Examining theoretical and pedagogical foundations of computational thinking in the context of higher education

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***Abstract*— This research paper examined theories, pedagogies, and contents explored by studies focusing on promoting computational thinking (CT) in higher education institutions (HEIs). CT has become a fundamental approach to building problem-solving skills, which requires a thought process. The field of CT is generally still maturing, and the use of CT as an approach to introduce freshmen to introductory programming courses in HEIs has been gaining scholars' interest in the recent past. To appreciate the strategies explored to promote teaching and learning of CT in HEIs; evaluate scholarly discussions, contributions, and potential impact of studies in this field, there is a need to ground the theoretical constructs that build the foundation for the field. A literature review methodology was adopted in this study. The data collected from the Web of Science, the Scopus, ACM, and ProQuest databases were analyzed to provide answers to the research questions. The findings from this study suggest that constructionism and constructivism are the prevailing learning theories explored by scholars in this field to deploy CT in HEI. Additionally, the study revealed that activity-based learning, problem-based learning, automatic assessment-based learning, and self-regulated or self-reflective learning are the prominent pedagogies used by educators. These findings provided a strong foundation for research in this growing field. Besides, the findings also create an opportunity for positioning CT in HEI's educational curriculum regarding how CT should be taught in that context.**

Keywords*— *Computational thinking, pedagogy, learning theory, higher education, university

I. INTRODUCTION

Computational thinking (CT) refers to thought processes involved in formulating steps for problem-solving [1][12]. problem-solving skills is necessary in every field including computer science and engineering. As asserted by many scholars [2][3][4], having CT skills may not necessarily mean knowing how to write computer programs. However, CT skill is required in every human endeavor. Since Wing 2006 [1] re-introduced the topic of CT, the term has become popular, and scholars have developed increasing research interest for CT in K-12 settings [5]. In this sense, a systematic review of CT in the general settings [6] and K-12 settings [7][5] revealed several contextual contributions, tools, and interventions developed to improve students' CT skills.

However, in higher education institution (HEI) settings, discussion regarding the potential of CT was seen to begin in the recent past [8]. A few studies have investigated the penetration of CT in the HEIs [9][10]. While these previous studies that reviewed articles on CT provided useful findings in terms of concepts, context, and interventions for promoting CT in K-12 and HEIs, there is a need to examine the theoretical foundation and pedagogical approaches used by researchers in the field, particularly in HEIs. This need is even more significant as the quest for mainstreaming computational thinking at all levels of education is growing in the developed regions such as the US and Europe [11]. Moreover, this knowledge may provide a strong foundation towards placing CT in the HEI educational curriculum and create opportunities to define how CT should be taught in this context [12]. A recent study by Ali and Yahaya [13] investigated learning theory on computational thinking through the lens of a systematic review of studies conducted between 2015 to 2020. Their findings revealed that constructivist learning theory is prevalent among studies on CT focusing on K-12 and high schools. One thing that was unclear in Ali and Yahaya's study is whether studies conducted within the boundary of HEI to promote CT are grounded in any learning theory since a few results found in that context did not reflect the well-known theories [13].

While this current study derives its motivation from previous related research, including [13], it narrowly focuses on examining published articles to provide research evidence regarding the theoretical connection and pedagogical approaches explored by previous studies to promote CT in HEIs context. This current study is relevant in making significant contributions to the field because a study that narrows its lens of investigation to theories and pedagogies for CT in HEI is missing. Authors deem it necessary to conduct a literature review to fill the gap. Besides, the study aims to hopefully unravel knowledge about the concrete theoretical foundation for CT research in HEI as the field is still maturing. We hypothesized that studies related to CT and programming education should generally have a foundational theoretical underpinning. Besides, scholars should connect their research to well-established theories. This study aims to investigate articles focused on CT in HEIs to unravel which theories or frameworks are being explored in studies focusing on CT in HEI, which pedagogies have been adopted in such studies, and what kind of topics and contents of CT are students learning. To achieve the goal of this study, the following research questions (RQ) will be answered.

RQ1. What are the theoretical foundations for studies focused on CT in HEIs?

RQ2. What pedagogies are explored to teach CT in HEIs, and to what extent have these pedagogies been impactful?

RQ3. What kind of CT topics and contents are students in HEI learning?

In order to concretely examine these research questions, the study adopts two approaches. First, to review the contents of articles that meet the study inclusion criteria presented in the methodology section. Second, to analyze authors' keywords which are in the quantitative bibliometric data collected from reputable databases. The reason for adopting this strategy is to deepen the investigation and minimize missing out on relevant information. Besides, the strategy will aid to see whether findings from the two approaches complement each other or otherwise.

II. OVERVIEW OF EDUCATIONAL THEORIES AND PEDAGOGIES

The field of CT in education is generally still maturing. Hence, to appreciate the approaches explored to promote teaching and learning of CT in HEIs, evaluate discussions, contributions, and potential impact of scholars in this field, there is a need to ground the theoretical constructs that build the foundation for the field. Therefore, this section provides a brief overview of a few learning theories connected to computing education [14].

Widely known learning theories have contributed to the foundational development of various educational fields, although mostly having differing viewpoints. Cognitivism learning theory believes that the human mind plays a vital role in learning. According to cognitivist, some cognitive processes of the mind are critical elements of learning - for example, motivation and imagination [15]. According to Clark [16], the theory of cognitivism accentuates the role of mental activities in the learning process. These activities can include “thinking, remembering, perceiving, interpreting, reasoning, and problem-solving” ([16], pp. 176).

Experiential learning theory holds the epistemological viewpoint that experience plays a central role in the learning process [17]. In this sense, ideas are constantly formed and reformed through experience [17][18]. Simply put, Yardley and colleagues [19] had described experiential learning as “constructing knowledge and meaning from real-life experience” ([19], pp. 161).

To evaluate and define what constitutes substantial experience, [18] recently conducted a systematic literature review of experiential learning theory as demonstrated in different educational applications. Morris found that for a learning experience to be concrete, learners are involved and active participants.

According to Kynigos [20], the constructionism learning theory was introduced by Seymour Papert in the 1970s based on an epistemology that focused on mathematics education. Constructionists draw our attention to the meanings generated by learners and support the idea that exposing a learner to concrete thinking is a crucial cognitive process to gaining abstract knowledge. Therefore, constructionism is continuously modified to create relevance as a learning theory in this technology era where digital media is increasingly used to support teaching and learning [21].

According to Zhu [22], constructivism learning theory postulates learning as an active, constructive process where learners create their mental representation of learning objectives. In order words, learning is obtained from mental construction, where students acquire knowledge by aptly fitting new information together with what they had previously known [23]. This learning theory is tailored towards learner-centered instruction to support an individual-based learning experience.

Technology-enhanced learning interventions usually adopt well-established pedagogy to present educational contents that support students' comprehension, motivation and enhanced learning outcomes [24]. Nowadays, scholars in educational technology have used pedagogies such as self-directed/regulated learning [25], game-based learning [26], participatory/collaborative learning [24], puzzle-based, and problem-based learning [27]. A previous study by Bower et al. [28] has demonstrated how to identify relevant pedagogies that can be explored for teaching and learning of CT. This study identified pedagogies that are classified into student-centered and teacher-centered pedagogies. In this study, we intend to investigate pedagogies currently employed for teaching and learning CT in HEIs.

III. METHODS

This section presents the study strategy and procedure by following the protocol proposed by Kitchenham and colleagues at the Keele University [29]. Therefore, Fig. 1 provides the research protocol in three phases, including the planning phase, conducting phase, and reporting phase.

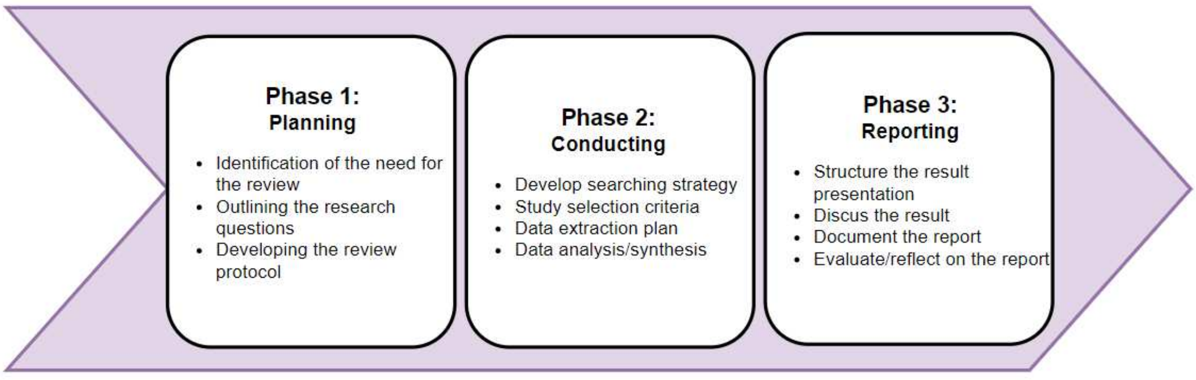

Fig 1. The research protocol adapted from Kitchenham and Charters [29]

A. Search strategy and data collection

The data collection for this study was structured to focus mainly on two dimensions of the review. First, we collected data to conduct keyword analysis from the bibliometrics. The second dimension of the data collection was meant for the systematic review. The reasons for our intention to conduct keywords analysis are: first, to gain general insight into what kind of study on CT in HEI is being published; second, to understand whether there are keywords mapping that can reveal research hotspots, pedagogies, and theories utilized for exploring CT in HEIs. On the other hand, the systematic review is meant to dig deeper into the papers and determine what pedagogies and theories exist among studies that have explored CT in HEIs. Therefore, our general protocol for data collection to service both intensions is presented in Fig. 2.

In this study, a total of four databases, including the Scopus, the Web of Science (WoS), ACM, and ProQuest, were considered for the data collection. While the Scopus and WoS databases were used to collect data mainly for the bibliometric analysis, the ACM and ProQuest databases were the data sources meant for the systematic review. The Scopus and WoS are databases that indexes huge number of publications in the field of science and engineering [11][30]. Besides, we took further steps of collecting data from the ACM and the ProQuest databases, which also publishes many studies in science and engineering, to limit the chances of leaving out relevant data. The search strategies were mapped out to contain primarily the keywords we considered relevant for the search. As shown in Table 1, each database search field contains all the main keywords but structured according to the specific webpage of the database and the advanced search provision. For example, the main strings used in the search were "computational thinking" AND ("higher education" OR "universit*" OR "college").

Although the search strings were the same, and selection conditions (inclusion and exclusion criteria) defined for this study were similar. However, each database has provided some slightly different approaches, which necessitated some slight modification of the criteria, as shown in Table 1. Since the focus of the study is CT in HEIs in general, and the field is still young, the authors did not limit the search to a date range. This is to allow the study to collect enough data for an in-depth analysis. The search conducted on the 19th April 2021 had varied results returned, as shown in Fig. 2. However, after applying the selection criteria, the number of results that met the final section criteria trickled down.

For the bibliometric analysis, a total of 627 data met the initial selection criteria. This total number consists of the combination of data retrieved from the Scopus and the WoS. Furthermore, we subjected data from all the databases (ACM, ProQuest, WoS, and Scopus) to a more rigorous screening where we skimmed article title, abstract, and keywords to determine whether they meet the criteria for content analysis or not. In this case, articles that are merely proposals, frameworks, and discussions were removed. Therefore, the content analysis utilized only empirical studies, design and development studies, and evaluation studies. The authors perceived that these types of studies provide more definite information regarding the theories and pedagogies.

B. Data Synthesis

The analysis of data collected both for the bibliometric mapping and content review is shown in Table 2. These data were used for further analysis to visualize the different components in the data. Recently, bibliometric mapping has become popular as an approach to investigate networks and relationships using indicators such as authors'keywords, social collaborations, citations, and terms others [11][30][31][32]. Therefore, 627 research papers were analyzed using VOSviewer version 1.6.16 [1] for the bibliometric mapping. The bibliographic data were aggregated from both databases into a 'CSV' file and uploaded to the VOSviewer software. We then created the visualization map based on co-occurrence analysis of the authors' keywords in the publications with a threshold of 5 occurrences of a specific keyword to be selected. The software also allows to further refine the selection manually before it plots them onto the map. Therefore, the data was refined to select relevant keywords used for the analysis. Moreover, 24 publications were also reviewed based on contents.

TABLE I. A COLLECTION STRATEGY AND SELECTION CRITERIA

Databases	An instance of a search strings	Selection criteria
Scopus	TITLE-ABS-KEY ("Computational Thinking" AND ("higher education" OR Universit*" OR "college"))	**Inclusion**: 1.English 2.Articles whose publication status is "Final." 3.Publications that are either "Article," "conference Paper" or "Book Chapter" **Exclusion**: 1.Articles whose publication status is "Article in Press" 2.Studies classified under letter, note, editorial, review, conference review, and short survey. 3.Articles whose source type is "Trade Journal"
WoS	TOPIC: ("Computational Thinking" AND ("higher education" OR "Universit*" OR "college"))	**Inclusion**: 1.Only documents types classified as "Article" and "Proceedings paper" 2.Articles whose language was English **Exclusion**: 1.Documents classified as "reprint", "review", and "editorial material" were removed 2.Articles whose language was not English
ACM	[Publication Title: "computational thinking"] AND [[All: "higher education"] OR [All: "universit*"] OR [All: "college"]]	**Inclusion**: 3.Under content type, we selected only "Research Article" 4.Under the publication type, we selected only "Journals and Proceedings" **Exclusion**: There were no exclusion criteria defined in this database since the inclusion criteria had taken care of it.
ProQuest	ti("computational thinking") AND ("Universit*" OR "higher education" OR "Universit*" OR "college" OR "undergraduate")	**Inclusion**: Under document type, we selected only "Article", "Dissertation/Thesis", and "Conference Proceeding" **Exclusion**: Articles whose source type is "Trade journal" and "Magazines"

[1] https://www.vosviewer.com/

TABLE II. MAIN INFORMATION OF DATA UTILIZED FOR THE BIBLIOMETRIC AND CONTENT ANALYSIS

Bibliometric data	
Total documents	627
Average years from publication	3.83
Average citations per documents	4.381
Average citations per year per doc	0.7837
References	14334
Document types	
Article	186
Book chapter	9
Conference paper	432
Document contents	
Keywords plus (ID)	1958
Author's keywords (DE)	1338
Authors	
Authors	1538
Author appearances	1920
Authors of single-authored documents	68
Authors of multi-authored documents	1470
Content analysis data	
Articles whose contents were reviewed	24

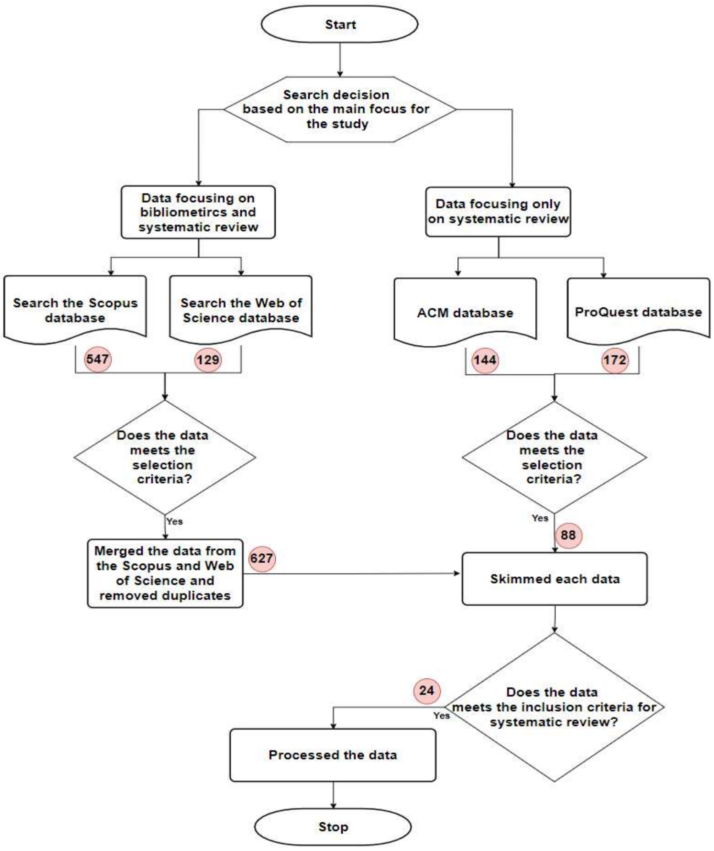

Fig 2. Data collection procedure

IV. RESULTS AND DISCUSSIONS

This section presents and discussed the findings from this study. To make the presentation easy and understandable, we structure the findings based on the research questions that the study seeks to answer. The approach to answering the research questions begins with the findings from the content review and is complemented by the bibliometric analysis. The bibliometric analysis approach was used in this study to explore the tendencies and realities of the theoretical foundations, pedagogies, and contents related to the application of computational thinking in higher education institutions.

A. *RQ1. What are the theoretical foundations for studies focused on CT in HEIs?*

To uncover the theories that are explored by studies on CT in HEI, the content analysis presented in Table 3 revealed that a few studies had indicated learning theory(s). Easily seen among the list of theories are the constructionism and constructivism learning theories. This finding aligns with previous study that was focused on CT in K-12 and high schools [13].

TABLE III. LEARNING THEORIES DEPLOYED IN STUDIES PROMOTING CT IN HEI

Theories	**Studies**
Constructionism	Gero and Levin [33], Romero et al. [34]
Design thinking	Romero et al. [34]
Constructivism/Social constructivism	Romero et al. [34], Buteau et al. [39]
Self-efficacy theory	Jaipal-Jamani and Angeli [35]
Cognitive learning theory	Koushik and Kane [36]
Universal design for learning (UDL) theory	Koushik and Kane [36]
Theory of contextual teaching and learning.	Baravov [37]
Experiential learning theory	Baravov [37]
Theory of Reasoned Action (TRA)	Fessakis and Prantsoudi [38]
Technology Acceptance Model (TAM).	Fessakis and Prantsoudi [38]

Other theories that have surfaced in this literature survey include design thinking, cognitive learning theory, self-efficacy theory, theory of universal design for learning, experiential learning theory, technology acceptance model, and theory of reasoned action. Furthermore, this study investigated the authors' keywords in the bibliometric data and discovered a list of theories that have cropped up from published articles focused on CT in the HEI context. As depicted in Fig. 3, those theoretical foundations shown are connected to the CT studies between 2010 to 2020.

Moreover, these theoretical foundations in Fig 3 have occurred in the bibliometric collection as keywords in more than 5 research papers, hence regarded as the more frequently used theoretical foundations in CT in HEIs context. It is revealed that learning theories such as constructionism, design thinking, constructivism, technology acceptance model, and theory of self-efficacy were seen in the bibliometric analysis, which correlates with the results from the content analysis.

Other foundational learning theories and frameworks not found in the content analysis but revealed by the bibliometric analysis include experimental teaching, design science research, and TPACK (technological pedagogical content knowledge).

B. *RQ2. What pedagogies are explored to teach CT in HEIs, and to what extent have these pedagogies been impactful?*

The aspect of pedagogies adopted by scholars to promote CT in HEI was also the focus of the content analysis. This study found that activity-based learning (ABL), problem-based learning, automatic assessment-based learning, and self-regulated or self-reflective learning are the central pedagogies used for CT in HEI. Other well-known pedagogies such as inquiry-based learning, game-based learning, creative design approach, workshop-based learning, and course design approach were not common among studies that promote CT in HEI. Notably are pedagogies such as micro-learning—small learning units designed to have short-term learning activities and outcomes-based education, which expects every learner to have gained a goal after each learning experience.

Further analysis of the author's keywords was conducted to examine the pedagogies that studies on CT in HEI have explored in the recent past. Figure 4 presents a visualization of the analysis and revealed findings that complemented the results of the content analysis.

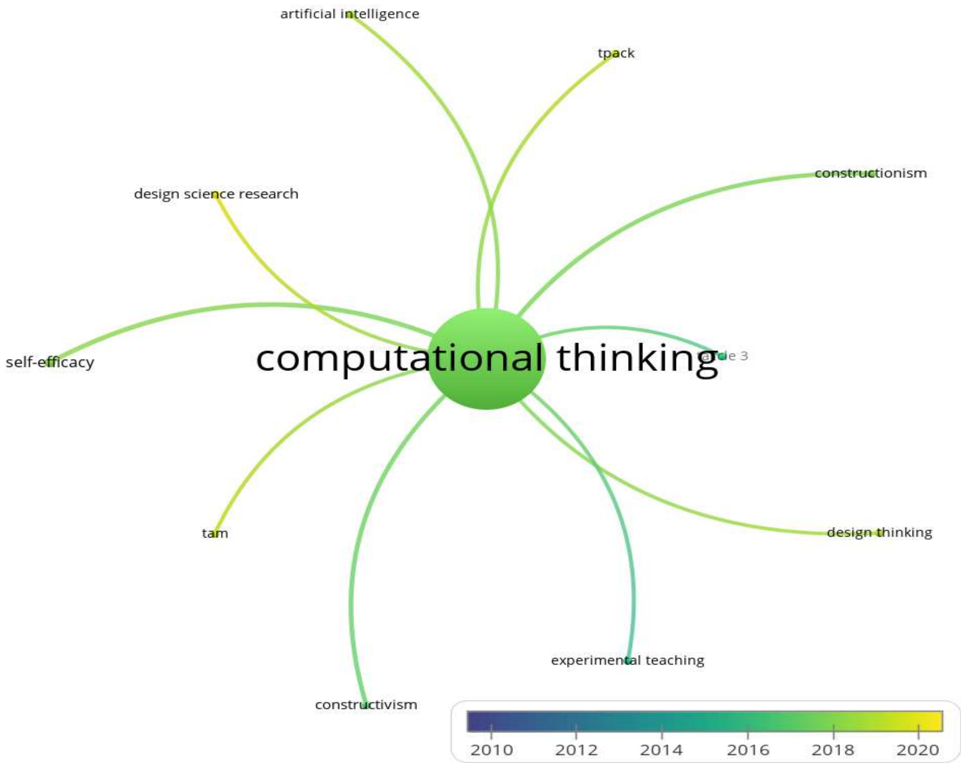

Fig 3. Analysis of theories employed by studies focused on CT in HEI based on author's keywords

TABLE IV. PEDAGOGIES DEPLOYED IN STUDIES PROMOTING CT IN HEI

Pedagogies	**Studies**
Activity-based learning (ABL)	João et al. [3], Gero and Levin [33], Romero et al. [34], Koushik and Kane [36], Dagienė et al. [40]
Problem-based learning	Jaipal-Jamani and Angeli [35], Calderón and Ebers [41], Salehi et al. [42], L'Heureux et al. [43]
Fishbone-based advanced computational thinking (FACT) pedagogy	Gopinath and Santhi [44].
Automatic assessment-based learning	Cutumisu and Guo [45], Koushik and Kane [36], Cachero et al (2020) [46], Gabriele et al. [67]
Self-regulated, self-reflection	Cutumisu and Guo [45], Rojas-López and García-Peñalvo [48], Álvarez et al. [49]
Inquiry-based	Koushik and Kane [36]
Peer-to-peer learning	Koushik and Kane [36]
Contextual teaching and learning design	Baravov [37]
Micro-learning approach	Leela et al. [50]
Game-based learning	Cao et al. [51]
Peer mentorship and formative assessment.	Pollock et al. [52]
Outcomes-based education	Xu et al. [53]
Workshop-based	Dodero et al. [54]
Course design and experimental	Hambrusch et al. [55]
Creative design approach	Buteau et al. [39]

C. *What kind of CT topics and contents are students in HEI learning?*

Regarding the contents of CT that students in HEI are learning, we investigated the focus of the 24 articles utilized for the content analysis and the keywords clustering analysis of the bibliometric data to arrive at findings presented under this section.

The first prominent theme in the contents of CT in the studies is "programming education". This theme was frequently used and connected to keywords such as programming concepts Koushik and Kane [36], introductory programming Álvarez et al. [49], Cachero et al. [46], and methodology of programming Rojas-López and García-Peñalvo [48]. As presented in Fig. 4, the map shows the most common pedagogies used to teach CT in higher education. These pedagogies are clustered into groups of similar modes. The red-colored clusters are modes of teaching CT used in HEI; the blue clusters are tools used in teaching CT in HEI, whereas the pink-colored clusters are areas of applications that CT teaching targets address in the HEI context. The green-colored cluster also indicates the common pedagogies, teaching environments, and methods. In contrast, the rest in various colored clusters refer to smaller pedagogies related to teaching CT in HEI. In general, the pedagogies shown on the map are based on their frequencies of occurrence in research works. Hence less referred pedagogies in the bibliometric collection are not visible on the map.

Further analysis of the bibliometric data revealed clusters of contents of CT that are explored in the HEI context, as shown in Fig. 5. The visualization in Fig 5 shows the CT-related contents and concepts that the students in HEI are learning.

The red-color cluster refers to CT application on relevant subjects such as computational science, engineering, and computer science. The blue-color cluster shows the CT concept applied to curriculum design and teaching-learning designs. Therefore, each colored cluster on the map shows application areas of CT in relevant domains.

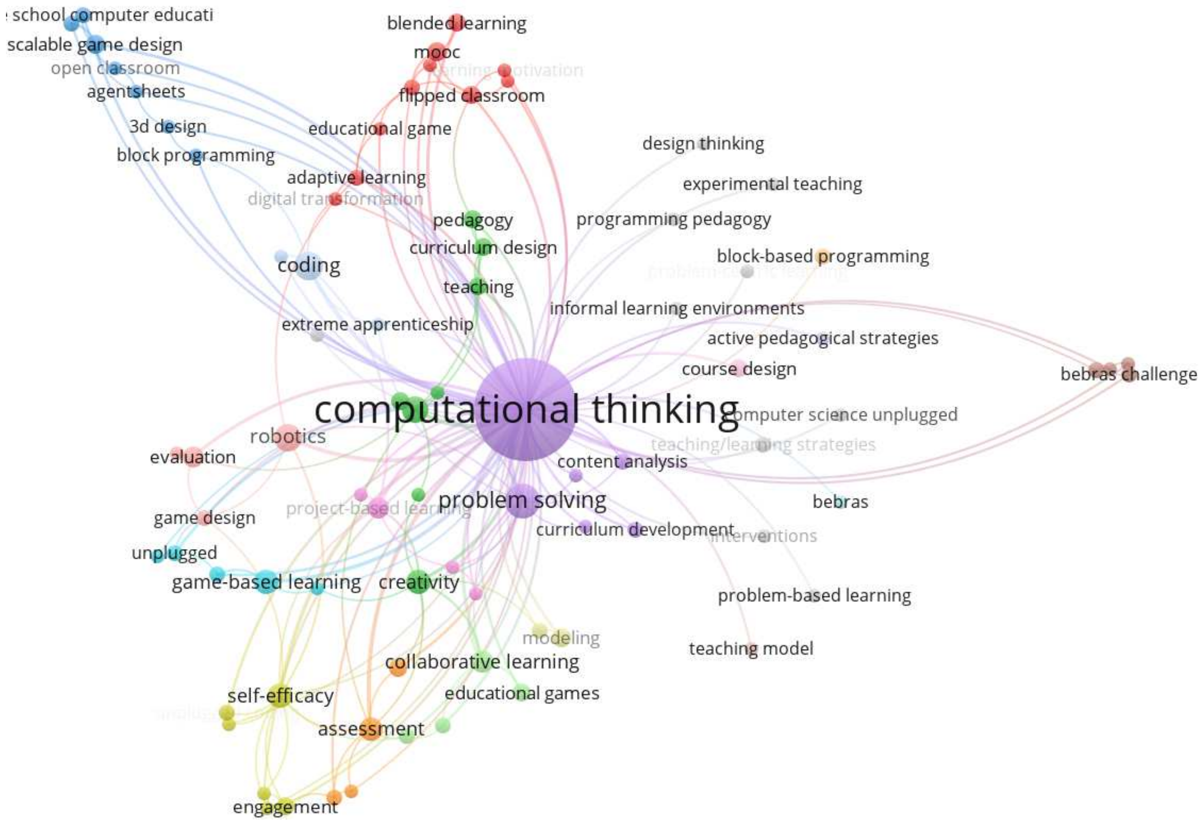

Fig 4. Analysis of pedagogies employed to promote CT in HEI based on authors' keywords

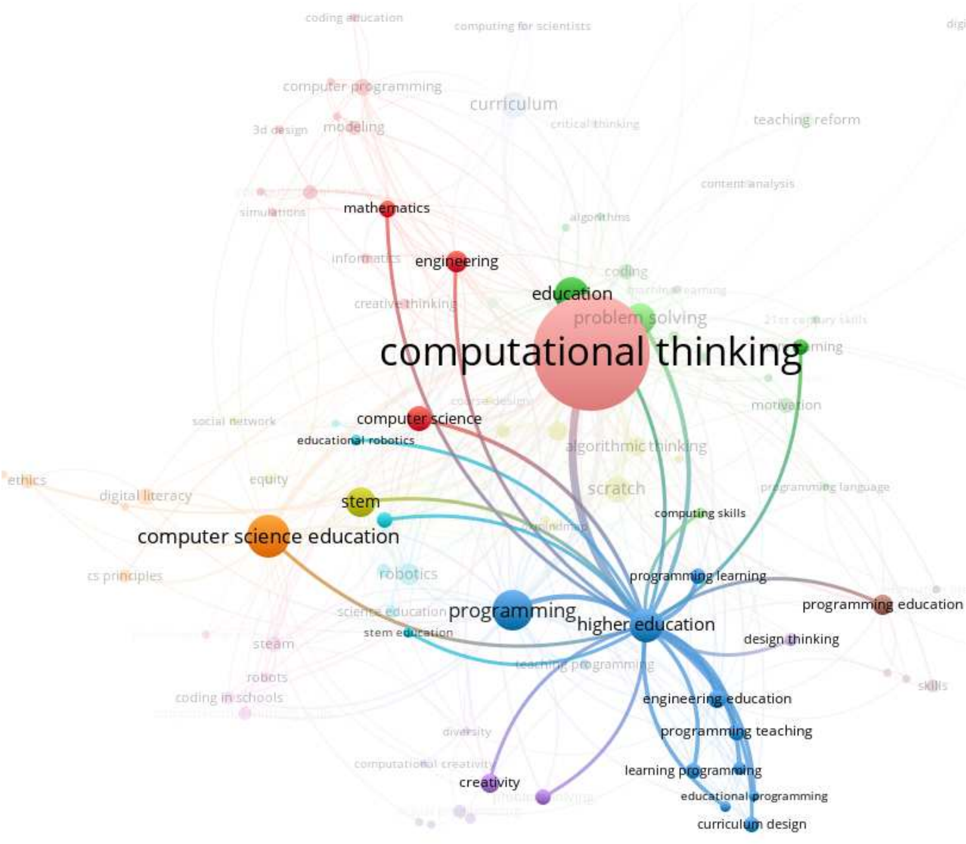

Fig 5. Visualization of CT contents and concepts students in HEI are learning

In general, one can deduce that CT is applied in diverse areas of use from curriculum design, teaching and learning design, concepts, and tools utilized in higher education institutions.

V. CONCLUSION

This study analyzed the articles focused on CT in higher education institutions utilizing four databases: Scopus, WoS, ProQuest, and ACM. Both systematic and bibliometric analysis techniques were adopted to provide answers to the questions guiding the study. CT theoretical foundations, pedagogies utilized in teaching CT coupled with its impact, and the contents of CT students are learning in HEIs are unraveled and discussed in this study. For the theoretical foundation, even though few of the included articles reported well-known learning theories, several studies did not specify the learning theory employed to teach CT in the HEI context. A mix of learning theories and information system theories are realized from our findings. Based on this study, the adopted learning theories included constructivism and constructionism, which corroborated the earlier findings of related study [13]. They foster individual learning and enable collaborative learning for effective learning outcomes among students [56]. Other identified theories include design thinking, cognitive learning, self-efficacy, universal design for learning, experiential learning, technology acceptance model, and theory of reasoned action. The pedagogical approaches prevalent for teaching CT in HEIs are also identified. Some of the pedagogies include activity-based learning, problem-based learning, automatic assessment-based learning, and self-regulated/self-reflective learning, among others. Regarding CT that students are learning in the HEIs context, programming education was the central concept. Others include computing concepts such as debugging, data structure, distributed computing, among other related concepts outside computing education.

From the findings of this study, one can conclude that CT can drive modern teaching, mainly in the engineering and computer science domains, and in the vocational education levels with microlearning contexts using virtual reality and augmented reality tools. Introducing CT in the higher education curriculum at the early stages would help the learners develop problem-solving skills and cognitive analytical capabilities, which should also help in all dimensions and domains of life-long learning. It provides a tactical approach to learning with purpose and applicable skills.

As CT is a trending reality in higher education, more research is required to explore practical ways of introducing its concepts in the curriculum at the HEIs. This will help learners apply CT skills in all areas of their learning, especially in programming courses. The combination of the literature survey and bibliometric analysis in this paper provides insight into the theories and pedagogies that future studies in CT can consider. This study is significant since its findings may provide the foundation for scholars to position CT in the HEI while the field continues to mature. While the authors admit that this study may have limitation related to missing data, the general outcome based on the findings from this study suggests that less studies on CT in HEI are explicitly connected to learning theories. Our recommendation is that future studies should connect their work to learning theories in order to make a meaningful impact on the learners and create a theoretical foundation for the field. Besides, these findings will be beneficial to researchers, curriculum designers, and instructors.

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