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Pedagogical Approaches in Computational Thinking-Integrated STEAM Learning Settings: A Literature Review

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Abstract. This paper aims to provide a comprehensive analysis of pedagogical approaches deployed in computational thinking (CT)-based STEAM curricula during the period 2015–early 2020. Based on a set of suitable search keys for querying the Scopus database we found 46 studies on CT-integrated STEAM learning settings in K-12 schools and universities. Nearly 46% of the studies were in K-12 science learning. Seven different pedagogies were used to introduce CT in STEAM (science, technology, engineering, arts and mathematics) environments. Collaborative learning, hands-on and learning by modelling activities, were found to be the main approaches in CT-integrated STEAM learning research settings. In addition, most of these studies used computing principles to teach CT + STEAM topics. However, the roles of pedagogies used in these studies were not clearly stated. Furthermore, CT principles in STEAM learning were not well-defined. Hence, our study provides evidence that it is critical to develop a possible inventory of successful pedagogies and supporting learning activities for CT-integrated learning environments.

Keywords: Computational thinking based STEAM learning · Collaborative pedagogy · Learning by modelling

1 Introduction

Computational thinking (CT) involves skills or techniques that include defining problems, collecting, analysing, identifying, evaluating and providing possible solutions in computational form for complex problems [1]. CT is considered as one of the required fundamental skill sets of the twenty-first century and relevant to all disciplines, including mathematics, science and humanities [2]. Integrating CT in school curricula has received much attention in educational research and practice. Many universities offer CT based courses for their STEAM students [3]. Furthermore, schools have already started introducing CT-integrated learning for STEAM subjects such as science, maths and crafts into their K-12 curricula [4]. CT-integrated STEAM learning environments have proved

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to be an effective method for learning and understanding STEAM domains and helping students to develop their key CT concepts and practices [5]. There has been much research on CT in STEAM learning for over the past decade [6]. Significantly, various pedagogical approaches and learning activities have been used to couple CT concepts to STEAM learning environments. In addition, several reviews of literature have been conducted on CT in education [7–9]. However, no previous studies have examined or listed a concrete inventory for use as a possible pedagogical approach for CT-integrated STEAM learning environments. Moreover, the influence of pedagogical approaches used in CT-integrated STEAM learning is not clearly defined in the literature. As such, this paper presents a more current review of pedagogical approaches; including learning activities used in CT-integrated STEAM learning in school and university contexts. The objective of this review is to provide a bibliographic evidence for researchers and educators to gain a better understanding of existing CT-integrated pedagogical approaches in STEAM learning. Furthermore, the scope of this research is to provide a possible guide for educators to develop effective teaching strategies for CT-integrated STEAM learning environments. Consequently, we pose and address the following research questions (RQs).

RQ1. What are the pedagogical approaches used in CT-integrated STEAM learning?

RQ2. What are the teaching and learning activities implemented in CT-integrated STEAM learning environments?

Towards addressing these questions, this paper is organised as follows. Section 2 presents some prior studies that have attempted systematic literature reviews of STEAM learning through CT activities. Section 3 presents the review method our study has adopted. Section 4 presents the results and discussion of our literature review, to address our research questions. Finally, Sect. 5 presents the conclusions and limitations in terms of how well the foregoing research questions are answered.

2 Previous Studies

Previous studies have attempted to provide comprehensive analyse of CT practices in STEAM learning over a decade [7, 9–12]. For example, a recent systematic review of CT examined the publication trends and research typology (2006–2018) and reported that game and peer collaboration were found to be the main pedagogies in CT-integrated classrooms [7]. Similarly, Barcelos et al. reviewed the articles published from 2006 to 2017 to evaluate the learning outcomes of mathematics learning through CT activities [9]. Ching et al. provided a list of educational technologies for young learners to develop CT skills in STEM learning [13]. Li et al. conducted a systematic review of STEM education journal articles published (n = 798) between 2000 and 2018 inclusive. They identified that of these only six articles focused on the connection between CT and STEM education [11]. Tang et al. reviewed the CT assessments in education and identified that more CT assessments are needed for school, college and vocational education development programs [6]. However, none of these studies focused on pedagogical approaches or educational theories to facilitate learning and understanding of STEAM domains which in turn, helps students to develop both STEAM and CT key concepts and practices. Our study aims to offer a list of pedagogical activities around CT that have been used in STEAM learning environments.

3 Methodology

The literature review process was carried out by Erasmus + research team members and authors of this article. The working group reviewed the articles published and indexed by Scopus [14] in the period start of 2015 to February 2020. The literature review process was conducted on the basis of guidelines proposed by [15, 16]. The working group followed the highly structured process steps described in Sects. 3.1 through to 3.5, below.

3.1 Defining and Implementing the Search Query

The search period was set in between January 2015 and February 2020. The database chosen for the automatic search was The Scopus. Scopus database contains a large volume of abstracts and citations of peer reviewed literature for papers that examine CT concepts in STEAM learning settings [14]. The search term for CT in the STEAM learning environment was defined by combining suitable key phrases to extract the relevant articles for this study. Figure 1 shows the search string used for paper retrieval via the Scopus database:

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( TITLE-ABS-KEY ( ”computational thinking” AND ( steam OR stem
OR science OR technology OR engineering OR arts OR
mathematics ) AND ( e-learning OR ”educational technology” OR
”instructional technology” OR mooc OR ”online course” OR
”learning environment” OR software ) ) AND LANGUAGE ( english
) ) AND PUBYEAR > 2014
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Fig. 1. Screenshot of search string used in the Scopus database

3.2 Defining Inclusion and Exclusion Criteria for the Review

The search phrase yielded 358 English articles relevant to CT practices in STEAM learning. As noted, the objective of this review was to identify and discuss the pedagogical approaches used in CT-integrated STEAM learning environments for students to integrate their CT skills in STEAM topics. As such, we defined the following inclusion and exclusion criteria to select the final set of articles for full-text review.

Papers were excluded if they:

i. did not address educational theory or pedagogical approaches in the context of CT-based STEAM learning;
ii. did not use the CT concepts/practices in the context of STEAM topics (one or more) learning;
iii. were works in progress or project work research papers;
iv. were CT and or STEAM related literature review articles (but used to address gaps in literature); and
v. were theoretical with no explorative studies.

3.3 Selection of Articles for Full-Text Review

The working group reviewed the abstracts of all articles retrieved (n = 358) individually, based on the selection criteria and procedures established for this review. Three members from the research group selected articles for full-text review. They independently reviewed each paper and recorded their responses in a pre-formatted excel spreadsheet with clear remarks (yes/no), and answered the question "Why did you select this article for full text review?" The reviewers were invited for subsequent discussion meetings. In total, three consecutive weekly review meetings were conducted with all members of the working group, including reviewers, to select the final set of articles for full-text review.

3.4 Extracting Data Based on Research Questions

As previously mentioned, in total 358 articles were initially selected for evaluation. Of these, 312 articles were excluded based on reviewers' feedback, including votes, remarks registered in the excel spreadsheet, and agreed in the discussion meetings. A total of 46 articles were finally selected for full-text review.

3.5 Synthesizing and Classifying the Results

Following the selection of articles, the selected articles (n1 = 46) were divided among the authors for full text-review. The reviewers classified the articles by STEAM categories for full evaluation. The data extracted by each reviewer were synthesised for preparation of review report to discuss further. In addition, the selected papers were classified based on pedagogical approaches used in STEAM learning environments including teaching and learning activities.

4 Data Analysis, Results and Discussion

The objective of this research was to list and identify the pedagogies adopted for CT-integrated STEAM learning environments, for teaching STEAM concepts with CT. Nearly 65% of studies were conducted in K-12 STEAM + CT learning settings. Table 1 presents the list of articles classified by STEAM categories for full-text review. Of the 46 articles classified nearly 46% examined the role of CT in science, and followed by arts (17%), mathematics (15%) and STEAM (11%) courses. On the other hand, only 11% of articles addressed CT in technology and engineering topics.

We were interested in identifying the type of pedagogical approaches that were used for C-integrated STEAM learning environments for the development of STEAM and CT skills. As such, we classified our results based on pedagogies including teaching and learning activities used in these studies to answer RQs 1 and 2. Table 2 presents the list of pedagogies and type of learning activities used in CT-integrated STEAM learning environment at school and universities.

Table 1. List of articles (classified by STEAM category) selected for full-text review

STEAM category	K-12	University	References
Science (basic science, physics, chemistry, biology, early computer science education, programming)	15	6	[5, 17–24] & [25–30]* [31–36]**
Technology	2	0	[37, 38]*
Engineering	1	2	[39]* [40, 41]**
Arts	6	2	[42–47]* [48, 49]**
Mathematics	4	3	[50–53]* [4, 54, 55]**
STEAM***	2	3	[56, 57]* [58–60]**
Total	30	16	46

* Research conducted at K-12 curricula.
** Research conducted at university (including vocational education).
*** Studies conducted on STEM or STEAM in general.

Table 2. Pedagogies and learning activities used in CT-integrated STEAM learning environments: 2015–February 2020

Reference	Subject/topic	K-12	HE	Pedagogy | learning activity
Science				
[17]	Animal learning (Thematic unit)	1–2		Collaborative | task based learning (puzzles, matching the picture)
[33, 36]	Elementary Science		Primary (grades 3–5) school teachers	Constructivist and Collaborative | Hands-on learning
[5]	Physics	7–9		Collaborative | learning by modelling (synergistic learning)
[61]	Physics	7–9		Collaborative | concept maps, learning by modelling and model simulations as group and scaffolding

(*continued*)

Table 2. (*continued*)

Reference	Subject/topic	K-12	HE	Pedagogy ǀ learning activity
[21]	Physics	7–9		Constructivist ǀ learning by modelling-tasks and rubrics
[32]	Physics		Sophomore students	Collaborative ǀ Synergistic learning – learning by modelling
[23]	Chemistry	7–9		Constructivist ǀ Learn by modelling and simulation (Computer based learning)
[20]	Biology	9–12		Cognitive-behaviourist pedagogy: Restructuration theory ǀ Learn by modelling and simulation
[35]	Data science		Non-CS students	Situated learning theory and Collaborative ǀ Project based learning
[28]	Programming	7–9		Reflective ǀ (game) Project based learning
[22]	Programming	7–9		Reflective ǀ Portfolio based learning and assessment
[31]	Programming		Non-CS students	Constructivist and Collaborative ǀ Task based learning
[27]	Programming	7–9		Constructivist and Inquiry ǀ Game based learning and simulation design
[34]	Programming		Primary and secondary education teachers	Constructivist and Inquiry ǀ Blended learning
[30]	Virtual reality programming	7–9		Inquiry ǀ Experiential learning (Hands on learning)

(*continued*)

Table 2. (*continued*)

Reference	Subject/topic	K-12	HE	Pedagogy ∣ learning activity
[18]	Physics and Computing	7–9		Constructivist and Collaborative ∣ constructionist learning (video game making)
[26]	Physics & Biology	6		Constructivist ∣ Learning by modelling
[29]	Physics & Biology	5		Constructivist ∣ Learning by modelling (synergistic learning)
[25]	Physics & Biology	5–8		Constructivist ∣ Learning by modelling and using simulation (agent based modelling)
[24]	Biology & Chemistry	7–9		Collaborative ∣ Simulation and Problem based learning
Technology & Engineering				
[37]	Robotics technology	3–6		Collaborative ∣ Hands on learning
[38]	Digital tools	3–6		Collaborative ∣ Challenge based learning
[39]	Programming and Circuit foundations	10–12		Collaborative ∣ Hands on learning
[40]	Robotics class for engineers		Both undergraduate and graduate engineering and IT students	Collaborative ∣ Project based learning (active learning) / computer aided engineering activities
[41]	Programming and CT for electronic engineering		Electronic engineering students	Collaborative ∣ Active learning includes project based learning
Arts				
[42]	Learning English	2		Inquiry ∣ Active learning includes visual learning

(*continued*)

Table 2. (*continued*)

Reference	Subject/topic	K-12	HE	Pedagogy ∣ learning activity
[43]	Design	7–9		Collaborative and Inquiry ∣ Inquiry-based teaching activities
[44]	Literature	9 (7–9)		Collaborative ∣ Project based learning
[45]	English	4–5		Constructivist: Papert's theory of constructionism ∣ learning by making or Hands on learning
[46]	Music + CT	3–10		Collaborative ∣ Hands on learning includes collaborative music composition based learning
[47]	Smart textiles	3–6		Constructivist ∣ Hands on learning
[48]	Social work	9–12	College students	Collaborative and Inquiry ∣ Problem based learning
[49]	Music + programming		Non-CS college students	Constructivist ∣ Continuous assessment based activities
Mathematics				
[50]	Preschool maths	K		Constructivist and Collaborative ∣ Hands on activities based learning
[51]	Fractions and shapes	3–6		Collaborative ∣ Web and game based learning
[52]	Mathematical grid diagrams	5–6		Collaborative and Inquiry ∣ Scaffolding includes inquiry-based learning
[53]	Geometry	7–9		Collaborative ∣ problem based learning (probe a set of mathematical questions)

(*continued*)

Table 2. (*continued*)

Reference	Subject/topic	K-12	HE	Pedagogy I learning activity
[54]	surface area and Volume- basic maths		Vocational college students	Micro learning / mobile learning
[4]	Arithmetic, Geometry, algebra		K-12 math teachers	Constructivist I Online / e-learning I Pedagogical essays and developing animated exercises for K-12 maths
[55]	Geometry		School teachers	Collaborative I e-learning and e-assessments
STEAM				
[56]	Water conservation and environmental sustainability	7–9		Culturally relevant pedagogy I game based learning
[57]	STEM Robot	10–12		Collaborative I Hands on learning based exercises
[58, 60]	Educational robotics – STEM pedagogy		School teachers	Collaborative I Hands on learning
[59]	Teacher training for STEAM and CT		Pre-service K-8 teachers	CollaborativeI Team based learning, flipped classroom and pair learning

We identified seven pedagogical approaches (see Fig. 2) were used in CT-integrated STEAM learning settings and they are: constructivist (20%), collaborative (44%), reflective (4%), inquiry (4%), cognitive behaviourist (2%), micro learning (2%), and culturally relevant pedagogy (2%) and combination of constructivist, collaborative and or inquiry pedagogy (22%). Figure 2 presents the list of pedagogical approaches used in CT-integrated STEAM studies.

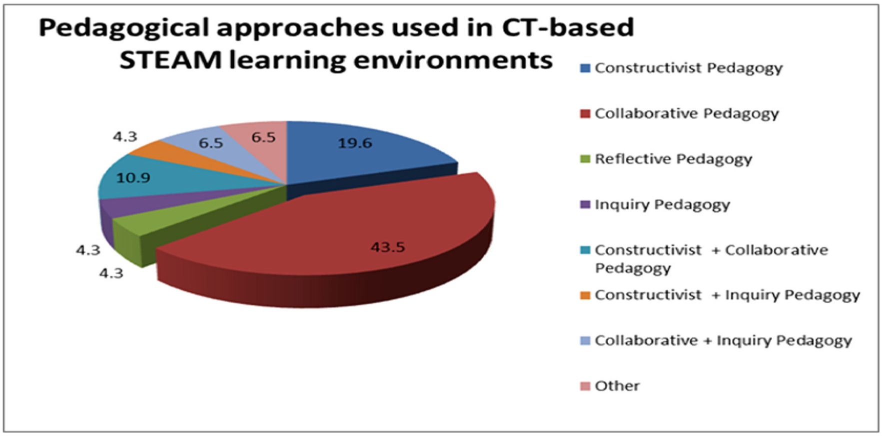

Fig. 2. Pedagogical approaches used in the CT-integrated STEAM learning environments

4.1 Constructivist Pedagogy in CT-Integrated STEAM Learning

Constructivist pedagogical approach focuses on critical thinking and problem solving. It promotes student-centred learning and can be used to improve student CT and STEM skills [62]. This pedagogy lets student interacts autonomously and enhance self-awareness of the knowledge construction process which is one of the key elements of CT. Figure 3 shows percentages of studies that used constructivist pedagogy in STEAM learning environments (Fig. 3). Nearly 20% of studies used constructive pedagogy to develop and enhance CT and STEAM skills.

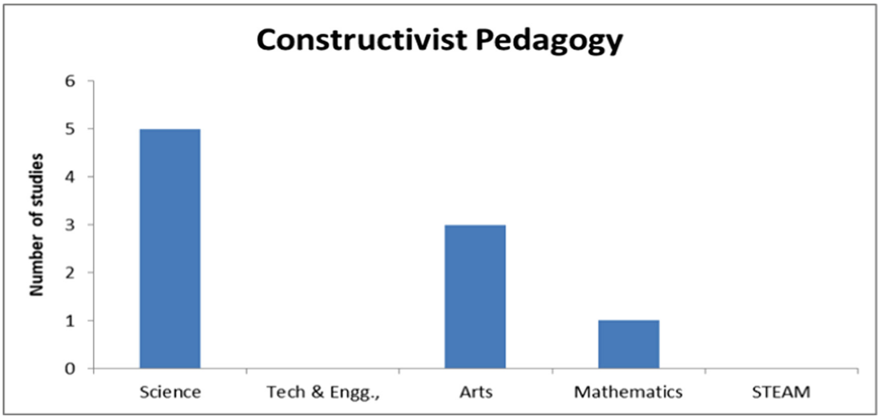

Fig. 3. Constructivist pedagogy in CT-integrated STEAM learning

4.2 Collaborative Learning Pedagogy in CT-Integrated STEAM Learning

Collaborative learning is an instruction method in which students work together as pair or group for the purpose of achieving a common academic goals and outcomes. Collaborative learning enables students to engage in analytical thinking and promotes student-student and student-instructor interaction and interest. In turn, it enhances critical thinking skills which are one of the key elements of CT and STEAM domains [63, 64]. In addition, it is found that collaborative learning promotes student CT and programming learning [65]. As noted, nearly 44% of the studies implemented a collaborative learning pedagogy for enhanced synergistic learning and understanding of STEAM domains via CT key concepts (Fig. 4).

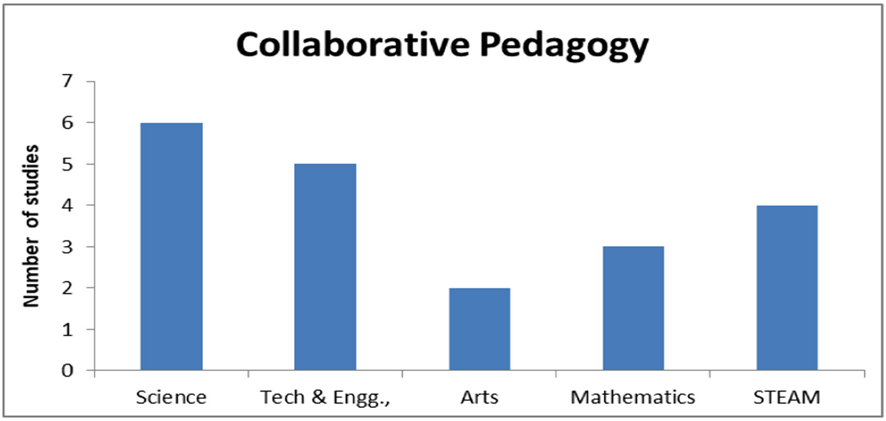

Fig. 4. Collaborative pedagogy in CT-integrated STEAM learning

4.3 Reflective Learning Pedagogy in CT-Integrated STEAM Learning

Reflective pedagogy lets learners reflect on their learning experiences to increase their self-awareness and support student-centered and experiential learning [66]. Two studies (4%) implemented a reflective learning pedagogy to capture school students' experiences on using educational tools and self-reflected programming tasks for the improvement of student programming and CT skills. However, this pedagogy was not used in other STEAM topics. This should be analysed further (Fig. 5).

4.4 Inquiry-Based Learning STEAM in CT-Integrated STEAM Learning

Inquiry-based learning approach focuses on investigation and problem-solving which is part of the key elements of CT and STEAM domains. Inquiry-based learning pedagogy enables students to develop their analytical and reasoning skills. It encourages learners to explore, interpret and reflect their findings and improve critical thinking and understanding in STEAM topics. In addition, Inquiry based learning approach improves interest, self-determination, self-efficacy and student learning outcomes [67]. We identified inquired based approach used in arts and science studies only (Fig. 6).

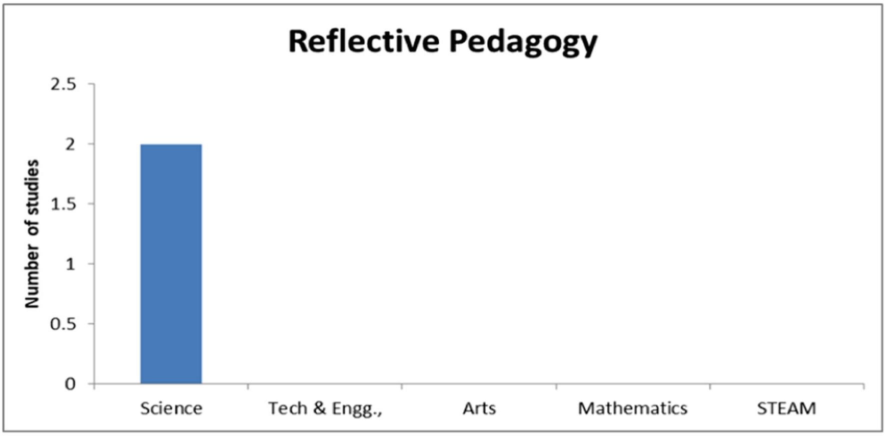

Fig. 5. Reflective pedagogy in CT-integrated STEAM learning

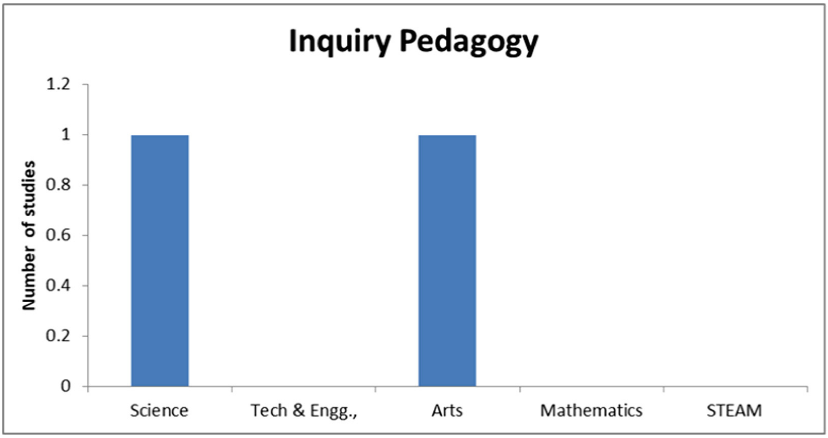

Fig. 6. Inquiry pedagogy in CT-integrated STEAM learning

4.5 Mixed and Other Pedagogies in CT-Integrated STEAM Learning Setting

Combining multiple pedagogies may boost student learning and interest [68] which in turn, enhance student STEAM and CT skills. There were studies that used the combination of constructivist, collaborative and or inquiry-based educational approaches for integration of CT into STEAM learning (Fig. 7). Notably, CT + science based studies used the combination of constructive, collaborative and inquiry pedagogical approaches to integrate CT in science topics. On the other hand, arts and mathematics + CT based studies used the combination of collaborative + inquiry-based pedagogies.

We also identified that a few other studies used cognitive behaviourist pedagogy, micro-learning and culturally relevant pedagogy (Fig. 8). Reportedly, culturally relevant pedagogy based learning improves student ability to learn, seek evidence and challenge beliefs [56]. Moreover, their results suggested that STEM + CT related activities that are

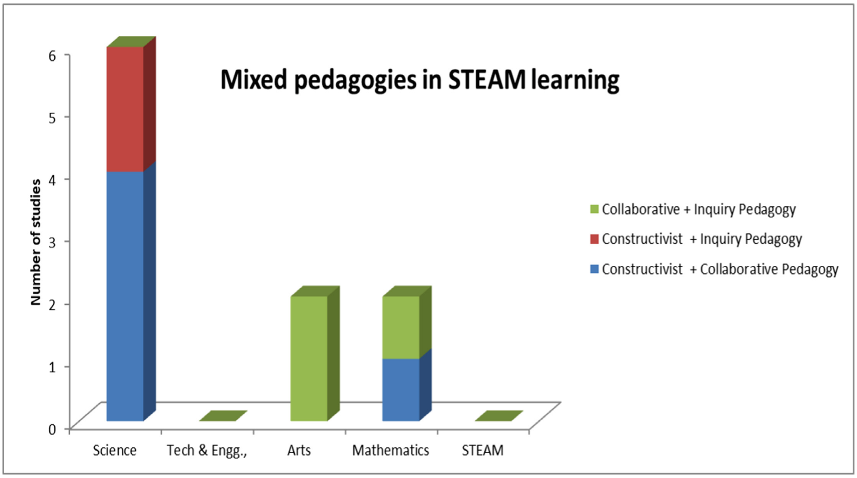

Fig. 7. Combined pedagogies in CT integrated STEAM learning

tied with familiar issues or problems known by student may improve student engagement in learning STEAM topics and fosters CT skills.

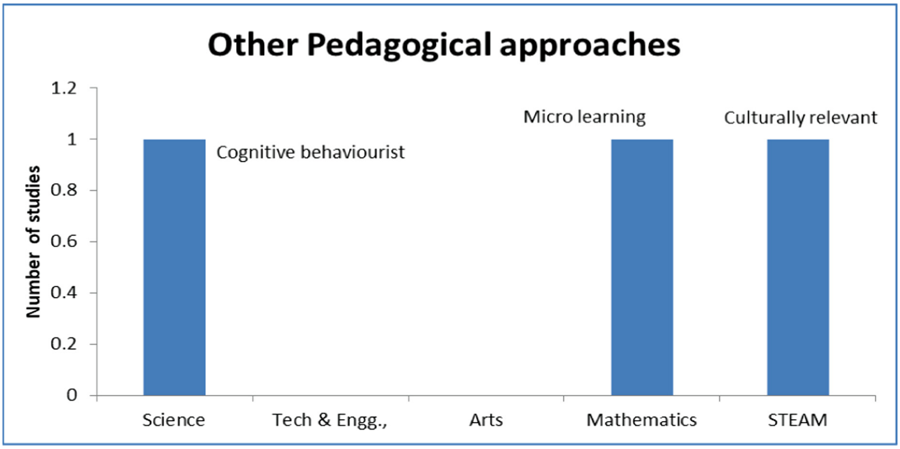

Fig. 8. Other pedagogies in CT-integrated STEAM learning

4.6 Mixed and Other Pedagogies in CT-Integrated STEAM Learning Setting

Our findings reveal that most of the studies used familiar pedagogical approaches such as constructive, collaborative or combinations thereof. The aforementioned results (Fig. 2 and 9) also imply that collaborative learning approaches blended well to use CT-integrated STEAM lessons within K-12 and HE curricula. In particular, these studies implemented technology enhanced collaborative learning methods to teach STEAM

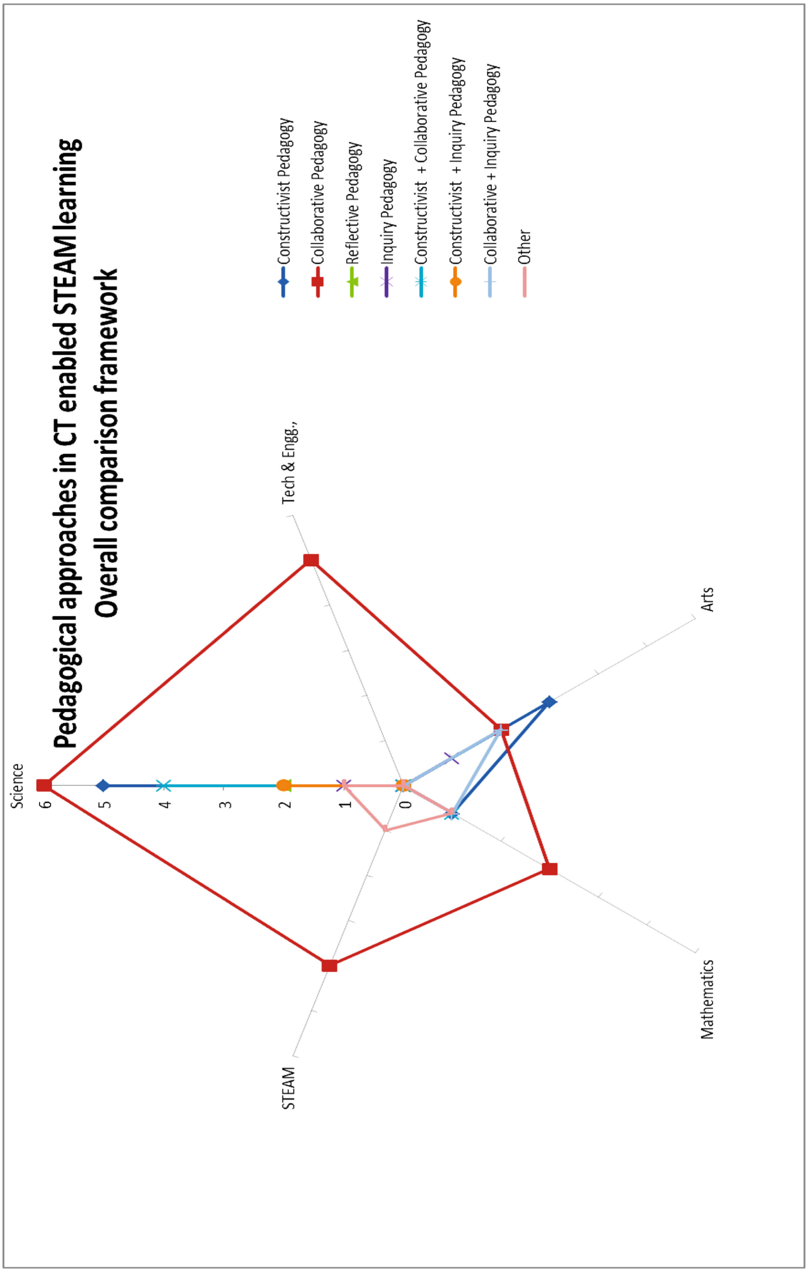

Fig. 9. Comparison framework: pedagogical approaches in CT enabled STEAM

and CT concepts in K-12 and HE learning settings for the improvement of algorithmic thinking, abstraction, characterizing problems and designing solutions, analysing and interpreting data skills. Studies conducted on CT-integrated technology and engineering learning settings used mainly collaborative learning and programming. For example, one study on computing with diverse-real-world dataset using situated learning theory with collaborative pedagogy reported introducing introductory computing to non-CS students [35]. On the other hand, studies on CT-integrated science learning attempted using various pedagogical approaches. For example, several studies used various combinations of pedagogies for introducing CT and elementary science, physics and fundamental programming skills in K-12 and HE learning settings [18, 27, 31, 34, 36]. However, most of these studies dodged from providing background study of pedagogical approaches used or why those were chosen over other approaches.

4.7 Teaching and Learning Activities Used in CT-Integrated STEAM Learning Settings

To answer RQ2 we analysed the most common teaching and learning activities used for integration of CT and STEAM. We identified hands-on, game based learning and learning by modelling as being often used to introduce CT-integrated STEAM learning in K-12 curricula. Similarly, flipped classroom, blended and online based learning & training were used to train K-12 school teachers in order to conceptualise CT in STEAM education (Fig. 9). On the other hand, project based learning and task based learning were used to learn STEAM domains and key CT concepts in university context. Many of these studies used programming language or coding-based activities to teach STEAM topics but loosely integrated with CT concepts (Table 2 and Fig. 10).

From these results the following points emerged. First, CT-integrated STEAM learning are designed to improve both STEAM and CT constructs. Therefore, attention should be paid to delivery methods and pedagogical approaches that influence the quality of learning outcomes. However, none of these examined the role of pedagogy in conducting CT-integrated STEAM lessons or the association between instructional setup and its influence on learning outcomes in the context of CT-integrated STEAM education with deep engagement. Moreover, the pedagogies used in these studies varied based on student demography and course contents. Hence, it is critical to develop a possible inventory of successful pedagogies and supporting learning activities for CT-integrated learning environments. Third, none of these studies used integrative pedagogy. Moreover, CT principles in STEAM learning are not well defined in these studies. These should be explored further.

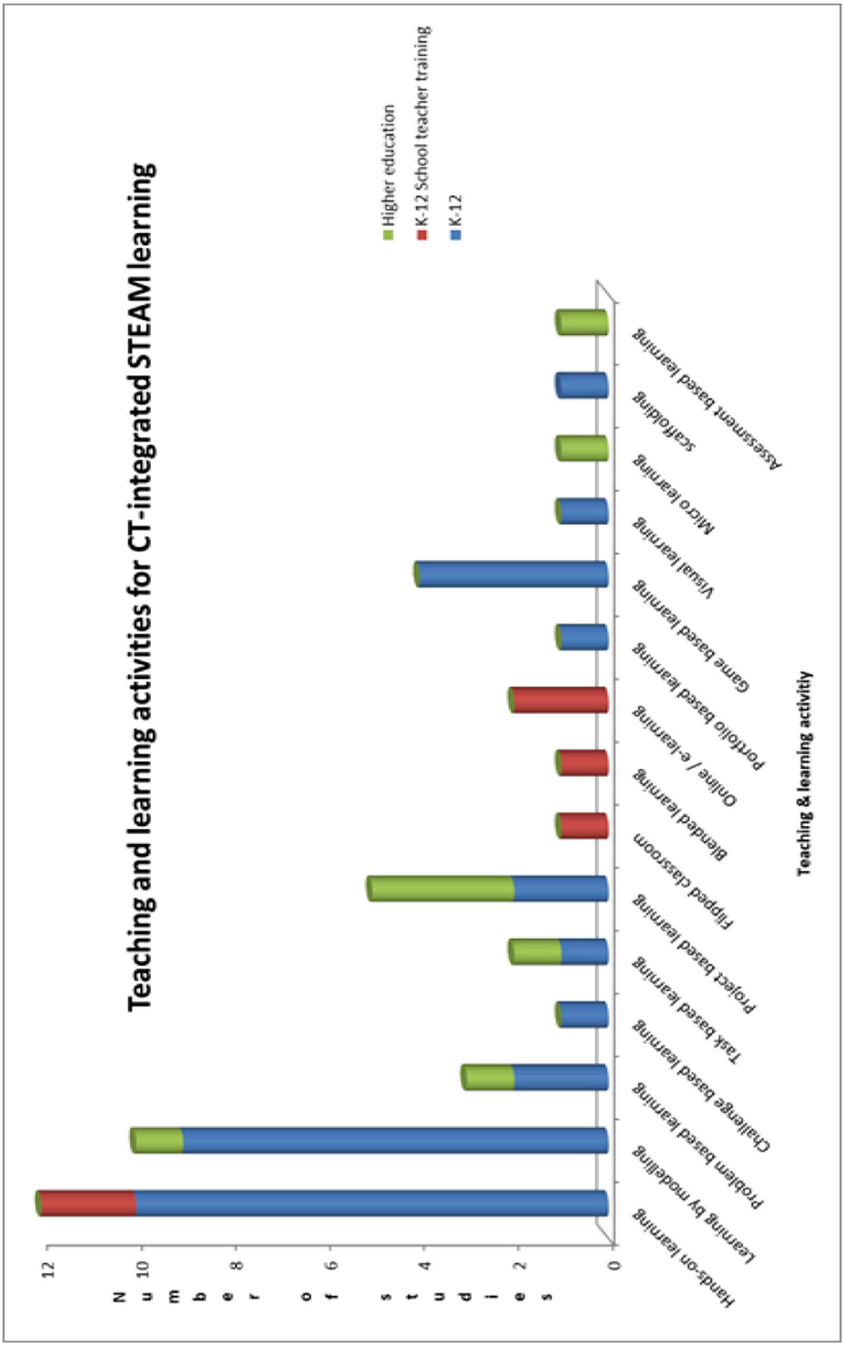

Fig. 10. Teaching and learning activities used in CT-integrated STEAM learning settings

5 Conclusions and Limitations

Our study presented a comprehensive review of pedagogical approaches deployed in CT-based STEAM curricula during the period 2015–early 2020. The results show that STEAM with CT education has become an emerging topic of discussion over the past decade. Collaborative learning pedagogy and hand-on learning based activities improves student STEAM and CT skills. Coding activities were mainly used as an outreach tool to understand the role of CT key elements in learning STEAM topics. However, the kinds of pedagogical approaches used in these articles were not clearly stated. This implies that well-grounded learning trajectories must be determined in CT-integrated STEAM curricula to obtain consistent progress in developing STEAM and CT skills. In addition, our review suggests that collaborative and hands-on learning methods may improve student creativity and problem-solving skills in STEAM disciplines.

This research has a few limitations. First, the articles examined in this review were extracted from a single database (Scopus), published in between January 2015 and February 2020 only. This may have been limiting in terms of the results reported in our study. However, we have planned to extend our research period with more key words and search of a broader category, for a larger data set. Second, our study did not conduct the deep understanding of qualitative study on pedagogies used in these articles, in the context of learning outcomes. Third, our study did not examine the role of educational technologies used. This will be addressed in future work. Despite these limitations, our findings provide some suggestions and evidence for instructors and educational institutions to research and develop pedagogical models for CT-integrated STEAM education.

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