First Steps towards K-12 Computer Science Education in Portugal — Experience Report

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ABSTRACT

Computer scientists Jeannette Wing and Simon Peyton Jones have catalyzed a pivotal discussion on the need to introduce computing in K-12 mandatory education. In Wing's own words, computing represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use.

The crux of this educational endeavor lies in its execution. This paper reports on the efforts of the ENSICO association to implement such aims in Portugal. Starting with pilot projects in a few schools in 2020, it is currently working with 4500 students, 35 schools and 100 school teachers. The main aim is to gain enough experience and knowledge to eventually define a comprehensive syllabus for teaching computing as a mandatory subject throughout the basic and secondary levels of the Portuguese educational system.

A structured framework for integrating computational thinking into K-12 education is proposed, with a particular emphasis on mathematical modeling and the functional programming paradigm. This approach is chosen for its potential to promote analytical and problem-solving skills of computational thinking aligned with the core background on maths and science.

CCS CONCEPTS

- Social and Professional Topics \rightarrow Computer Science Education; K-12 Education; Computational Thinking.

KEYWORDS

Computer Science, Computational Thinking, K-12 Education, Basic School, Secondary School.

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1 INTRODUCTION

Computer scientists Jeannette M. Wing (USA) and Simon Peyton Jones (UK) have catalyzed a pivotal discussion on the need to introduce a K-12 computing syllabus into mandatory education [14, 25]. This trend was galvanized by Wing's influential paper, '*Computational Thinking*' (CT), in which she posits that computing '[...] represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use.' However, the crux of this educational endeavor lies not in its justification but in its execution, and the literature does not yet show consensus on the broader inclusion of Computer Science (CS) in mandatory K-12 education [22, 23, 27]. Quoting [19]:

> [...] however, there is no unified conclusion on how to design programming activities to promote the acquisition of CT skills more effectively.

ENSICO [8] is a private, non-profit association founded in Portugal (2019) to address the challenge mentioned above that believes that incorporating computing into the first twelve years of education can promote equity and enhance scientific and technological literacy. Moreover, this has the potential to foster creativity and multidisciplinary learning, as well as to improve oral and written communication skills, understanding of formal concepts, and awareness of scientific history. As a member of the INFORMATICS FOR ALL coalition, ENSICO follows the Informatics Reference Framework [10], which advocates that

> [...] informatics should exist as a discipline at all stages of the school curriculum, starting early in primary school and continuing to exist and develop through upper secondary school. Moreover, we suggest that education in informatics should be compulsory for all pupils from primary through secondary education, having a status and standing similar to that of language and mathematics. Well-educated teachers and teacherteachers are essential to realise this vision.

Starting with pilot projects in a few schools, ENSICO is currently working with 4500 students, 35 schools and 100 school teachers. Its main aim is to gain enough experience and knowledge to eventually define a comprehensive program for teaching computing as a mandatory subject throughout the basic and secondary levels of the Portuguese educational system. However, this raises some questions: should the focus be on technology or science, programming or general computing, concepts or procedures, formative or informative education, training or entertainment?

This paper aims to address these pivotal questions and propose a structured framework for integrating computational thinking into K-12 education, with a particular emphasis on mathematical

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Figure 1: Introducing computing in K-12 education calls for a "New Trivium" [4] able to heal the "big divide" between science and the humanities, while linking computing to its very foundations on maths [15].

modeling and the functional programming paradigm. This approach is chosen for its potential to promote the analytical and problemsolving skills that are central to computational thinking, naturally aligned with the core background on maths and science.

Although the bulk part of ENSICO's activity takes place in Portugal, an international arm was developed in parallel between 2020 and 2023 through the ERASMUS+ project CS4ALL [9], in partnership with The Open University, Cisco ASC in the UK and Colectic in Spain.

The remainder of this paper is structured as follows: section 2 briefly addresses basic principles concerning the overall teaching plan. Details about ENSICO's efforts to frame itss plan into the Portuguese K-12 educational system are given in section 3. The efforts since 2020 to fulfill this plan are presented in section 4. Section 5 provides details about classes and their different teaching styles. The organization of events and ENSICO's presence on social media are the subject of section 6. Finally, section 8 concludes and gives an outlook for future activities.

2 BASIC PRINCIPLES

There are three basic challenges when adding a new topic to an educational track [23]: WHEN to start, WHAT to teach and HOW to teach. Concerning WHEN and HOW, the ENSICO general principle is that initiation to computing can start at early ages, and it does not require much equipment: just a piece of paper, a pencil and, above all, grey matter. Essentially, a new problem is thrown into the classroom: how to *communicate with a machine*? And how different is this from communicating with people?

Where communicating with people requires written and spoken language proficiency, communicating with machines requires what is nowadays called *computational thinking* [25]. This requires logical thinking and the ability to abstract from complex situations in real life into simple models that computers understand.

This triggers immediate synergies with two other core subjects: *natural language*, since no one can convey to a computer what cannot be communicated to another person; and *mathematics*, since this is the form of expression that better deals with abstract information that computers are able to understand (Fig. 1).

Concerning the WHAT challenge above, one honestly must admit that it traverses CS education as a whole, in particular at the university level.¹ In his landmark book "Algorithms + Data Structures = Programs" [26], Niklaus Wirth — the creator of the programming language PASCAL who sadly passed away in January of this year (2024) — shows a constant pedagogical concern starting from a basic intuition that programming theory later confirmed:

[...] data precede algorithms: you must have some objects before you can perform operations on them.

(quote from the Preface). Strangely, many introductory programming courses still ignore, almost half a century later, such a relevant message — a message of which the book provides ample evidence [26].

ENSICO follows this intuition, which is all the more relevant the younger the students are: even before data, one should start with the physical things that computer data (will later) model, i.e. *dematerialize*. Computing terminology is highly metaphoric precisely because of such a need to abstract from physical entities think e.g. of terms such as "stack", "queue", "tree", "memory" and so on. Clearly, children need to understand such physical entities prior to abstracting from them. This matches nicely with the "unplugged" method [1] that is followed for the very early K-12 stages, as explained later concerning HOW to teach.²

Two basic data structures shine in such a *data-oriented* introduction to computing — lists and pairs. It is surprising how so many concepts [12] can be taught on such a simple basis³ as the pedagogical materials already produced show (section 5).

Data processing, i.e *transformations*, comes next. Children literature is full of fantastic tales in which things *transform* into other things by *magic*. Now, what else can better capture the transformation of thing x into thing y by "magic" f than the proper concept of a mathematical function, y = f(x)? May this serve as a simple explanation for the decision to follow the functional paradigm [3] when it comes to move from the *unplugged* to the *plugged* phases of the teaching sequence.

A thorough explanation of this and other pedagogical decisions is, however, out of scope of the current paper, which is intended to focus on the difficult thing — the path that is being followed concerning the *execution challenge* mentioned above.

3 THE CONTEXT

The Portuguese K-12 educational system comprises two levels: basic and secondary school. Children in Portugal usually begin basic school at age 6, which spans nine years and is segmented into a first cycle (ages 6 to 9), a second cycle ages 10 to 11) and a third cycle (12 to 14). Students typically reach secondary school at age 15, which continues for three years.

3.1 Basic School

In the first two years of the first cycle (ages 6–7), ENSICO'S methodology focuses on learning without the use of computers (Fig. 2).

¹See e.g. the recommendations by the ACM/IEEE-CS Task Force on Computing Curricula [18].

²One cannot *dematerialize* what one does not materially know about. In a sense, ENSICO lets children start from the "metaphors [they will later] program by" [16].

³Just a few examples: bit maps, look-up tables, key-value stores, midi (music), 2Dgraphics, matrices, finite state automata, dictionaries... – the list is long!

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The learning starts through stories with captivating characters that implicitly link to computing subjects (Fig. 4). These characters create emotional connections with the students that allow for the exploration of computational themes in a funny and pedagogically effective way. That is, knowledge begins to be acquired subliminally and indirectly, becoming progressively more explicit and direct as years advance (Fig. 3). In the final two years of the first cycle (ages 8–9), the aim is to leverage the teaching of computing in the learning of Mathematics and Portuguese (and potentially foreign languages).

The introductory computer classes start in a *semi-plugged* style, JUPYTER Notebook-based exercises directed by the teacher, followed by *plugged*, hands-on sessions conducted by the students themselves using JUPYTER Notebooks. At this stage, the exercises consist basically of evaluation simple expressions in the purely functional HASKELL programming language [13]. Haskell was chosen due to the simplicity of its syntax, bearing very little *language impedance* when compared to the maths expressions that students find in other textbooks.⁴

The second cycle (ages 10–11) further integrates computing with the study of mathematics and languages. It delves into linguistic concepts essential for mastering the native language and mathematical terminology, laying the groundwork for programming. Building on their initial computer experiences from the first cycle, students progress to creating their first data models and algorithms.

The third cycle (ages 12–14) aims to consolidate learning going deeper into the *function* concept alongside the math curriculum, which begins the study of functions at this stage. Consequently, the functional programming paradigm is deliberately embraced. The frequency of semi-plugged and plugged classes increases, eventually leading up to the beginning of collaborative programming activities and the adoption of multi-paradigm programming languages such as F# and Python.

3.2 Secondary School

Secondary school (ages 15–17) building upon the foundations of basic education, ENSICO's plans at this level are to emphasize the study and exploration of computationally significant fields, including Cybersecurity, Artificial Intelligence, Big Data, the Internet of Things, Blockchain, and more. This exploration is facilitated by advanced programming environments and languages endowed with extensive and educationally valuable libraries, such as PYTHON. At this stage, one should aim to expand and develop domain-oriented specialised modules in collaboration with various universities, which will be available to students as elective courses tailored to their personal and professional interests.

4 ACTION PLAN

Central to the overall strategy is ENSICO's roll-out of its five-year pilot program, segmented into six phases. The initial phase (2020), that included only school teachers, was followed by five phases that incorporate both students and teachers from pilot schools.



Figure 2: The 'LEIBNIZ' notebook, ENSICO students' "first computer", promotes the *CS-unplugged* teaching method pioneered by Tim Bell [1].

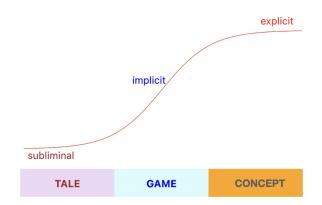


Figure 3: ENSICO's knowledge "modulation wave": starting from *subliminal* messages hidden in little stories or tales (first years), knowledge becomes *implicit* in games or the physical manipulation of concrete objects (middle years) before becoming explicit in *concepts* [12] and, finally, *programs* in the "plugged" phase.

These participate in weekly computing classes over five consecutive school years, spanning from 2020/21 to 2024/25. Since day one, ENSICO's strategy has embraced an experimental, bottom-up approach, focusing initially on engaging school teachers, directors, students and parents. For this initiative ENSICO has obtained significant financial support, predominantly from private entities and local authorities (see Section 9). Moreover, frequent dialogue established with the Portuguese presidency, the government, municipalities and educational stakeholders aims to ensure the necessary commitment

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⁴The IHaskell kernel [11] is used to enable Haskell interpretation in Jupyter cells. Haskell's minimalist syntax is enabled by its sophisticated type inference, which allows concise code without explicit type annotations — an advantage recognized by practitioners [17].

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for a final political decision on the nationwide implementation of ENSICO's computing program.

4.1 March to July 2020, Phase I

The pilot project started with a sequence of webinars, 18 hours in total, involving 25 school teachers from both basic and secondary school and coming from 3 different schools, two public and one private, located in Oporto.

The involvement of teachers of a large spectrum of disciplines, such as math, ICT, physics, natural sciences, Portuguese, English and music, among others, was crucial to check their awareness of the opportunity to incorporate such a body of knowledge in the Portuguese curriculum. It was equally important at this stage to clarify concepts and present *computer science* (CS) as a potential mandatory topic, and showing how well it can blend with other courses, in particular with Portuguese and Mathematics. Questionnaires filled at the end revealed a positive perception about the inclusion of CS into the Portuguese curricula:

- 82% of teachers expressed interest in teaching CS concepts within their discipline;
- 55% of teachers expressed interest in becoming CS teachers;
- 100% of teachers believed that CS had the potential to help students perform better in the subjects they taught;
- 91% of teachers considered that acquiring CS skills would substantially contribute to students' future;
- 90% of teachers identified possible synergies between CS and their own teaching discipline;
- The majority of teachers considered CS skills to be equally or slightly more important than skills in Mathematics or English;
- 75% of teachers found it important to make CS education mandatory in the first three cycles of learning, while 27% considered it important for secondary school as well.

4.2 July 2020 to June 2024, Phases II to V

From July 2020 onwards the different pilot phases established the step-by-step execution plan that had started in just 3 schools and 8 classes of grades 5 to 8.

The main focus of the current plan for CS education lies in students in the second and third cycles. As stressed by Kramer [15], it is on this age range that, according to Jean Piaget, the cognitive transition between the 'concrete' stage (ages 6–11) to the 'formal' or 'abstract' stage (ages 12–17) takes place. Computer education should explore this crucial period of cognitive development.

The main goal of the first year of the pilot project was the production of pedagogical material and its evaluation in the classroom, involving students and teachers. The joint work with school teachers was of a major importance to promote their CS and digital skills while conducting continuous training on computing contents at the same time.

Between July 2021 to June 2023 there was an expansion of the teaching plan, reaching grade nine. Also important was the geographic expansion, not in terms of quantity, but in terms of representative schools/groups across Portugal. ENSICO's goal is to create a program as inclusive as possible, reflecting both regional and gender realities and sensibilities. Running mainly in the Oporto



Figure 4: Born tongeless, LILI needs to communicate using a binary, non-verbal language. Lili's adventures introduce children to the binary language and binary communication codes, initiating a path that will lead them to the Braille and Morse codes, to bitmaps (Fig. 5), QR-codes (Fig. 6) and so on and so forth.

and Lisbon regions, the pilot is currently spreading to schools in the Douro Valley, Minho and Trás-os-Montes provinces.

In the 2021/22 school year, a total of 1216 computing lessons, each lasting 50 minutes and covering grades 3 to 9, were conducted. These sessions were spread over 40 classes, with each class receiving around 32 lessons throughout the year.

The current and the next school years (2023–2025) are regarded as vital for the national expansion of the ENSICO's computing program. For the first time, a formal training program started to prepare (mainly first cycle and maths) teachers to lecture K-12 computing classes to their students. As shown in table 1, 100 teachers were trained in 2023 to start lecturing computing classes in the 2023/24 school year. In 2024, we expect to train more than 200 teachers, reaching more than 300 in total, in order to expand the computing classes in the 2024/25 school year. These "new computing teachers" are trained to follow the proposed computing program and to use the provided materials, which include slides, activities, JUPYTER Notebooks, etc.

The first group of 100 teachers are being coordinated and evaluated since September 2023 and the results so far seem promising. The majority of schools in the municipality of Cascais have adopted ENSICO's computing education program. For the next four years, ENSICO will conduct an impact assessment in collaboration with the Nova School of Business and Economics (see Section 8). First Steps towards K-12 Computer Science Education in Portugal - Experience Report

Table 1: Pilot Evolution

Number of	2020/21	2021/22	2022/23	2023/24
students	172	1600	2500	4500
teachers	8	62	100	300
schools	4	21	28	35
classes	280	2555	3990	7945

5 ABOUT THE CLASSES

This section briefly explains how the basic principles of section 2 get implemented by ENSICO in the classroom. The *golden principle* of always conveying new knowledge on top of knowledge students already have (Jean Piaget) calls for *backwards chaining* the cognitive stages of Fig. 3. That is, if content *C* is to be taught at year Y_n , then there should be some content *C'* taught at year Y_m (m < n) such that *C'* prepares *C*. Otherwise, *C'* should be background knowledge.

5.1 The unplugged classroom

As already mentioned, the adopted teaching model starts "unplugged" in year one, with short stories that subliminally introduce the binary system of information representation and communication (Fig. 4). Eventually, such stories lead to black and white representation of things and animals that get *transformed* into each other via black-white level operations (Fig. 5) using pen and paper.

Black and white will soon give room to symbols 0 and 1 (faster to draw than painting black squares on the notepad) that can be listed. Lists of such things ("bits") convey the concept of a *bitmap* representation, which is the first (abstract) *data model* that students encounter.

With lists (finite sequences) come concepts such as order, repetition, reversing and mapping. Soon children will know about letters and numbers and lists of these come handy, giving birth to words ("strings") and introducing the concepts of dictionary order and sorting.

Unfortunately, computers are like LILI: they cannot communicate using such letters, words and numbers, only using *bits*. Representing letters by bits comes next, leading to a rich path of knowledge acquisition that, through e.g. "toy QR-codes" (Fig. 6) eventually teaches message encryption and decryption — a topic students love to do (e.g. Cæsar's Cypher) on their notepads.

The second, basic data-structuring concept is *pairing*, introduced through the "zipper metaphor" (Fig. 7). Lists of pairs — the first data-structure compound in the teaching — are fertile ground for exploring a wealth of new concepts given by example: the "following" network of Instagram, roads between cities, price lists, etc. Abstract concepts so important as *graphs* and *key-value stores* sneakily get into the students minds just by playing with situations they know about from outside experience.

5.2 The "semi-plugged" classroom

Before the end of the second grade new characters are added to the narrative: *robots* that have names and do the magic of transforming things into other things, inputs on one hand, outputs on the other (Figs. 8 and 11). Thus robots are a metaphor for *functions*. Students engage in various activities that make them familiar with robots that

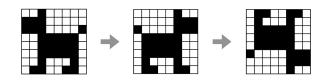


Figure 5: Bitmaps are introduced in black-and-white grids easy to draw and manipulate on the square pages of the notebook offered to ENSICO students (Fig. 2). At this early phase, manipulation is bound to bit-level operations (*flip* or *keep* the bit). When later on bitmaps become structured as lists, manipulation becomes list-structured [26], involving operations such as (in Haskell) *map*, *reverse* and son on. Thus the 'atomistic' start gives place to the structured view that eventually will lead to programming.

									-					
0	0						Ζ.	=	0	0	0	1	=	В
0	0						Z	=	1	0	0	0	=	Ι
0	0						Z	=	0	1	0	1	=	F
0	1						Z4	- =	0	1	0	0	=	Ε
1	0						Z	; =	0	0	1	0	=	С
0	1		0	1	0	0	Ze	i =	1	1	1	0	=	0
0	1	0	0	0	0	1	Z	' =	1	1	0	0	=	М
1	1	1	1	0	0	1	Z	=	0	0	0	0	=	Α
0	0	0	1	1	1	0	ZS	=	1	0	1	1	=	L
0	0	0	1	0	0	0	Z1	0 =	0	1	0	1	=	F
	1	1	0	0	0	0	Z1	1 =	0	0	0	0	=	А
					0	1	Z1	2 =	0	0	1	0	=	С
							Z1	3 =	0	1	0	0	=	Ε

Figure 6: ENSICO's toy 'QR-code'. More than technology, the emphasis is on teaching *concepts* [12], first with pen and paper and later on the computer. This promotes digital literacy in a natural, inclusive and enjoyable way.

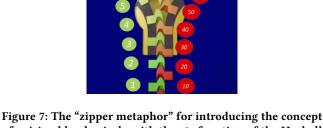


Figure 7: The "zipper metaphor" for introducing the concept of pairing blends nicely with the *zip* function of the Haskell Prelude [13].

now do what they were doing on paper before (e.g. *sort*, *reverse* and *nub*) and a few others that do new magics, e.g. *maximum*, *sum* and *length*. And, of course, robots can join hands and dance. Then a new kind of magic comes through: by joining hands robots pass things

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to each other, chaining their transformative powers (Fig, 11). In this way, students implicitly learn the essence of *function composition* in the second grade.

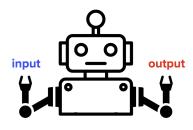


Figure 8: In the *data-oriented* teaching style advocated by ENSICO for the first steps in programming, computations are approached via data-transformers, i.e. "robots" who do the "magic" of transforming inputs to outputs.

The robot metaphor is also intended to implicitly convey the shift from *manual* to *automatic*. Robots are machines that promise to replace the children in carrying out their assignments. How can this take place? As robots are functions in disguise, teachers can "run" them as HASKELL expressions executed in the JUPYTER platform (Fig. 9).

5.3 The plugged classroom

The final modulation of the ENSICO teaching strategy for the first two cycles is to give students direct access to the on-line JUPYTER platform in lab sessions (Fig. 9 and 10). Towards the end of the second cycle, they become more and more familiar with the JUPYTER environment and how to solve problems by chaining *robots*, i.e. functions that transform data in JUPYTER cells.

As this "plugging" them into a programming environment gradually occurs, the all-important cognitive shift from *analysis to synthesis* takes place: instead of the analytical exercise of predicting the outcome of evaluating a JUPYTER cell expression by their teacher (or doing that by themselves), students are now invited to create such expressions themselves. In other words, what might be called *evaluate* mode gives room to a *define* mode. This challenge is new to them and this is where the functional programming style and the syntactic simplicity of HASKELL really helps to introduce programming (Fig. 10).

Throughout the three years of the third cycle, computer activities become more intense, enhancing analytical and problem-solving abilities through their breakdown using loops and *divide and conquer* strategies (Fig. 13). This is also the time to diversify the technology and introduce students to other programming languages and paradigms, e.g. F# and PYTHON.⁵

Also significant was the creation of a first prototype of the ENSICO on-line platform, which provided continuous access to pedagogical materials for students. Financially supported by the Belmiro de Azevedo Foundation and initially developed using WORDPRESS/

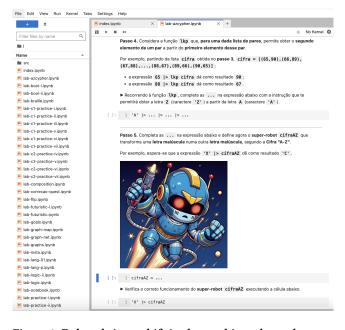


Figure 9: Robots bring a shift in the teaching: classes become *semi-plugged* in the sense that students' answers on paper are validated by the teacher's computer (the only machine in the classroom). Interestingly, their reaction is often negative: $I \text{ don't need a computer to sort that (short) list - I can do it myself! And they are right. However, when challenged with (say) sorting a list of a thousand numbers, they will immediately agree that JUPYTER far outperforms them, to their amazement. Thus they meet the concept of dematerialization: computers are machines that help us fulfilling tasks that are too boring or complex for us to do manually.$

LEARNDASH⁶, it featured over 30 online computing classes for grades 5 and 6, along with 500 resources across six categories: slides, articles, videos, unplugged activities, JUPYTER plugged activities and questionnaires. This platform was made accessible to 1000 students at the start of the 2022/23 academic year. Currently, it is being migrated and centralized within $MOODLE^7$ to ensure its availability for the final phase of the pilot (2024/25).

6 ENSICO AND SOCIETY

To achieve its main goal ENSICO has felt the need to contribute to explaining to the civil society why teaching computing is needed in schools. Significant efforts were made in 2021-2022 with the aim to introduce CS topics to a general audience, involving the online publication of 13 newspaper articles in collaboration with JORNAL PÚBLICO [6]. The total weekly views for these publications surpassed 500. The social media, e.g. INSTAGRAM⁸ and YOUTUBE⁹, are also important vehicles for the dissemination of its activities and messages to the educational community and the general public.

⁵ENSICO classroom experience in this cycle is less consolidated than that in the previous cycles because most students have not reached that level yet.

⁶https://www.learndash.com/

⁷https://moodle.org/

⁸https://www.instagram.com/ensico.pt/

⁹https://www.youtube.com/channel/UC5c66xEDYKZVSgmwRk_ANow

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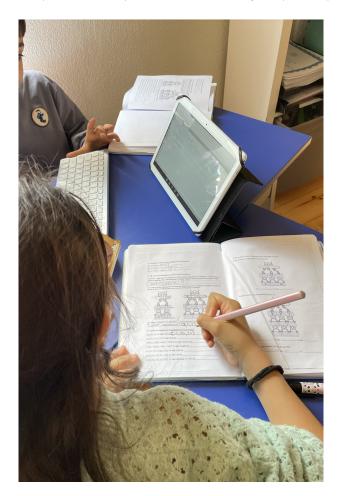


Figure 10: In plugged classes students learn by doing, solving lots of exercises available either in physical or digital notebooks. Thus "Leibniz meets Jupyter", i.e. the "first computer" of Fig. 2 gives room to the Jupyter platform, whose notebook cells can be interpreted and programmed. Eventually, thoughts that started expressed on paper become programs.

On March 25, 2022, ENSICO and APDC organized the event "Living with Technology: Innovation in Education" [7] hosted by the Faculty of Engineering of the University of Porto. Invited speakers Simon Peyton Jones and Simon Humphreys presented the CAS UK initiative, triggering a lively discussion on several key topics, including the significance of computational thinking, the need for computing as a compulsory topic, its influence on the scientific community, the ways in which curricula should evolve to integrate computing, and the socio-economic effects of such changes to the curricula. The testimony of Tim Bell (from CS Unplugged) was also very important for a in-depth reflection on the dilemma of integrating computing in standard K-12 curricula. In fact, ENSICO has been greatly influenced by these two movements and their pioneering founders.

7 RELATED WORK

Although CT is a topic older than 2006, it was only after Wing's paper [25] that it became a global trend. In 2019, Denning and Tedre wrote a book about the subject [5] that traces it back to the 1960s and thoroughly discusses CT from various perspectives, giving useful pointers for further reading. It praises the *CS Unplugged* approach [1] for, since the late 1990s, gaining worldwide followers and influencing the design of the ACM K-12 and code.org curricula recommendations.

Weintrop *et al* [24] argue for the inclusion of CT in mathematics and science classrooms, seeing among the main benefits for the approach the fact that it brings science and mathematics education more in line with current professional practices in these fields.

Regarding currently widespread CT as "Basic CT", or "CT 1.0", Tedre *et al* [20] face the need for stepping further to "CT 2.0", i.e. machine learning (ML) enhanced CT. They regard CT 1.0 outdated for several reasons. One of them is that it is dominated by imperative programming in e.g. Python, Pascal, Basic, Java, Scratch, languages that have been a "mainstay of computing education for nearly three quarters of a century". Quantum computing and machine learning are given as examples of knowledge areas that have few counterparts in traditional computational thinking.

The authors agree with these criticisms, which partly explain their decision to develop a *functional-first* approach to CT - a possibility that, surprisingly, seems absent from the literature. Arguing how this possibility remedies, at least in part, the criticisms made of the imperative CT mainstay is, however, outside the scope of this report and will have to wait for another time.

8 SUMMARY AND FUTURE WORK

Since its very start in 2020, the ENSICO pilot project has been a "hands-on", out-of-the-box experiment. Portugal is behind in computing education and time cannot be wasted. Its unplugged flavour fights the "digital drug" syndrome that is afflicting so many schools and social environments. The worst thing computing education could do is to *spoil the child's brain* — it should rather contribute to its development and creativity [15].

Above all, we believe that *learning should be fun*, not only for students but also for teachers, who in this way get motivated and engaged in the project ideas. Furthermore, students and parents should not be fooled by the idea that computing is a form of enter-tainment at school - studying computing is "hard work", just like mathematics, arts and science.

Since 2020 ENSICO has collected many data concerning its pilot project but thoroughly analysing them is out of the scope of this experience report. Some plain figures can nevertheless be given, further to those of Table 1. In the current academic year, 2000+ slides are being used in classes altogether (one hour per week). Many of these slides are targeted to teachers only, containing notes, explanations and suggestions about the slides to display in class.¹⁰ This teaching material is supported by more than 100 JUPYTER notebooks, 150 unplugged activities and 150 evaluation sheets.

¹⁰The prospect of converting all this material in textbooks and exercise books is currently under consideration. Also, a formal curriulum for Computing is currently being prepared according to the current standards [21].

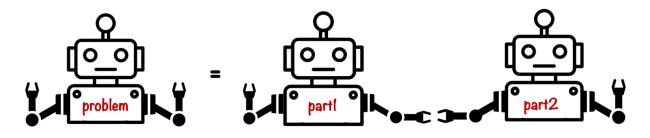


Figure 11: Robots can solve difficult problems by seeking help from others who give hands to collaborate with each other. Being able to decompose problems into sub-problems is the essence of Computational Thinking [25]. In functional programming this is achieved by function composition, for instance by declaring problem = part1 » part2 in the illustration above, where ">" denotes forward (left to right) composition. This stimulates code reuse because, instead of inventing problem from scratch, students are invited to reuse functions part1 and part2 that already exist (or that they programmed before).



Figure 12: Computing is far more than using computers and can be taught without them. This view is inclusive in the sense that even the least equipped schools can implement ENSICO's teaching. Above all, it promotes authentic digital literacy and not just technology skills. In this respect, it is also gender inclusive as it does not assume the technological proclivity that boys often have when compared to girls at a young age.

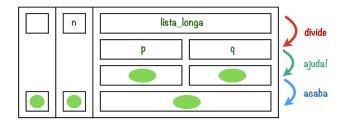


Figure 13: One of the templates used to plan (on paper) a *divide and conquer* algorithm over lists late in the third cycle. The students are invited to fill in the boxes marked in green as preparation for laying down the code. The idea that one should not rush to write code but rather think about it on paper beforehand is central to the teaching, at this stage. In this way, much later at the university, students will not feel unprepared to learn the formal theories that underlip such easy-to-use templates [2].

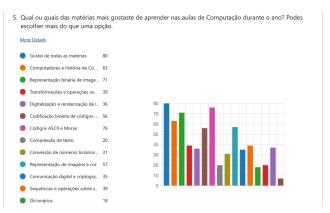


Figure 14: Sample questionnaire enquiring students about which subjects they enjoyed most (2021/22). Most students liked the course as a whole. Topics such as ASCII, Morse code and binary representation of images were the most favored.

Activity reports are sent to ENSICO sponsors every school year. These reports typically include multi-dimensional statistics and opinion polls for students, teachers and parents (Fig.14).

For the next four years, ENSICO will conduct a rigorous impact assessment in collaboration with Nova School of Business and Economics¹¹ in order to evaluate the influence on students of having computing classes from grade 7 (3rd cycle of basic school) to grade 10 (1st year of secondary school). The outcome of such a joint venture is regarded as a key factor for the national-wide implementation of ENSICO's program in Portugal.

Preparations are underway for the final school year of the pilot program (2024/25). Over ten thousand students are expected to participate in computing classes, some of them reaching their fourth year of computing. Moreover, if everything goes according to the plan, such students will be the first in Portugal to finish mandatory schooling with a complete, K-12 education in computer science.

In the short term, two significant milestones are to be pursued. The first and foremost is the government's decision on the adoption of ENSICO's program into the national basic and secondary school curricula. The second, equally ambitious, concerns the international adoption of our program. Observing the various initiatives across Europe, we are confident that many could benefit from our experience in Portugal.

Last but not least, the prospect of a nation-wide K-12 education on computing will bring new opportunities for the teaching of more ambitious subjects at higher education levels. In other words, it has the potential to revolutionize and update the current IT pedagogical content taught in universities and polytechnics. ENSICO would like to be involved in discussions in this regard, contributing to generating a new dynamic with valuable economic potential in Portugal and throughout Europe.

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¹¹ https://www.novasbe.unl.pt/en/

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 $^{12} https://www.brookings.edu/articles/what-do-we-know-about-the-expansion-of-k-12-computer-science-education.$