Computational Thinking – Back to the Future

Andrew Csizmadia[1], Helen Boulton[2]

Abstract

Computational Thinking is regarded as a gift from Computer Science to other discipline areas, a digital literacy skill and a cornerstone of the computing programme of study has been delivered as part of the National Curriculum in English Schools since September 2014 [1]. Since Wing's [2] seminal article sets outs with a clear and concise call to embed Computational Thinking in all subject areas, the impact of, and influence of, Computational Thinking can be seen worldwide. This is evident in the ubiquitous and pervasive nature of computing, the engagement and interaction with big data in a range of disciplines and the development of the computer science curriculum in countries globally. However, there is continuing discussion and debate [3] regarding the need for a robust distinct definition of the term "Computational Thinking", as at present there is no collective consensus definition for this term.

In this paper, the authors seek to contribute to this ongoing dlalogue by presenting the findings of a desk-based academic literature review relating to computational thinking which utilised both Influential Literature Analysis [4] and Citation Analysis [5] to identify relevant key texts. These key texts were then analysed to identify the most frequent occurring items (i.e. terms, descriptions and meanings) and coded using appropriate synonyms. This review does not use Wing's article [2] as its epicentre but identifies the historical roots which have developed and shaped computational thinking.

Criteria are proposed for the objectives of a definition of computational thinking, in accordance with the findings presented in the literature review. The criteria were then used as a theoretical framework together with the identified criteria as the vocabulary to propose a definition for computational thinking. The proposed definition was then evaluated against definitions proposed by other computer science educational researchers [6, 7, 3] to determine its effectiveness.

The authors look back to identify the historical roots of computational thinking, and look to the future in which educators use a consensus definition of computational thinking.

1. Introduction

In 2012, ICT was disapplied as a subject from the national curriculum that was taught in state primary and secondary schools in England [8], and was replaced by the computing programme of study as part of the introduction of a new compulsory national curriculum which was first taught from September 2014 [1, 9]. The opening sentence of this programme of study states:

> A high-quality computing education equips pupils to use computational thinking and creativity to understand and change the world.

The prominence of the phrase "computational thinking" in this sentence generated an ongoing debate and discussion amongst teachers and academics regarding "What is computational thinking?", how to teach and assess it. The term computational thinking was popularised in Wing's seminal essay [3], in which she challenge the education establishment to:

> Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability.

[1] Newman University, England, a.p.csizmadia@newman.ac.uk
[2] Nottingham Trent University, England, helen.boulton@ntu.ac.uk

Consequently, Computing At School, the subject association for computer science teachers in the United Kingdom, produced guidance for teachers regarding teaching computational thinking [10].

2. Method

The systematic literature review that was conducted between November 2016 and January 2017 and utilised the PRISMA framework [11]. The PRISMA framework involves a four stage iterative process of: identification, screening, eligibility and inclusion. The primary search terms used were: "defining computational thinking", "definition of computation thinking" and "computational thinking definition". During this literature review both academic literature (i.e. electronic databases (ACM Digital Library, IEEE Xplore and Education Information Resource Centre (ERIC)), conference proceedings, journal articles, academic books) and grey literature (i.e. blogs, websites, online magazines) were searched.
The *Publish and Perish* software tool was utilised in order to allow both Influential Literature Analysis [4] and Citation Analysis [5].

3. Evidence from Literature

3.1 Findings

Publish and Perish identified that 54 academic works contain the term "defining computational thinking", 232 academic works contain the term "definition of computational thinking" and 14 academic works contain the term "computational thinking definition". These are analysed by year in the following table.

Search Term	Pre 2006	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
defining computational thinking			2			3	1	1	5	9	13	15	1
definition of computational thinking	3		1		3	10	13	12	27	36	49	73	5
computational thinking definition			1				2	1	2	3	1	4	

Table 1: Yearly analysis of primary search terms

The majority of the sources identified in the literature review have Wing's seminal article [3] as their epicentre, even though Wing did not provide a definition of computational thinking in her article.
The literature clearly indicates that determining a consensus definition of computational thinking has proved to be problematic for the computer science education community and this fact has been recognised by its members [3, 17]. Many individuals [3, 7, 14] and organisations [12, 13] have attempted to derive one.
The systematic literature review revealed that there were 4 related academic works which documented computational thinking literature reviews [6, 7, 14, 15]. The following table provides a comparison of these literature reviews in chronological order:

Literature Review	Author(s)	Date	No of relevant papers identified
Computational Thinking in K–12 A Review of the State of the Field	Grover and Pea	2013	41
Computational Thinking: The developing definitions	Selby and Woollard	2014	20
Developing Computational Thinking in Compulsory Education	Bocconi et al	2016	570
Computational Thinking in Education: Where does it fit in?	Lookward & Mooney	2017	136

Table 2: Comparison of Computational Thinking Literature Reviews

3.2 Historical Roots of Computational Thinking

A number of computer science education researchers [16, 17, 18, 19] look beyond Wing's seminal article in an attempt to identify the historical roots of computational thinking. Tedre and Denning in their award winning paper *The Long Quest for Computational Thinking* [20] summarise their investigation into and discovery of the historical roots of computational thinking as:

- Perlis highlighted the value of coding as a mental tool for understanding all kinds of problems;
- Perlis emphasised the need to cultivate a certain style of reasoning about problems and designing solutions;
- both Dijkstra & Knuth argue that computing's disciplinary identity arises from its unique mental processes;
- Dijkstra argues that the uniqueness of computing arises from algorithmic thinking;
- Knuth identified two thinking patterns that computer scientists used: complexity and causality;
- Forsythe argued that computing's unique ways of thinking provide general-purpose mental tools would last a lifetime;
- Bolter introduce the idea of "Turing's man" as the quintessential image of humanity in the digital age;
- Feurzeig et al. argued that teaching programming improves logical and rigorous thinking;
- Papert in his book *Mindstorms* introduces the idea of procedural thinking as a powerful intellectual tool and was the first uses the phrase computational thinking.

The authors as a consequence of their literature review, identified 43 key text which comprised of:

- 1 landscape survey of Computational Thinking;
- 2 literature reviews on Computational Thinking;
- 6 Working Group reports om Computational Thinking;
- 4 existing definitions of Computational Thinking;
- 20 discussions on defining Computational Thinking;
- 8 discussions on the implications of not defining Computational Thinking;
- 2 discussions on what Computational Thinking is not.

4. Terminology

In spite of a wide variety of definitions, there appears to be a subset of core concepts and skills that recur within the literature. Bocconi et al [14] juxtapose computational thinking skills identified in five prominent papers and a concise summary of their analysis is presented in the following table.

Barr and Stephenson 2011	Lee et al 2011	Grover & Pea 2013	Selby & Woollard 2013	Angeli et al 2016
Abstraction	Abstraction	Abstraction	Abstraction	Abstraction
Algorithms & procedures		Algorithmic notations of flow of control	Algorithmic thinking	Algorithmic thinking
Automation		Automation		
	Analysis			
		Conditional logic		
Problem decomposition		Structured problem decomposition	Decomposition	Decomposition
	Debugging and systematic error detection			Debugging
		Efficiency and performance constraints	Evaluation	
			Generalisation	Generalisation

Table 3: Comparison of Terminology with Identified Literature

5. Proposed Definition

Having critically examined the definitions presented to-date for computational thinking and then compared and contrasted the terms identified in those definitions; the authors present the following definition for computational thinking to both the computer science education community and the wider education community for their consideration and deliberations:

> Computational thinking is the usage of concepts, processes and practices drawn from computer science in problem-solving carried out by an information processing agent either individually or collaboratively.

The authors would welcome constructive feedback from the wider community regarding the definition presented.

6. Conclusion

There is a general need for a robust and consensus definition of computational thinking, which not only can facilitate the development of the curriculum in line with Papert's legacy for educational computing and Wing's original vision of computational thinking for all. The authors present their definition of computational thinking as a discussion point in the debate regarding a consensus definition. An agreed definition will ensure that computational thinking activities can be designed, computational thinking resources can be developed, and appropriate assessment tools can be designed, developed and deployed in order to measure computational thinking skills. This review of the literature provides a glimpse into the past as the historical roots of computational thinking are presented so that we appreciate and understand what has shaped its development and what can influence us as we embed computational thinking in our teaching now and in the future.

7. Acknowledgment

The first author wishes to thank his supervisory team, Professor Gren Ireson and Dr. Helen Boulton for their ongoing support and guidance.

References

[1] Department for Education (DfE) "National curriculum in England: computing programmes of study", Department for Education, London, 2013

[2] Wing, J.M. "Computational thinking", Communications of the ACM, 2006, pp.33-35

[3] Brennan, K. and Resnick, M. "New frameworks for studying and assessing the development of computational thinking", Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada , 2012, pp. 1-25

[4] Hoepner A.G.F. and McMillan D.G. "Research on responsible investment: an influential literature analysis comprising a rating, characterization and investigation", Working Paper, 2009

[5] Harzing, A.W. "Citation analysis across disciplines: the impact of different data sources and citation metrics", http://www. harzing. com/data_metrics_comparison.htm, 2010

[6] Grover, S. and Pea, R. "Computational Thinking in K–12 A Review of the State of the Field", Educational Researcher, *42*(1), pp.38-43

[7] Selby, C. and Woollard, J. "Computational Thinking: The developing definitions", In Proceedings of the 45th ACM Technical Symposium on Computer Science Education, SIGCSE, 2014

[8] Department for Education (DfE) "Disapplication of the National Curriculum Programme of Study, Attainment Targets and statutory assessment arrangements for ICT from September 2012", Department for Education, London, 2013

[9] The Royal Society. "Shut down or restart? The way forward for computing in UK schools", The Royal Society (2012). Shut down or restart? The way forward for computing in UK schools. http:// royalsociety.org/education/policy/computing-in-schools/ report/ [accessed 27 February 2014], 2012

[10] Csizmadia, A., Curzon, P., Dorling, M., Humphreys, S., Ng, T., Selby, C. and Woollard, J. "Computational thinking: A guide for teachers", *http://community. computingatschool. org. uk/resources/2324*, 2015

[11] Moher, D., Liberati, A., Tetzlaff, J. and Altman, D. G. “Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement”, International Journal of Surgery, 8, 2010, pp. 336–341
[12] National Research Council. “Report of a workshop on the pedagogical aspects of computational thinking”, Washington, DC, National Academic Press, 2011
[13] National Research Council. “Report of a workshop on the scope and nature of computational thinking”, Washington, DC, National Academic Press, 2010
[14] Bocconi, S., Chioccariello, A., Dettori, G., Ferrari, A. and Engelhardt, K. “Developing Computational Thinking in Compulsory Education-Implications for policy and practice (No. JRC104188)”, Joint Research Centre (Seville site), 2016
[15] Lookward, J. and Mooney, A. “Computational Thinking in Education: Where does it fit?”, Name of Journal/Work/Source, Maynooth, Maynooth University, 2017
[16] Dede, C., Mishra, P. and Voogt, J. “Working group 6: Advancing computational thinking in 21st century learning”, 2013
[17] Guzdial, M. “Education Paving the way for computational thinking”, Communications of the ACM, 51(8), 2008, pp. 25-27
[18] Mannila, L., Dagiene, V., Demo, B., Grgurina, N., Mirolo, C., Rolandsson, L. and Settle, A. “Computational thinking in K-9 education”, Proceedings of the working group reports of the 2014 on innovation & technology in computer science education conference, 2014, pp. 1-29
[19] Voogt, J., Fisser, P., Good, J., Mishra, P. and Yadav, A. “Computational thinking in compulsory education: Towards an agenda for research and practice”, Education and Information Technologies, *20*(4), 2015, pp. 715-728
[20] Tedre, M. and Denning, P.J. “The long quest for computational thinking”, Proceedings of the 16th Koli Calling Conference on Computing Education Research, 2016, pp. 24-27