepts by students during solving a computational problem from the propositional and predicate logic. Our findings correspond to Hwang and Son (2021), who discovered a positive relationship between students’ attitudes toward mathematics and mathematics achievement.

We can perceive the contribution of the study from two points of view. We have no knowledge of anyone researching or tried to identify relationships and/or links among the concepts of computational thinking (decomposition, pattern recognition, and algorithmic thinking) in the context of solving propositional logic tasks. From this point of view, the research is original. The second practical contribution of the study comprises the identification of relationships and/or patterns of computational thinking concepts among students who have a relationship to mathematics, who cannot assess their relationship to mathematics, as well as among students who have no relationship to mathematics. Our results indicate a different occurrence of computational thinking concepts as well as links and/or relationships between them. Our findings are in line with Mensah and Okyere (2019), the more students advance in mathematics courses, the more they develop an interest in mathematics. The study sample consisted of 114 students. To confirm our findings, we plan to repeat the research in the future with a larger group of students, or to investigate how students manage to apply specific computational thinking concepts when solving other types of problems. We consider the contribution of the research to be the exploration of specific computational thinking concepts, not just the application of computational thinking by students in general. In this context, we are not aware of similar research being conducted focusing on specific computational thinking concepts.

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