Computational Thinking vs Artificial Intelligence in Mathematics Teaching

Jaime Carvalho e Silva*

University of Coimbra, Department of Mathematics, CMUC, 3000-143 Coimbra, Portugal

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ABSTRACT
The use of technologies in mathematics education at all levels has been discussed extensively for a number of years. It is one of the few themes that was the object of two ICMI studies, the most recent being published in 2010.

Two new approaches, emerging lately in the teaching and learning of Mathematics at all levels, will be discussed: Computational Thinking (CT) and Artificial Intelligence (AI). We will discuss both in comparison, arguing they are very different and can even induce very different directions to Mathematics Education.

Considering the CT approach as a variation on the theme of Problem Solving puts it as a skill that is as fundamental as numeracy. AI is also connected to problem solving as an emulator of human problem solving approaches. Inappropriate use of AI has been considered problematic, being called a "stochastic parrot".

We will try here to compare CT and AI using Curriculum Analysis: which are the educational purposes, which relevant experiences can we point out, how can these be implemented in school, how are they effective. We will argue that CT is important in introducing an "algorithmic dimension of mathematics" in Mathematics Teaching and that AI in its present form as Generative AI is not adequate to develop concepts of mathematical literacy.

We will show how the "algorithmic dimension of mathematics" can be implemented in school with the example of the curricular options that were made in the new curriculum for Mathematics in Portugal.

KEYWORDS
Computational Thinking; Artificial Intelligence; Mathematics Teaching

1. Introduction

The use of technologies in mathematics education at all levels has been discussed, analysed and documented extensively for a number of years. It is one of the few themes that was the object of two ICMI studies, published in 1986 and 2010. In the introduction to this last study it is stated that digital technologies are "becoming more ubiquitous" and it is "hard to conceive of a world without high-level interactivity and connectivity" (Hoyles & Lagrange, 2010). ICMI, the International Commission on Mathematical Instruction, is a worldwide organisation devoted to research and development in mathematical education at all levels and is the biggest international

CONTACT* Email: jaimecs@mat.uc.pt
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organisation working on mathematics education. So far it produced 25 studies and two more are being prepared.

The evolution of technology is so fast that two new approaches, emerging lately in the teaching and learning of Mathematics at all levels, Computational Thinking and Artificial Intelligence, are not mentioned there. We will discuss both in comparison, arguing they are very different and can even induce very different directions to Mathematics Education.

A very recent paper with a systematic review on the integration of Computational Thinking (CT) in mathematics education concludes that "CT-based mathematics learning entails an interactive and cyclical process of reasoning mathematically and reasoning computationally" (Ye et al., 2023).

The author considers the CT approach as a variation on the theme of Problem Solving and it is no surprise that a recent report considers "Computational Thinking and related concepts (...) have been promoted by educational stakeholders as skills that are as fundamental for all as numeracy and literacy" (Bocconi et al., 2016).

Artificial Intelligence (AI) is also connected to problem solving in that it tries to emulate human problem solving approaches. The temptation to rely on AI to solve problems is real. Some argue that "The debate and the innovation should focus on the potential benefits of Generative Artificial Intelligence, such as improved learning, teaching" (Gimpel et al., 2023). Others have identified a number of dangers of inappropriate use of AI namely Large Language Models (LLM) like ChatGPT: "a system for haphazardly stitching together sequences of linguistic forms" but "without any reference to meaning: a stochastic parrot" (Bender et al., 2021).

We will try here to compare "Computational Thinking" and "Artificial Intelligence" using Curriculum Analysis: which are the educational purposes, which relevant experiences can we point out, how can these be implemented in school, how are they effective. We will stress the point of view of quality Mathematics teaching, in the perspective of the technological tools that better reflect changes in mathematical and societal practices.

The use of Technology in Mathematics Teaching has been discussed in many important international documents. We will use as framework the UNESCO position paper (UNESCO - Education Sector, 2012), made in collaboration with ICMI. In it we can read:

> (...) the concept of mathematical literacy should take into account the technological tools that are used in social practices today and, in particular, in basic education, the practices of calculation. The expansion of access to data, means of representation, interaction among representations produced by digital technologies and the way in which technological development influences the development of mathematics itself (...) (UNESCO - Education Sector, 2012, p. 35).

There are difficulties and it is recognised that "Basic mathematics education is still all too often boring because (...) technology is quite rarely used in a relevant manner" (UNESCO - Education Sector, 2012, p. 21). There is also another challenge specific to the speed of the evolution of technology:

> (...) the teaching of mathematics must be adapted continuously to developments in mathematical sciences and their relations with the outside world, changes in social demands, developments in teaching conditions and resources, especially technological resources (...) (UNESCO - Education Sector, 2012, p. 27).

The use of technology in Mathematics teaching is clearly unavoidable, however difficult and challenging it may be:

> Account must be taken of changes in mathematical practices closely related to technological change, as evidenced by the importance and rising profile of experimental mathematics, the technological support for calculation, visualisation and simulation, the strengthening of and new approach to the algorithmic dimension of mathematics, the reasoned and effective management of the current diversity of information sources and possible modes of collaborative work. (UNESCO - Education Sector, 2012, p. 17).

A clear example of the difficulties pointed out in this UNESCO paper is the emergence of the two mentioned new approaches in the educational scene: "Computational Thinking" and "Artificial Intelligence", both within the "algorithmic dimension of mathematics". As the approach of problem solving using AI is very recent there are no substancial comparisons between the two, from the point of view of curriculum implementations.

We will try to show how "Computational Thinking" completely fulfils the inclusion in Mathematics Teaching of "changes in mathematical practices closely related to technological change" and how the present tools of "Artificial Intelligence" do not satisfy it "in a relevant manner".

We will show how the "algorithmic dimension of mathematics" can be implemented in school with the example of the curricular options that were made in the new curriculum for Mathematics in Portugal.

We will begin with some discussion around "Computational Thinking" and "Artificial Intelligence".

2. Computational Thinking

We will follow in this paper the definitions and examples of Computational Thinking mentioned in the report of the European Union "Developing computational thinking in compulsory education - Implications for policy and practice" (Bocconi et al., 2016). There it is written that "Computational Thinking (CT) is a thought process (or a human thinking skill) that uses analytic and algorithmic approaches to formulate, analyse and solve problems" (Bocconi et al., 2016, p. 9).

Jeanette Wing introduced the modern term "computational thinking" in 2006 this way:

> Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools that reflect the breadth of the field of computer science (Bocconi et al., 2016, p. 9).

The Computer Science Teachers Association and the International Society for Technology in Education produced lists with all the operations that constitute Computational Thinking as a practice. They are reproduced in this same report:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them;
- Logically organizing and analysing data;
- Representing data through abstractions such as models and simulations;
- Automating solutions through algorithmic thinking (a series of ordered steps);
- Identifying, analysing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources;
- Generalizing and transferring this problem-solving process to a wide variety of problems (Bocconi et al., 2016, p. 16).

It is clear that Computational Thinking is problem solving that uses at some point an algorithm to obtain a solution. This fits perfectly in mathematical problem solving that uses some kind of algorithm to get a solution, adding an "algorithmic dimension of mathematics".

3. Artificial Intelligence

We will follow the concepts, examples and classification of Artificial Intelligence contained in the web pages of the celebrated company IBM that can be accessed here:

`https://www.ibm.com/topics/artificial-intelligence`

There we can learn that Artificial intelligence is a technology that enables computers and machines to simulate human intelligence and problem-solving capabilities. We find again the process of problem solving, so there must be some connection with Computational Thinking.

IBM considers that there are two types of Artificial Intelligence (AI): weak AI and strong AI. Weak AI is defined as:

> (...) also known as narrow AI or artificial narrow intelligence (ANI) is AI trained and focused to perform specific tasks. Weak AI drives most of the AI that surrounds us today. "Narrow" might be a more apt descriptor for this type of AI as it is anything but weak: it enables some very robust applications, such as Apple's Siri, Amazon's Alexa, IBM watsonx, and self-driving vehicles.

Strong AI can be artificial general intelligence (AGI) or artificial super intelligence(ASI):

> Strong AI is made up of artificial general intelligence (AGI) and artificial super intelligence (ASI). AGI, or general AI, is a theoretical form of AI where a machine would have an intelligence equal to humans; it would be self-aware with a consciousness that would have the ability to solve problems, learn, and plan for the future. ASI?also known as superintelligence - would surpass the intelligence and ability of the human brain. While strong AI is still entirely theoretical with no practical examples in use today, that doesn't mean AI researchers aren't also exploring its development.

Weak AI is what we have today and artificial general intelligence seems a bit far, if even possible.

One of the most popular weak AI tools today is Generative Artificial intelligence in a context of the so called Large Language Models (LLM). According to IBM:

> Generative AI refers to deep-learning models that can take raw data - say, all of Wikipedia or the collected works of Rembrandt - and "learn" to generate statistically probable outputs when prompted. At a high level, generative models encode a simplified representation of their training data and draw from it to create a new work that's similar, but not identical, to the original data. Generative models have been used for years in statistics to analyze numerical data. The rise of deep learning, however, made it possible to extend them to images, speech, and other complex data types.

So, Generative AI, that includes the now famous ChatGPT, generates "statistically probable outputs when prompted". That is unique in the sense that the outputs are **probable** according to current written production but not necessarily **true**. And also unique because ChatGPT can solve some mathematical problems, even Olympiad type problems, failing at others (Tao, 2024).

The mathematician and Fields Medalist Terence Tao gave a talk organized by Oxford University in 2024 where he discusses the possible uses of ChatGPT in Mathematics and Science. He describes ChatGPT as a "guessing machine" that may be useful if we have some way of checking the results of ChatGPT (Tao, 2024). One of the examples he gives is for mathematics research to search for proposed new results or solutions that can then be checked automatically with other tools like automatic theorem provers.

4. Limitations of Artificial intelligence

Artificial intelligence is not a new topic. In fact, the mathematician Norbert Wiener (1894-1964) dedicated his research to this field, then called Cybernetics, and stated:

> Can man-made machines learn and can they reproduce themselves? We shall try to show in this chapter that in fact they can learn and can reproduce themselves, and we shall give an account of the technique needed for both these activities (Wiener, 1961, p. 234).

The big notoriety of Artificial Intelligence is now due to the recent capabilities that somehow relate to "intelligence" and are perceived as efficient, namely handling huge quantities of data and giving as output something that seems logical. The capacity to handle (efficiently?) huge amounts of data has some consequences, particularly if we do not know exactly which data was used and who controls and interprets the output.

Pedro Domingos, professor emeritus of computer science and engineering at the University of Washington, gave an interview to the Portuguese newspaper *Expresso* that was titled "AI is a dictator's dream". He explains:

> Everything a dictator would like to do but couldn't do because he had finite human resources for disinformation and surveillance, AI does it at an unprecedented level. He is the ultimate bureaucrat who spies on everyone and never gets tired (Domingos, 2024).

That is not a comfortable situation: is there really a superpower entity that is so efficient (and intelligent?) that not only we cannot control it but some humans can use to also control other humans?

Arlindo Oliveira, a Portuguese specialist on AI recognizes that "The emergence of ChatGPT has had a huge impact on the public perception of what is possible with artificial intelligence technologies" (Oliveira, 2024). He points out that ChatGPT is in fact a "statistical language model":

> (...) a statistical language model is exactly that. It is a model that generates texts in a probabilistic way, according to the statistics of the content on which it was trained, texts that are generally plausible but not necessarily correct and factual. No matter how perfect a language model is and the instructions it receives for each task (the context, which includes both that which is provided by the user and that which is hidden but which also conditions the generation of text), there will always be some limitations that result from the way these models are created (Oliveira, 2024).

But he also points out that AI has three essential limitations:

> The first of these limitations is that your knowledge is limited to the period in which the content used for training was obtained. The second limitation is that statistical models are typically trained only on public data, and do not have access to private data from companies and organizations. Finally, the third limitation is related to the limitations inherent in the ability of statistical models to elaborate complex reasoning in specific fields, such as mathematics, geography, or law, to name just a few examples.

The fact that mathematics is left out of the capacity of these statistical models might be perplexing because AI is based on algorithms and these algorithms are inherently mathematical. But ChatGPT does not work in a logical way. Some researchers even consider it to be a "stochastic parrot" because it combines, in a probabilistic way, without any reference to meaning, "sequences of linguistic forms it has observed in its vast training data" in a "haphazardly" way (Bender et al., 2021, p. 617).

5. Power of Generative AI

The output of ChatGPT is so impressive that many people think/believe/hope it might be useful in education. We will try to understand what has been proposed looking at a Discussion Paper, that does not specifically address mathematics, produced by a project of four german universities (Gimpel et al., 2023), that somehow gathers what has been proposed in a lot of different studies.

The Discussion Paper considers that "Conversational agents" like ChatGPT are "valuable tools for university students", and it has nine "recommendations" for students that include to respect the law. In fact, as is pointed out there, ChatGPT has "the inability to trace the sources of each statement and the process used to create them" and so it should be indicated that AI was used because the reliability cannot be guaranteed; if the process is not explicitly mentioned, then school regulations are not respected and "involuntary" plagiarism can occur.

Another recommendation is to use ChatGPT as a "writing partner" but only as a "supplementary tool, such as Wikipedia, Google, or translation programs". Another recommendation is to use ChatGPT as a "learning partner" in dialogue 24/7 in order to clarify what the students might need to understand. There is never the idea that the 'intelligent" software is relieving students from hard work.

The Discussion Paper also includes recommendations for Lecturers at the teaching level like

> ChatGPT can create custom exercises and quizzes, offer feedback, and generate tailored educational materials that align with a student's learning style and progress.

It is not clear how these "tailored exercises" can be effective in practice for different subjects because, as the paper points out, "AI is limited in understanding complex relationships and combining information from different sources" (Gimpel et al., 2023, p. 30).

Finally the paper includes Recommendations for Lecturers at the Assessment level, including care to be taken not to create questions that can easily answered by AI. Also it recommends to avoid "assignments without supervision process" and to "design assessments that promote students' abilities to think creatively and critically".

The Discussion Paper recognizes that "traditional patterns can be disrupted by technology" and what is important is to determine "which competencies students should develop". It is clear that "Domain-specific skills always have been important and remain important." (Gimpel et al., 2023, p. 40)

The picture we get from this Discussion Paper is not that AI will be able to, all alone, teach whatever is needed in our century.

6. What is ChatGPT doing...

Stephen Wolfram, the maker of *Mathematica* and *Wolfram Alpha* writes in his highly informative blog and in a book taken from it, that ChatGPT is "merely" pulling out some "coherent thread of text" from the "statistics of conventional wisdom" that it has accumulated, while recognizing that it is "amazing" how "human-like the results" of ChatGPT are (Wolfram, 2023b).

In the same blog Stephen Wolfram explains clearly that essentially, "ChatGPT is a system for generating linguistic output that "follows the pattern" of what's out there on the web and in books and other materials that have been used in its training" (Wolfram, 2023a). And the output from ChatGPT "is always "statistically plausible", at least at a linguistic level. But "it certainly doesn't mean that all the facts and computations it confidently trots out are necessarily correct" (Wolfram, 2023a). Stephen Wolfram gives several examples of ChatGPT incorrectly solving mathematical problems. The examples include calculating the circumference of an ellipse, calculating the calories contained in a cubic light year of ice cream, determining the distance from Chicago to Tokyo, the calculation of

$$3^{73},$$

the calculation of the integral of

$$x^2 cos(2x),$$

the search for the largest country in Central America, the search of moons in the Solar System that are larger than Mercury, and the determination of which planets are visible on the night of the question. Stephen Wolfram explains how the software he produced can give the calculations needed to answer all these questions.

The previous discussion gives Stephen Wolfram the idea to combine the "coherent thread of text" from ChatGPT and the mathematical power of his own software. It then offers a (paying) software that gives "Wolfram Superpowers" to ChatGPT. We see that the Generative AI is the communication tool but Wolfram's *Mathematica* is really the mathematical expert. He explains that

> (...) as an LLM neural net, ChatGPT - for all its remarkable prowess in textually generating material "like" what it's read from the web, etc. - can't itself be expected to do actual nontrivial computations, or to systematically produce correct (rather than just "looks roughly right") data, etc. (Wolfram, 2023c)

This same idea is used by *Khan Academy* with its "Khanmigo's New Academic Essay Feedback Tool" (Khan, 2023) that uses ChatGPT as a communication tool between the user and the *Khan Academy* content. GeoGebra Discovery is version of GeoGebra that enlarges GeoGebra reasoning tools allowing the study of geometric relations. Botana et al. propose that a combination of ChatGPT and Geogebra Discovery might be useful because "the natural language abilities of ChatGPT and the certified computer algebra methods in GeoGebra Discovery can cooperate in order to obtain sound and - more relevant - interesting results" (Botana et al., 2024, p. 1).

7. Intrinsic limitations of ChatGPT

Amos Azaria was one of the first to study the mathematical limitations of ChatGPT, concluding that ChatGPT

> has difficulty in multiplying large numbers, computing roots of a number, computing the value of a number to a power of another number (especially fractions), and adding (or subtracting) a number to an irrational number (e.g., π or e) (Azaria, 2022, p. 1).

When ChatGPT is not able to do some calculation it almost always gives an answer with a guessed number, even when incorrectly making the calculation because he does not know the answer or how to verify the result. ChatGPT may even criticize the user when he/she discusses the correctness of the answer. Azaria reports that he received as a reply to the questioning of an incorrect answer to the calculation of $3.2^{3.3}$, as follows:

> It's possible that you may be expecting a larger result because you are misunderstanding the meaning of the exponent. An exponent represents the number of times that a base number is multiplied by itself (Azaria, 2022, p. 1).

Azaria arrived to the surprising conclusion that the number mostly used by ChatGPT is 7, apparently also the number more popular to humans (Azaria, 2022, p. 2).

The American philosopher Harry G. Frankfurt (1929-2023), that was professor of philosophy at Princeton University, wrote a book titled "On bullshit" (Frankfurt, 2005) where he discussed statements that have a lack of concern for its own truth and so are "extremely dangerous" (Hicks, 2024, p. 4). Three researchers from the University of Glasgow analysed ChatGPT with Frankfurt's philosophy (Hicks, 2024), (Slater, 2024). They claim that

> (...) these programs cannot themselves be concerned with truth, and because they are designed to produce text that looks truth-apt without any actual concern for truth, it seems appropriate to call their outputs bullshit. (...) Their inaccuracy is not due to misperception or hallucination. As we have pointed out, they are not trying to convey information at all. They are bullshitting. (...) It can also lead to the wrong attitude towards the machine when it gets things right: the inaccuracies show that it is bullshitting, even when it's right. (Hicks, 2024, p. 9)

8. "Computational Thinking" vs "Artificial Intelligence"

We can consider Computational Thinking (CT) as a thought process (or a human thinking skill) to solve a problem and it can easily be verified that the solution obtained is correct. It adds clearly in a significant way an "algorithmic dimension of mathematics". When it comes to Artificial Intelligence (AI), this is a technology that enables computers and machines to "simulate" human intelligence and problem-solving capabilities but the output cannot be verified (or a different kind of technology needs to be used to verify its correctness).

It is clear that Computational Thinking (CT) as a thought process intrinsically connected to problems solving, is a part of the concept of mathematical literacy. It naturally uses digital technologies that allow the execution of an algorithm that might contribute to solving a mathematical problem, so it is important for mathematics education.

"Artificial Intelligence" in its present state of Generative AI does not satisfy any of these characteristics and it certainly has nothing to do with the concept of mathe-

matical literacy. We argue that CT should be included in the mathematics curriculum as it reflects the "strengthening of and new approach to the algorithmic dimension of mathematics, the reasoned and effective management of the current diversity of information sources and possible modes of collaborative work. (UNESCO - Education Sector, 2012, p. 17).

In the next paragraph we show how the technological recommendations of (UNESCO - Education Sector, 2012) can be implemented in school with the exploration of "Computational Thinking" through the new curriculum for Mathematics in Portugal.

9. New Syllabus for Mathematics in Portugal

The new Syllabus for Mathematics in Basic and Secondary Education (grades 1-12) in Portugal, recently produced (2021 to 2023) addresses the question of using technology in Mathematics Teaching, trying to incorporate the best practices recommend in literature, including international reports. Computational Thinking is included but also different aspects of using technology in the classroom, but Generative Artificial Intelligence is not considered. Of course the developments of Generative Artificial Intelligence are extremely recent, but there may be other educational reasons that we will try to analyze.

In the new Syllabus for Mathematics in Basic Education (grades 1-9) in Portugal, we can read:

> Mathematics learning benefits from the use of diverse resources that enable, among others, the use and exploration of multiple representations efficiently. Technological tools must be considered as unavoidable and powerful resources for teaching and learning Mathematics. Students' digital literacy should include performing calculations, constructing graphs, carrying out simulations, collecting, organizing and analyzing data, mathematical experimentation, research and modeling, and sharing ideas (Canavarro et al, 2021).

A direct reference to Computational Thinking is found here:

> Develop and mobilize computational thinking [that] presupposes the development, in an integrated way, of practices such as abstraction, decomposition, pattern recognition, analysis and definition of algorithms, and the development of debugging habits and process optimization. These practices are essential in mathematical activity and provide students with tools that allow them to solve problems, especially those related to programming (Canavarro et al, 2021).

We can observe the main goal of using the technological tools is to contribute to the "mathematical activity" of students, namely as 'tools" to "carrying out simulations, collecting, organizing and analyzing data, mathematical experimentation, research and modeling".

In the new Syllabus for Mathematics in Secondary Education (grades 10-12) in Portugal, we can see the orientation to make "Systematic use of technology" in order to "Encourage the exploration of ideas and concepts, integrating technology as a lever for understanding and solving problems" (Carvalho e Silva et al., 2023). The principle that students should be active agents in the mathematics classroom is clear also from this passage:

> The exploratory approach to mathematical ideas and concepts is decisive, which involves leading the student to actively participate in a process of construction and deepening, motivated by challenging questions, problems and the search for justifications. The in-

> tegration of technology is considered essential in this process, due to the possibilities it offers for experimentation, visualization, representation, simulation, interactivity, as well as, of course, numerical and symbolic calculation (Carvalho e Silva et al., 2023).

The idea that students should solve mathematical problems and apply mathematics to other areas with, namely, a computational thinking approach, is also clear from this extract:

> Programming activities must be integrated with progressive complexity, being relevant to the development of algorithmic processes, structured thinking and logical reasoning, providing a vast field of application of Mathematics and genuinely involving the formulation and resolution of problems, in addition to promote the development of computational thinking (Carvalho e Silva et al., 2023).

This new syllabus comes after careful analysis in a previous report that summarised the main recommendations produced nationally and internationally in the last 30 years, looking also in detail to the syllabus and practice of countries like France, Finland, Estonia and Singapore (Carvalho e Silva, 2018), (Carvalho e Silva et al., 2020).

It is clear that this syllabus tries to address mathematical literacy taking into account the "expansion of access to data, means of representation, interaction among representations produced by digital technologies".

The new Syllabus for Mathematics in Basic and Secondary Education in Portugal has just begin being implemented and we cannot assess yet if it is effective in the introduction of an "algorithmic dimension of mathematics" in the Teaching of Mathematics. This will be done in a future paper.

10. Conclusions

A recent report from UNESCO, written by 32 mathematicians and thought leaders from across the globe and titled "MATHEMATICS FOR ACTION Supporting Science-Based Decision-Making", alerts that Mathematics "is fundamental to how we understand nature" and it "empowers sustainable development" (Dhersin et al., 2022, p. iii). This report not only gives numerous examples how Mathematics is important in our times, but also stresses clearly certain points:

> Mathematics education develops problem-solving and critical-thinking skills that can be transferred to new situations and a range of occupational fields (Dhersin et al., 2022, p. 15).

> Mathematics education is important for developing reflective and critical citizens who can deal with the mathematical demands of everyday life, and also for preparing a sufficient number of mathematicians and scientists capable of meeting the challenges of the contemporary world (Dhersin et al., 2022, p. 15).

It is clear that developing problem-solving and transferable critical-thinking skills in a mathematical framework are more important each day.

From the educational point of view, CT, as a problem solving process, is clearly superior to AI that "solves" the problem for the student. With AI the user does not in general solve problems expecting that the machine will give the full results that it needs. The user may just verify if it is really solvable. Reflective and critical citizens need to be able to criticize what was obtained and that is not possible when using AI because its process is not transparent and verifiable.

It is clear the importance of a systematic introduction of algorithms and computational thinking in mathematics education, with the intensive help of technology, that will help to refocus the teaching of mathematics in the place where it should always have been, the solving of real, concrete problems using the logical schemes of mathematics, with the adequate technological tools and practical algorithms. These include necessarily, at the secondary school level:

- Understanding polynomial growth, exponential growth, logistic growth
- Solving any polynomial or transcendental equations approximately
- Building mathematical models, applying them to concrete data, criticizing the results

In the words of late President of ICMI, Miguel de Guzmán, when speaking about the impacts of new technology on mathematics teaching: "What is truly important will be the preparation [of students] for an intelligent dialogue with the tools that already exist, which some already have and others will have in a future that is almost present" (Guzmán, 1992).

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