Computational & Algorithmic Thinking: an enhanced 21st century skills model for the classroom

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Abstract

Following from the seminal work of Jeannette Wing on Computational Thinking we propose three enhancements in this article. These are based on the original P21 education model and the question faced by instructors in the classroom- '**What are 21st century skills**?' In trying to arrive at an answer we propose a →new (thinking,learning,life) skill ← (read as a regular expression between the arrows!) based on Jeanette Wing's idea as well as two other life and literacy skills which we deem are almost indispensable for students graduating from high school in 2025 and beyond. In an age where we are 'straddling' two universes, one virtual and one physical and wading knee deep in 'Big Data' it may be long overdue to take a critical look at the skill set we are offering in our classrooms and ask if this set needs to have some new tools to help the learners of this century find their way through the jungle of processed data in which they live.

0. Introduction

In her seminal presentation on Computational Thinking [1,2] Jeannette Wing proposed the 'dream' that CT would become part and parcel of our learning and thinking skills in the 21st century basing her ideas on the two pillars of Computational Thinking: Abstraction and Automation. In this article we try to take this idea slightly further by marrying it to the concept of 21st century skills put forward by Thoughtful Learning [3] (Fig 1).

It is left to the reader to study the concepts put forward in [3] in much more detail. What we propose as a new skill in each category is highlighted in Fig.1 and these are discussed in order below:

Learning skill	Literacy Skills	Life Skills
▪ Critical Thinking ▪ Creative Thinking ▪ Collaborating ▪ Communicating ▪ Computational & Algorithmic Thinking	▪ Information Literacy ▪ Media Literacy ▪ Technology Literacy ▪ Processing Big Data Literacy	▪ Flexibility ▪ Initiative ▪ Social Skills ▪ Productivity ▪ Leadership ▪ *AT*-Intelligence Quotient

Fig 1: Thoughful Learning model of 21st century skills

1. Computational & Algorithmic Thinking

We propose the rigorous addition of not just Computational Thinking as originally put forward by J Wing but rather **Computational and Algorithmic Thinking** under this category. The Computational part addresses Abstraction and Automation and how these need to be incorporated into teaching and learning – be it in Mathematics or Computer Science or any of the other sciences. It is interesting to note that the concept of Computational Thinking has been introduced into the International Baccalaureate Computer Science Higher Level syllabus since 2014 and as such constitutes the largest section (45 hours of the 200 total teaching time). From 2016 Computational Thinking will also form part of the new OCR Computer Science GCSE syllabus in the UK.

The **algorithmic** part addresses a very different section of learning as follows:

1. Given a problem $P(x_i)$ where the x_i are the various parameters on which the problem depends (here we only address P and not NP problems) find what type of abstraction best lends itself to the solution by stripping $P(x_i)$ of all unnecessary details
2. Determine which sections of $P(x_i)$ require functional and/or procedural abstraction by breaking those into sub-tasks T_j
3. Determine which T_j need automation – this completes the Computational part
4. Now comes the additional thinking skill which would be to derive suitable ***algorithms*** for the execution of the T_j.
5. These algorithms, which for brevity we denote as $A(T_j)$, can now be put forward in terms of flow charts or pseudo-code as solutions to the sub-tasks of $P(x_i)$

   It is important to stress that there is no obvious 1-1 correspondence between the x_i and subtasks T_j.

The main premise here is that the algorithmic thinking skills required in step 4 above are very different to the thinking skills which find the necessary abstraction and automation required and as such must come under the new label of ATS (Algorithmic Thinking Skills).

2. Processing Big Data Literacy

Under the second category of **Literacy skills** we propose the addition of the new skill entitled 'Processing Big Data Literacy'. This skill brings with it the power to be able to manipulate 'Big Data' successfully using heavy processing power and the coding element would be crucial in being able to interrogate a data warehouse.

Of course it goes without saying in this digital age that we need our learners to be digitally literate. Our learners are no longer living in one universe . The parallel e-Universe which the Internet and Smart phone technologies has created means that we may be e-shopping as we are shopping. We may be surfing as we are walking. Such 'worm-holes' joining us at the same time to two very different universes one virtual and one physical are very much a notion of the 21st century. And just as our physical lives in our physical universe has brought with it by products such as carbon emissions and global warming, our virtual lives have produced by products such as 'Big Data'. Thus our actual lives which 'straddle' two universes at any given point in time need to be handled with equal literacy in both. Whilst digital literacy would imply that a learner/user is conversant with the use of a given application on a given device, what we suggest here is a new type of literacy. Now a brand new addition to the 2015 A-Level Computer Science syllabus is the topic of 'Big Data'. This again is a relatively 'old' concept in the International Baccalaureate Computer Science syllabus, As the by- product of the huge processing power of this century how else but through proper data mining techniques would one have been able to find a correlation between the famous 'beer and nappy' sales! Our learners, in trying to equip themselves for the 21st century, particularly those entering into Economics or Business Studies should I believe possess the knowledge and skills to be able to process 'Big Data' and be aware of the very rigorous mathematical models driving them. They should also possess the necessary coding skills to be able to interrogate data warehouses successfully and to be able to cleverly 'mine' for correlations between seemingly unrelated products.

In an excellent set of presentations, Elena Boralis [4,5,6] puts forward the ideas of interrogating a data warehouse using SQL, ETL and OLAP. (Structured Query Language, Extract Transform Load, Online Analytical Processing). The basic model for a Data Warehouse Architecture is given in Fig 2 below.

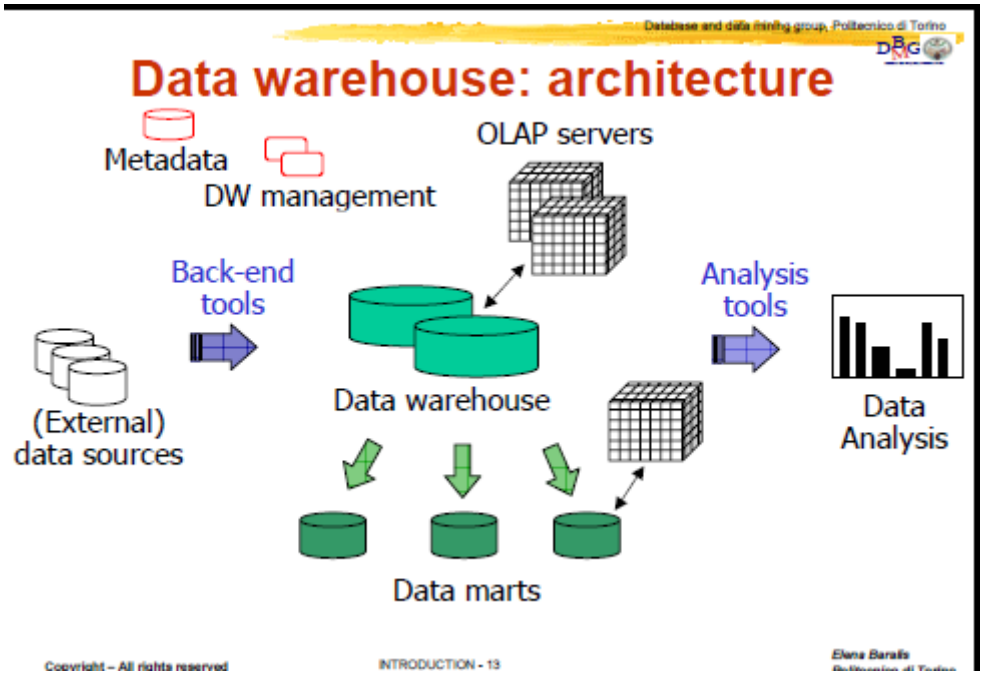

Fig 2: Big Data Processing [4]

Essentially the drivers behind these are the n-dimensional cubes (shown above as a 3D model) of 'commodities' sold at a given time/place. Prospective Economists and Business Managers would be two potential groups who would hugely benefit from these enhanced analytical skills as applied to Big Data.

As such young learners need not only to understand them but also to be able to work with them successfully. We only need to take a look at the hugely exciting new Data Observatory opened by Imperial College [7] to see that this type of new establishment very much needs 21st century skills.

3. *AT*-IQ

Finally, as an enhancement to the Life Skills for the new century we propose an IQ entitled *AT*-IQ (Algorithmic Thinking IQ). It is well known that many of our standard IQ tests are based on multiple choice questions which ask the person to find hidden patterns in shapes, numbers or letters. Often the underlying pattern is quite intricate and quite impossible to separate from the underlying mathematical notions of the questions – such is their interdependence. The *AT*-IQ is now proposed in order to test how well for example a child/adult is able to cope with some of the following ***new*** skills:

a. How successfully can a person decode a piece of cipher text – ranging from easy to hard
b. How apt is the person at just looking at a piece of code (be it SQL, Python, C# or any other language for that matter) and being able to know 'intuitively' what that piece of code does when run.

c. Can the person identify the very important notion of Abstraction (one of the two pillars of Computational Thinking) – e.g: what would be the abstraction required to draw a typical house on a screen? Possible solution: A rectangle with a triangle sitting on top.
d. Can the person identify the other important notion of Automation (the other pillar of Computational Thinking) – example: given a task which part would require automation?
e. Can they distinguish between Functional & Procedural Abstraction?
f. Can they distinguish between Finite and Infinite Iteration?
g. Given a regular expression can they expand it?

This list is in its infancy and much work can be done to improve and change it. However, the basic notion which is put forward here to the reader is this: The ability to perform mental distinctions in a *AT*-IQ test would not depend on the person knowing any particular programming language but rather being able to just 'sense' from looking at a piece of text what their main purpose would be – akin to having 3 or 4 shapes in a question and trying to spot a hidden pattern.

References:

[1] Jeanette Wing, 2006, https://www.cs.cmu.edu/~15110-s13/Wing06-ct.pdf

[2] Jeanette Wing, 2008 , https://www.cs.cmu.edu/afs/cs/usr/wing/www/talks/ct-and-tc-long.pdf

https://k12.thoughtfullearning.com/FAQ/what-are-21st-century-skills

[4] Elena Baralis, *Data Warehouse Introduction*

[5] Elena Baralis, *Data Warehouse: OLAP*,

[6] Elena Baralis, *Data Warehouse Architecture & Processes*

To be found at:

http://dbdmg.polito.it/twiki/bin/view/Public/Publications#Journals

[7] (http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/newssummary/news_3-11-2015-9-56-32)