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A Review of Common Features inComputational Thinking Frameworks in K-12 Education

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Abstract. Computational Thinking (CT) is not just another application of computer science principles in humans' life. Computational Thinking has emerged as a systematic way of thinking, and problem-solving process. The awareness of inculcating CT into education, at different curricular level has started in various directions, and contexts. The article aimed to introduce the basic concepts of CT and highlight common key features within K-12 education frameworks, deployed by different bodies. Computational thinking is closely relatedto critical thinking, STEM (science, technology, engineering, and math) learning, as well as project-based learning. From the review, various computational thinking definitions and key features within education frameworks were identified, and this contributed in how computational thinking is being integrated in different context, respectively.

1. Introduction

Over the last decade, a growing body of research has provided evidence on the relevance of computational thinking in K-12 education. The concept of CT is gaining more attention due to the numerous benefits CT has to offer within different education level, for teaching and learning process across different subjects. Many study relates computational thinking as a great tool for harnessing interest in Science, Technology and Engineering (STEM) courses, for students at different level in education. In the context of K-12 education, it is highly valued as application of computer science principles within kindergarten, primary and secondary levels educational practice, by teachers and their pupils/students in classroom setting, or beyond. The National Research Council [13] emphasized the significance of introducing CT to students as early as possible, and assisting them to understand the application of these essential skills. The pervasive nature and potential of computational thinking is undeniable, as it permeates almost all diciplines, which includes both sciences and humanities [6].

Thus, the aim of this article is to highlight the common features available frameworks, or models which have been adopted in various K-12 educational context, as a useful guide for current and future endeavour to implement CT within various setting and objectives.

The Bureau of Labor Statistic [7] reported there were more computing jobs created annually. Nevertheless, there were insufficient number of graduates in computer science course, as substantial job opening for this qualification is estimatedin the future. Numerous studies have evidenced various advantagesof learning computational thinking, including improved student engagement,enthusiasms, with better confidence level, problem solving, communication, as well as a catalyst in STEM learning and performance [19]. A study by Israel, Pearson, Tapia, Wherfel and Reese [12] indicated even struggling learners, including students with disabilities and those living in poverty, also gain benefit from computing education through scaffolding, modeling, and peer collaboration.

As computing and the advances of artificial intelligence become more prevalent in human's life, computational thinking is emerging as very much neededcritical skill, and many international bodies are recognizing this fact. Support for teaching computing in K-12 schools is rising in the U.S. and other countries. Many developed nations such as England, Finland, South Korea, and Australia has made it compulsory for children education to learn computing or computational thinking [18].

2. History of Computational Thinking

In March 2006, Jeannette Wing released her seminal article titled "Computational Thinking" in the Journal of the Association for Computing Machinery. Wing suggested that "computational thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science. It represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use"[21]. Wing further said "to reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability" [21]. She also asserted computational thinking as a critical skillset for everyone, not just for computer scientist nor exclusive to computer science field.

Piaget coined the term 'Constructivism' to reflect that children construct their own knowledge through experience rather than being taught by teachers [16]. Later, Papert and Harel [15] introduced 'constructionism' which extend the definition of constructivism by adding another useful dimension to it. Learning process was considered as developing knowledge structures regardless of learning conditions. The aim was to inculcate contentment during the conscious meaning making process in constructing new knowledge. This "learning by making" connotation echoes the concept of computational thinking, as the computational thinking core elements comprehends (at least with this four basic core elements), which requires learners to perform decomposition, recognizing available patterns, abstracting from existing knowledge and finally, designing algorithm, in problemsolving, and eventually developing new knowledge. Since then, computational thinkingteaching has conventionally been viewed as a primarily constructionist endeavour [4, 8].

3. Definitions of Computational Thinking

Computational thinking is a phrase frequently used in the literature, but there is little consensus on a common definition [1, 2, 13], although generally there are some agreement on the similarities and differences. Therefore, it is vital for researchers and educators to acknowledge the diverse version by different authors and organizations.

3.1 Operational definition

The International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) have collaborated with experts from K-12 education, higher education and industry, and developed an operational definition of CT. The definition has afforded a framework and some terminologies which are relevant to K-12 educators. ISTE and CSTA [11] regarded computational thinking as a problem-solving process whichcomprisesof (but is not limited to) all the below:

"Formulating problems in a way that enables us to use a computer and other tools to help solve them;Logically organizing and analyzing data; Representing data through abstractions such as models and simulations; Automating solutions through algorithmic thinking (a series of ordered steps); Identifying, analyzing, 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."

Google For Education [10] defined CT as "problem solving process that includes a number of characteristics, such as logically ordering and analyzing data and creating solutions using a series of ordered steps (or algorithms), and dispositions, such as the ability to confidently deal with complexity and open-ended problems". In mathematics and science field, Weintrop et al [20] proposed a definition of computational thinking in the form of a taxonomy consisting of four main categories: data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices.

4. Common features for Computational Thinking frameworks within K-12 Education: A work in progress

Collaboration with the computer science education community is essential to achieve the overarching objectives of computational thinking and "the process of increasing student exposure to computational thinking in K-12 is complex, requiring systemic change, teacher engagement, and development of significant resources" [2].Following the definition of computational thinking, CSTA and ISTE [11] presented a framework specifically for K-12 education, and nine major computational thinking concepts. Below table shows the summary of the framework:

Table 1.CT core concepts for Computational Thinking framework in K-12 education in different context

Author	CT core concepts (or elements) introduced	K-12 Education framework / context of use
Jeannette Wing	• problem-solving process, designing systems, and understanding human behavior [21] • Abstraction and automation [22]	Main reference to many CT framework in different countries
CSTA and ISTE [11]	• data collection, • data analysis, • data representation, • problem decomposition, abstraction, • algorithms and procedures, • automations, • parallelization • simulation	USA, Framework for K-12 Science Education (2012) [14] UK, Computing at School (2014) for primary and secondary school
Curzon, Dorling, Ng, Selby and Woollard [9]	Definition,Concepts,Classroom techniques and Assessment (Four interconnected stages of development)	UK's computational thinking framework
Selby and Woollard [19]	algorithmic thinking, evaluation, decomposition, abstraction and generalization	
Brennan and Resnick [5]	*computational concepts* (repetition, parallelism, etc) *computational practices* (debugging projects or reproducing) *computational perspectives* (the perspectives designers build about the world around them, and about themselves)	MIT Media Lab, using Scratch

The National Research Council [13] suggested mathematics and computational thinking to be part of the eight central practices for scientific and engineering development, as stated in "Framework for K-12 Science Education" [14]. In this framework, mathematics and computational thinking encompasses the use of computer tools to signify physical variables and the relationships among them.

MIT Media Lab, through its Lifelong Kindergarten research has developed Scratch, a computational authoring environment where learners would design their individual interactive media, which cover stories, games, animations, and simulations. This visual programming tool allow programming-like blocks to be incorporated during the process of designing, just like how LEGO bricks or puzzle pieces are snapped together [17]. Scratch is a visual programming environment that enables learners to develop interactive stories, games, and simulations, and then share it in an online community with others from around the world. By using Scratch as the context, Brennan and Resnick [5], promoted three key dimensions of computational thinking frameworks. The idea of the framework is in line with constructionism when learners participate as designer themselves whilst using interactive media with Scratch, to support the development of computational thinking among young learners.

In Malaysia, the Prime Minister has declared the integration of computational thinking skills into all subjects, starting from 2017 with Year 1 primary students [3]. Therefore, there is a crucial need for schools and especially teachers to be equipped with all the necessary skills to integrate computational thinking in their teaching and learning process. The newly revised curriculum was made available, with reference made from international bodies, and following the global trends, which also includes benchmarking.

5. Limitations

The scope of this article review is limited to only selected publications between 2006 and 2018, with focus on selected countries, not worldwide. This is mainly due to limited length of discussion allowed in this publication.Hence, more details can be addressed in a more comprehensive article in the future.

6. Conclusions

In summary, computational thinking is a thoughtful way of solving problems that is extensively appropriate throughout the K-12 curriculum and progressively relevant in the 21st century. Although there are varying definitions and multiple views of computational thinking frameworks in K-12 education. with some different core elements (constructs) being identified. This could be due to different epistemological perspective, and degree of application in various educational context. Integrating computational thinking into core and elective subject areas can help students to achieve better understanding and enable them to make imperative cross-curricular connections, which would improve their academic performance, and develop important skills for creating solutions in the wide variety of aptitudes. As computational thinking is gaining more popularity and significance, a lot of countries, states, and institutions are implementing it into their school curriculum. In general, it is important to acknowledge common key elements of CTs in ensuring successful computational thinking integration within K-12 education.

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