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A Review of Reviews on Computational Thinking Assessment in Higher Education

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ABSTRACT
There is an urgent need for educating the next generation of learners with digital tools and making use of digital practices and skills. Education on computational thinking (CT) is widespread around the world with a dominant focus on K-12. Recently also higher education has come more to the focus of CTE. However, most of the work on CT in higher education has been focused on teaching and learning programming while less attention has been paid to the underlying skills and competences of CT in different domains. In this article 11 reviews were analyzed to identify constructs being assessed, methods and their characteristics for the delivery of assessment and the context in which the assessment were conducted. The findings indicate that there is certain consensus in the field on what constructs to measure. Last but not least, it was determined from our study that there are often no standards or principles followed for the design of assessment.

KEYWORDS
Computational Thinking, Assessment, Higher Education, Literature Review

1. INTRODUCTION
According to Denning (2016), Computational Thinking (CT) is skillset that human beings utilized for problem-solving regardless of the rapid change of technology throughout history. Additionally, the importance of CT for modern citizens is stressed in Royal Society (2012) in UK and Royal Netherlands Academy of Arts and Sciences (2013) since CT is regarded as imperative for enabling people to better work and live in a digital environment.

Though the long historical usage of CT skills was highlighted by Denning (2016), research in the field of CT education is still in its early age. Computational thinking was first mentioned by Papert (1980) in his book and then promoted by Wing (2006)'s viewpoint delivered through Communications of the ACM, described as an imperative skill for everyone just like 3R (reading, writing, arithmetic). Since then, researchers, practitioners and policymakers who are proponents and critics of this topic started to explore and study teaching, learning and assessment of CT by examining different dimensions of the topic across all education levels with more attention to K-12 education. Dimensions being studied include but are not limited to the definition of CT (Lyon & J. Magana, 2020; Shute et al., 2017; Tang et al., 2020), the integration of CT to the current curriculum (García-Peñalvo, 2017; Henderson et al., 2007; Leathem et al., 2019), the interventions used for CT teaching (Constantinou & Ioannou, n.d.; Ezeamuzie & Leung, 2021; Taslibeyaz et al., 2020), the tools developed for CT teaching and learning (Ambrósio et al., 2015; Angeli & Giannakos, 2020), or the assessment of CT (Y. Li et al., 2020; Rom An-Gonz Alez et al., 2016; Sondakh et al., 2020). Often it still remains unclear what CT is, how they are operationalized in educational activities, what distinguishes it from other kinds of thinking skills and how it can be incorporated with other subject domains (Specht, 2020).

Irrespective of the controversies and ambiguity mentioned above, a considerable amount of knowledge has been accumulated in this field. Theoretical frameworks have been established over the years to facilitate CT understanding and promotion, such as Brennan and Resnick's (2012) three-dimensional framework, Weintrop's (2016) taxonomy of CT in mathematics and science, Grover and Pea's (2018) competency framework, which are seemingly the most adopted ones in the literature. Tools such as Alice, Scratch, Bebras (Tang et al., 2020), have been developed for teaching, learning and assessment of CT in different contexts (Cutumisu et al., 2019). Curriculums have been developed for teaching CT in different contexts (Hsu et al., 2018). It is noteworthy that though CT has also been interpreted as a model of thinking essential for everyone which can be applied to not only a broad range of domains such as engineering and mathematics, but also daily life scenarios relevant to problem solving (Angeli & Giannakos, 2020; X. Li & Gu, 2020; Tedre & Denning, 2016; Wing, 2006), CT has been mostly linked to Computing Science and programming and more contributions are made in the context of K-12 than in higher education (Cutumisu et al., 2019).

In the process of CT education, assessment is a core component for ensuring learning outcomes. As Van de Vleuten et al. (2011) concluded, the determining factors for the quality of an assessment program and the quality of assessment consist of the types of constructs being assessed, the method used for collecting and collating of information, the role of human judgement and the psychometric methods which requires further investigation. Some of those factors have been examined in several reviews on CT studies in higher education, nonetheless, there is no work providing a holistic view on those factors affecting the quality of assessment up to our knowledge. Thus, in this work, drawing on the conclusion of van de Vleuten (2011), we aim to systematically investigate and synthesis existing knowledge within the following dimensions in terms of CT assessment in higher education: the types of constructs being assessed, methods used for collection and collation of the information, the role of human judgement and the psychometric methods and the assessment context (an extra dimension which lay the background for conduction of assessment) and some additional characteristics of assessment methodologies.

The method we applied is a systematic umbrella review of CT assessment in higher education to provide an holistic view on the 5 dimensions crucial for assessment mentioned in the previous paragraph by answering the following research questions (RQs):

RQ1 What are the characteristics of the included reviews, such as year of publication, country of the work, type of publication, and the methodological features such as type of study, principles, methodology followed for the study and tools that are used?

RQ2 What knowledge that can help suggest developing a high quality of assessment program has been gathered in existing studies regarding assessment of CT in higher education?

- o **RQ2.1:** Assessment objects/constructs: which components were examined as assessment constructs?
- o **RQ2.2:** Assessment methodology: What perspectives of assessment methodology have been examined?
- o **RQ2.3:** Assessment context: What is the assessment context in which CT has been measured?

2. METHODOLOGY

The study adopted the systematic process depicted by Jesson et al. (2011) for gathering the literature to be used as the data set. The major steps followed were (1) identify scope and research question, (2) plan the review and document protocol, (3) develop inclusion and exclusion criteria, (4) search and screen the studies, (5) data extraction and synthesis. The first two steps were performed through narrative analysis on literature and with assistance of an expert and PRISMA is adopted as the plan for primary steps of the review and the others are documented in an excel file. The quality of the studies included in this review was examined through discussions between the authors where necessary. The rest of the steps will be reported in detail in the following subsections. The principal results for the key steps were recorded in the PRISMA flowchart and are shown in Figure 1.

Identification: Number of records through database searching (Scopus = 212, WoS = 143) = *355 + Google Scholar (first ten pages most relevant results)*
Screening: Number of records after duplicate removal = Number of records for screening = *298 (Scopus + WoS)*
Eligibility Checking: Number of full-text articles assessed for eligibility = *129 (Scopus + WoS)*
Included: Number of studies included for analysis = 7 (Scopus + WoS) + 3 (Google Scholar) = *11 in total*

Figure 1. PRISMA Flowchart with Results

3. RESULTS AND ANALYSIS

3.1. General Characteristics of the Included Studies

Overall, eleven studies examined CT assessment in higher education have been included in this analysis. In terms of bibliographical characteristics of the included studies were published within the last five years and no studies have been found before the year of 2016, indicating an increase in the attention to this topic. Over those years, the effort into CT can be found worldwide, with the United States, Turkey and Canada the most active ones. The contributions of those countries in the last years were published as journal articles, conference papers, and book chapters in journals such as Informatics in Education, conferences such as Frontiers in Education Conference and books such as Research on E-Learning and ICT in Education, respectively.

Regarding the methodological characteristics over the included studies the type of study that the review belongs to, it can be observed that most of the included studies are systematic review, followed by scoping review, narrative review and systematic mapping study. In addition to that, besides the work of Vinu (2021), the rest of the other studies referred to existing methods or guidelines for conducting a review.

Among all reviews studied, only Lu (2022)'s work fully focused on investigating empirical evidence of CT assessment in higher education. Eight included reviews examined objects being assessed and characteristics of the objects in their selected studies regarding the skills and competencies and the underlying constructs. Of those studies left, two examined the definition of CT with which the assessed constructs can be deduced by applying constructive alignment theory (Biggs, 1996). In terms of assessment methodology, except for De Jong and Jeuring (2020)'s work, all other studies examined perspectives relevant to the delivery of the assessment, namely - instrument developed for assessment and its characteristics, tools used for assessment and its characteristics, the categorization of assessment methods, the quality indicators for the assessment methods. The context in which the assessment is conducted is examined by all included reviews within the following perspectives: educational setting, education level and academic domain and studies. Detailed examination and result analysis are presented in the following subsections.

3.2. Characteristics of Assessment Objects/Constructs

Cutumisu et al. (2019) and Lu et al. (2022) outlined the assessment constructs by mapping the assessed CT skills to Brennan and Resnick (2012)'s three-dimensional framework and a hybrid framework inferred from Brennan and Resnick's (2012) three-dimensional framework, Weintrop et al. (2016) framework of CT for mathematics and science classrooms, and Grover and Pea (2018)'s two-dimensional framework, respectively. Though the framework of Brennan and Resnick (2012) adopted by Cutumisu et al. (2019) and the hybrid framework adopted by Lu et al. (2022) both depicted CT competency in a three-dimensional framework inclusive of CT concepts, practices and perspectives, the latter was claimed to be more generic and independent of specific subjects which also allows a broader coverage of CT skills and dimensions.

The other five studies presented only the overarching categories of assessed constructs (De Jong & Jeuring, 2020; Taslibeyaz et al., 2020) that provide high-level categorization of constructs being assessed without revealing the constructs itself; or the constructs being assessed in studies (De Araujo et al., 2016; Poulakis & Politis, 2021) or both the constructs and its overarching categories (Hasesk et al., 2019).

It is noticeable that some categories are named almost the same, such as CT skills versus CT skills / ability and attitudes towards CT versus attitude-motivation. However, it is considered improper, by the authors, to merge them at the current level of investigation with insufficient information on its meaning. Thus, the categories of constructs and the constructs are regarded as distinct elements unless they are proven to be identical. The results also show that Taslibeyaz (2020)'s and De Jong and Jeuring (2020)'s works identified six distinct categories of constructs including attitude towards CT, attitude-motivation, CT knowledge, CT skills, problem-solving skills, programming skills while De Araujo (2016), Haseski (2019), and Poulakis (2021) identified five categories of CT construct consist of affective achievements towards CT, cognitive achievements towards CT, CT skills / abilities, CT concepts, CT patterns with enumeration of the underlying constructs in their reports.

Table 1 presents the constructs which appeared in at least 3 reviews while 120 unique constructs were identified from all reviews since it can be too long to present it here. Additionally, the constructs were categorized according to the hybrid framework in Lu et al. (2022)'s work. Example definitions of these constructs from the work are provided in the table when it is accessible according to the hybrid framework.

Table 1. Assessed Constructs Identified from Reviews.

Category	Constructs & Frequency (f)	Definition
CT Concepts	Algorithm / algorithmic thinking / algorithm skills (f =5)	The skills involved in developing an algorithm which is precise with step-by-step procedures to solve a problem. (Grover & Pea, 2018).
	Data / data analysis / data collection, data analysis / data representation (f=5)	Including storing, retrieving, updating values as well as analyzing, and visualizing data (Brennan & Resnick, 2012; Weintrop et al., 2016).
	Automation / automating solutions (f=4)	A key component of computational thinking, for computer science as well as computing in other domains that aims at a solution to be executed by a machine (Grover & Pea, 2018).
	Logic / logic and logical thinking (f=4)	Logical thinking involves analyzing situations to make a decision or reach a conclusion about a situation (Grover & Pea, 2018).
	Critical thinking (f=3)	Not found.
	Evaluation (f=3)	Solutions to problems are evaluated for accuracy and correctness with respect to the desired result or goal(Grover & Pea, 2018).
	Pattern / pattern recognition (f=3)	Pattern recognition in CT could result in a definition of a generalizable solution which can utilize automation in computing for dealing with a generic situation (Grover & Pea, 2018).
	Synchronization / synchronize (f=3)	Not found.
CT Practices	Abstraction (f=5)	Abstraction is 'information hiding'. Through 'black-box'-ing details, one can focus only on the input and output and provides a way of simplifying and managing complexity (Grover & Pea, 2018; Weintrop et al., 2016).
	Problem-solving (f=4)	Not found.
	Modularity / modularizing / modelling (f=3)	Building something large by putting together collections of smaller parts, is an important practice for all design and problem solving (Brennan & Resnick, 2012).
	Testing / testing and debugging (f=3)	Practices that are relevant to dealing with – and anticipating – problems include identifying the issue, systematically evaluating the system to isolate the error and reproducing the problem so that potential solutions can be tested reliably (Grover & Pea, 2018; Weintrop et al., 2016).
CT Perspectives	Creativity and creation (f=4)	Creativity as a CT practice acts on two levels – it aims to encourage

		out-of-the-box thinking and alternative approaches to solving problems; and it aims to encourage the creation of computational artefacts as a form of creative expression (Grover & Pea, 2018).
	Collaboration and cooperation (f=3)	Perspectives about working with CT skills in a collaborative or cooperative format (Grover & Pea, 2018).

3.3. *Characteristics of Assessment Methodology*

There are 10 out of 11 studies investigating the topic of assessment methodology. As shown in table 2, four of them discussed the types of assessment methods emerged from their investigation.

*Table 2.*Assessment Methods.

Types of Assessment Methods	**Reference**
Block-based assessments, knowledge/skill written tests, self-reported scales/survey, robotics/game-based assessments (tangible tasks), combinations	(Cutumisu et al., 2019)
Block-based assessments, knowledge/skill written tests, self-reported scales/survey, text-based programming assessment, course academic achievements of CS courses, interviews and observations, combinations	(Lu et al., 2022)
Interviews, Assignment/course grades, survey/questionnaire, knowledge/skill tests, artefacts (classroom/students), problems external to class, combinations	(Lyon & J. Magana, 2020)
Using specific programming environments, using CT assessment criteria and/or psychometric tools, using multiple forms of assessment	(Poulakis & Politis, 2021)

Lu et al. (2022) and Cutumisu et al. (2019) both identified the following types of assessment in their work: **1) block-based assessments** - solving programming problems without taking into account syntax by using programming blocks in block-based programming environments such as Scratch; **2) skill written tests** - using generic forms for assessment such as constructed response questions or multiple-choice questions to assess CT skills, e.g. Computational Thinking Knowledge test (CT Knowledge test); **3) self-reported scales / survey** - mostly concerned with assessment of CT perspectives which includes inter- and intra-personal skills such as communication, collaboration, or questioning, for example, Computational Thinking Scales (CTS) is a questionnaire that measures five factors including communication, critical thinking, problem-solving, creative thinking and algorithmic thinking. In addition to that, Cutumisu et al. (2019) also identified **robotics/game-based assessments** as a unique category with which indicating the assessments that are based on robotic tangible tasks or artefacts produced in game-based assessments such as AgentSheets. Lu et al. (2022) identified another three categories compared with categories of Cutumisu et al. (2019)'s work, being: **text-based programming assessments** - using text-based programming tasks to assess students' CT competency, for example, a Python programming task; **interviews and observations** - commonly used for studying practices of incorporating CT into traditional classrooms; **course academic achievement** - academic performance in coursework including students achievement in quizzes, exam, projects and assignments.

3.4. *Characteristics of Assessment Context*

All studied reviews contain information about assessment context. A summary of major aspects its corresponding references is presented in table 3.

Table 3. Assessment Context

Aspects	**Description**	**Reference**
Academic Domain	Concerned with investigation into academic disciplines, program of studies or subject matter for the assessed group of users.	(Cutumisu et al., 2019; De Jong & Jeuring, 2020; Ezeamuzie & Leung, 2021; Lu et al., 2022; Lyon & J. Magana, 2020; Tang et al., 2020; Taslibeyaz et al., 2020)
Education Level	Concerned with the level of education for the assessed group of users.	All included reviews
Educational Setting	Concerned with the type of educational activities that the assessed group of users were involved in.	(Cutumisu et al., 2019; De Araujo et al., 2016; Ezeamuzie & Leung, 2021; Lu et al., 2022; Tang et al., 2020)
Intervention	Concerned with the actions taken for the development of skills and / or their corresponding characteristics.	(Cutumisu et al., 2019; De Jong & Jeuring, 2020; Ezeamuzie & Leung, 2021; Lyon & J. Magana, 2020; Taslibeyaz et al., 2020; Vinu Varghese & Renumol, 2021)

For academic domain, besides De Jong and Jeuring (2020) presented a list of academic disciplines, distinguishing the academic background according to the relevance of its study program to Computer Science (CS), Science, Technology, Engineering and Technology (STEM), and Programming Education is found a phenomenon across the studies (De Jong & Jeuring, 2020; Ezeamuzie & Leung, 2021; Tang et al., 2020; Taslibeyaz et al., 2020).

In terms of education level, all reviews included for analysis examined it. However, results were presented differently varying from listing the exact grade level of the examined studies to showing the distribution of grade level in categories with descriptive text. Even with the studies of Lu et al. (2022), Lyon (2020) and De Jong and Jeuring (2021) which delimited their studies in higher education, Lu et al. (2022) presented the exact grade level of the examined studies in a table while the other two regard undergraduate itself as a category.

4. CONCLUSION AND FUTURE WORK

To comprehensively study existing knowledge on CT assessment in higher education, this study systematically reviewed eleven reviews that either fully focused on review of CT assessment in higher education or include CT assessment in higher education as a composition of all investigation dimensions.

In terms of the bibliographical and methodological characteristics of the included studies (for answering RQ1), it was determined that there is a worldwide increase in attention to explore knowledge on the topic of assessment of CT higher education from different dimensions from various perspectives.

To gain a comprehensive view about major components in an assessment and to answer RQ2, this work identified, regarding CT assessment in the context of higher education, constructs being assessed, the characteristics of methodology for assessment and assessment context. Only one of the three works which examined CT in higher education specifically studied assessment (De Jong & Jeuring, 2020; Lu et al., 2022; Lyon & J. Magana, 2020).

First of all, regarding the constructs being assessed in assessments, this work identified more than 100 unique constructs. While some work clustered the constructs from included studies, only with the work of Cutumisu et al. (2019) and Lu et al. (2022) identified constructs by drawing on Brennan and Resnick's CT framework and the hybrid framework consisting of Brennan and Resnick's framework, Grover and Pea's framework and Weintrop (2016)'s framework, respectively. None of the studies examined if certain constructs or constructs types appeared more often and considered more appropriate to be assessed at a certain educational level.

Moreover, assessment methods were categorized differently in the four reviews in which the methods are grouped and presented. It is recognized that whether the method concerns with programming a major distinguishing factor. Meanwhile, combined use of different assessment methods were positively promoted and suggested from the results and the text of those four reviews.

Furthermore, with regard to assessment context, this study identified four major dimensions that provide information about academic background: academic domain, education level, educational setting and intervention. Results show that there is an increased number of studies bringing CT into various disciplines, with more attention to non-CS majors in recent years. Most studies are conducted in a formal educational setting and assessments are mostly conducted with entry-level or lower-level students in higher education which is integrated in a course or curriculum.

While CT education is a part of education, existing studies apply no assessment framework or reason about the design of the assessment. We argue that design of assessment, especially assessment for learning, plays a critical role in assisting students in learning skills. This study provides an overview of potential factors that need to be considered, according to the evidence of existing research, when designing assessment for assessing CT skills.

5. AUTHOR STATEMENT AND DATA ACCESS STATEMENT

5.1. Author Statement

Xiaoling Zhang: Conceptualization, Methodology, Data Collection, Analysis, Writing - Original Draft, Writing – Review & Edit, Visualization, Resources

Marcus Specht: Conceptualization, Methodology, Writing – Review & Edit

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5.2. Data Access Statement

All papers used for analysis in this work can be approached via the following three indexing databases: SCOPUS, Web of Science and Google Scholar. Collated data that is used for reporting the results are accessible upon request to authors..

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