A Systematic Literature Review of the Design Thinking Application in the Early Childhood Integrated STEM Education

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***Abstract*—Design thinking is often defined as a process of analysis and creation. The design thinker needs to take into account the opinions, insights, and feelings of the people being studied and to experiment, create prototypes, test reflect, and redesign. There is a growing awareness of the importance of design thinking in teaching and learning as an effective way to help improve students' 21st century skills. Although many researchers have been exploring and analyzing the use of design thinking in teaching and learning, the field of early childhood has remained neglected. There is very limited research on the application and presentation of design thinking in early childhood education settings. Therefore, this study will systematically review relevant literature on the application of design thinking in early childhood STEM education and how early childhood teachers apply design thinking pedagogy to help young children acquire conceptual knowledge and develop learning skills. The research question for this study will be: How design thinking is being applied in early childhood integrated STEM education? The study will synthesize, evaluate, and analyze the sample literature based on Thibaut *et al.*'s theoretical framework for instructional practices in integrated STEM.**

***Keywords*—STEM education, design thinking, Early childhood, systematic review**

I. Conceptual Framework

The theoretical framework for this study draws on nine categories summarized from Thibaut *et al.*'s [1] systematic theoretical review of instructional practices of integrated STEM. The nine categories were integration of STEM content, focus on problems, inquiry, design, teamwork, student-centred, hands-on, assessment, and 21st century skills. The majority of studies considered the integrated STEM education to be based on social constructivist learning theory [2–6]. This learning theory states that knowledge is constructed by students based on their existing ideas and their learning experiences [7], while the social aspect of social constructivism implies that student learning is not purely an individual experience, but more is shared and collaborative [8]. These nine categories, therefore, represent the ways in which students learn and the learning environments teachers create for students to achieve conceptual change and knowledge understanding.

Many different instructional practices methods and implications were covered in each of these nine categories, for example:

Integration of STEM content: multidisciplinary/interdisciplinary approach, merging two or more STEM content areas.

Focus on problems: Problem-based/Problem-centred learning, authentic problems.

Inquiry: Inquiry-based learning, scientific inquiry, investigation and discovery.

Design: Developing prototypes and using tools, solution design, engineering design, redesign based on the failures.

Teamwork: Collaborative/cooperative learning, work with others in small groups, communication.

Student-centred: Student-centred pedagogies.

Hands-on: Hands-on activities, effective use of tools to solve problems.

Assessment: Performance and formative assessment, understanding children's misconceptions and capabilities.

21st century skills: Creativity, critical thinking, problem solving, communication, collaboration.

However, Thibaut *et al.* refined the five most common elements of teaching and learning through a systematic review: integration of STEM content, problem-centred learning, inquiry-based learning, design-based learning, and cooperative learning (Fig. 1). All of these were considered to be the most important principles in integrated STEM teaching and learning rooted in social constructivist learning theories. The elements were chosen according to the importance of the teacher's guidance strategies, for example, in cooperative and collaborative learning, where cooperative learning was more emphasized on the strategy of the teacher's guidance. Although other categories were not explicitly shown in the framework, they were inseparably associated with these categories in an overarching way [1]. For example, these principles are all student-centred approaches to teaching and learning, both inquiry-based learning and design-based learning promote the use of hands-on practices. Cooperative learning, on the other hand, fell into the category of collaboration in 21st century skills.

Manuscript received August 14, 2024; revised September 10, 2024; accepted September 19, 2024; published October 30, 2024.

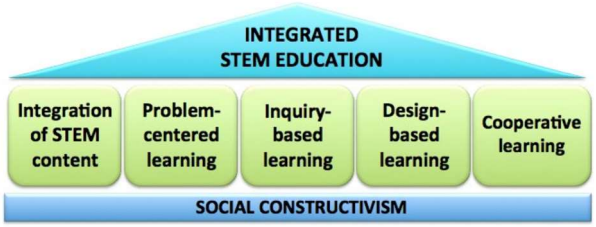

Fig. 1. Theoretical framework for instructional practices in integrated STEM.

Although each area of the STEM represented a different content, the process of inquiry within it was very similar across these disciplines, for example, encouraging students to identify and ask questions and engage in investigations [9, 10]. While Thibaut *et al.*'s [1] framework has been used widely to analyze the application of STEM pedagogy in secondary schools [11–13], this interdisciplinary integration and process of inquiry was just as important in relation to early childhood education and helps early childhood teachers to be able to uniquely utilize these pedagogies to better implement stem education. In addition, the emphasis on inquiry, teamwork, real-world problem solving, and hands-on skills [14, 15] in design thinking matches the five important principles in this framework. Therefore, this study will generalize and analyze the application approach and situation of dt in early childhood education based on Thibaut *et al.*'s [1] theoretical framework.

II. Methodology

A systematic literature review allows for an understanding of the breadth and depth of existing work and identifies gaps that need to be explored [16]. By identifying, summarizing, analyzing, and assessing the existing literature on a particular topic against a criterion, can disclose the validity and quality of existing work, as well as their weaknesses and contradictions [17, 18], thus providing research guidance and implication to the future researchers.

The data sources for this study were drawn from four databases: SpringerLink, ERIC, Science Direct, and SCOPUS. The researcher first accessed the relevant existing literature by entering "design thinking" AND STEM AND "early childhood", but as the definition of design thinking varies for different subject groups and much of the literature is biased towards the use of "design and make" instead. Besides, the key term "early childhood" had the same meaning as "kindergarten". Therefore, the search terms were broadened by entering a combination of ("design thinking" OR "design and make") AND STEM AND ("early childhood" OR "kindergarten"), resulting in 102 relevant articles (Table I). The articles must be published between 2018 and 2022, and must be peer-reviewed journals in English. The content of the articles must be relevant to the learning and teaching of STEM and must involve the application of design thinking or design and make concepts in early childhood education. After filtering, only 7 existing articles were used as review samples for this study.

These data samples will be analyzed in two ways. Firstly, the cases mentioned in the articles regarding the teaching and learning of STEM in early childhood education will be organized in Table II. These cases will then be further classified and analyzed based on the conceptual framework (Table III).

TABLE I. Search Results

Keywords	Database	Number of articles	Number of articles after filtering	Search limitations
("design thinking" OR "design and make") AND STEM AND ("early childhood" OR kindergarten)	SringerLink	74	4	The articles must be from scientific peer review journals in English between 2018 to 2022.
	Eric	7	1	
	ScienceDirect	9	1	The articles must involve teaching and learning in the STEM field.
	Scopus	12	1	The articles must clearly show the application of design thinking or design and make.
	Total number of articles	102	7	

III. Results

This study collated examples and approaches to teaching design thinking that are mentioned and applied in early childhood education settings in the existing literature (Table II). The pedagogical approaches involved in these cases were categorized under different principles based on Thibaut *et al.*'s [1] framework (Table III).

TABLE II. Cases Analysis

Researchers	Cases and approaches
Chatzigeorgiadou *et al.* (2022)	Used scientific inquiry process, design thinking (IDEO model), and digital technologies to enable children to explore and understand the "water cycle".
Hachey & Golding (2022)	Sparked children's thinking with questions from the storybook and created a Makerspace for them to work in teams to construct solutions to problems.
Hatzigianni *et al.* (2021)	Through the example of the Macedonian Crisis, teachers used design thinking (IDEO model), digital technologies (eShadow and ePuppet softwares), and arts to explore the concepts of peace, war, and social justice with young children.
Yalçin (2022)	Designed small groups activities with a design thinking model (Emphise, define, ideate, prototype, test).
Lottero-Perdue & Tomayko (2019)	Used inertial knowledge to design a fence for the Hexbug Nano® robot to prevent it from getting lost when moving on a smooth hard surface.
Bartholomew *et al.* (2019)	Identified an explicit question from the nursery rhymes and used these questions to frame criteria and constraints for children to think about and use when designing.
Hatzigianni *et al.* (2021)	Designed hands-on activities using 3D technologies within the Makerspace.

TABLE III. ALIGNMENT WITH THE FRAMEWORK

Principles in framework	Categories	Researchers
Integration of STEM content	Integration of technology Involve two or more STEM content areas	Chatzigeorgiadou *et al.* (2022), Hachey & Golding (2022), Hatzigianni *et al.* (2021), Lottero-Perdue & Tomayko (2019), Hatzigianni *et al.* (2021)
Problem-centred learning	Open-ended questions Problem-based learning Solution-based learning	Chatzigeorgiadou *et al.* (2022), Hachey & Golding (2022), Yalçin (2022), Lottero-Perdue & Tomayko (2019), Bartholomew *et al.* (2019)
Inquiry-based learning	Scientific inquiry Involve discovery, planning, collecting and analyse information, testing	Chatzigeorgiadou *et al.* (2022), Hachey & Golding (2022), Hatzigianni *et al.* (2021), Yalçin (2022), Lottero-Perdue & Tomayko (2019), Bartholomew *et al.* (2019)
Design-based learning	Engineering-based design Design solutions Prototypes	Chatzigeorgiadou *et al.* (2022), Hachey & Golding (2022), Hatzigianni *et al.* (2021), Yalçin (2022), Lottero-Perdue & Tomayko (2019), Bartholomew *et al.* (2019), Hatzigianni *et al.* (2021)
Cooperative learning	Working in small groups Teamwork Communicate and discuss with peers	Chatzigeorgiadou *et al.* (2022), Hachey & Golding (2022), Hatzigianni *et al.* (2021), Yalçin (2022), Lottero-Perdue & Tomayko (2019), Bartholomew *et al.* (2019), Hatzigianni *et al.* (2021)

The case review showed that teachers attempting to adopt design thinking as a new pedagogical approach in early childhood social studies and science lessons were better able to help children acquire knowledge of scientific concepts, and understand the existence and occurrence of things around them through exploration and experimentation [19–21]. The use of technology was emphasized in design thinking STEM practices in early childhood, such as interactive boards, computers, software, and 3D design and printing technology [19, 20, 22]. To allow children to immerse in the process of exploration, teachers created a Makerspace where children had more opportunities to explore, think, and create [22, 23]. Apart from identifying problems from real life, teachers also work with children to find problems in children's literature, for example from illustrated stories and nursery rhymes, and provoke children to think, plan, and design solutions through small group activities and teamwork [23, 24].

IV. DISCUSSION

Even though all of these research cases used design thinking in early childhood education, the models they used were not identical. For example, the main purpose of adopting the IDEO model in design thinking is to help children build subject knowledge (e.g., Chatzigeorgiadou *et al.* [19], Hatzigianni *et al.* [20], Hatzigianni *et al.* [22]), while Yalçin [25] used the five-staged design thinking model (i.e., Emphise, define, ideate, prototype, test) in order to improve children's 21st century skills. Regardless of the focus of design thinking in early childhood education, all the research cases emphasize the importance of collaboration skills and the use of small group activities and teamwork to implement.

In addition, when design thinking is implemented in early childhood STEM education, the elements of T and E are emphasized. Design thinking is a solution-based approach to teaching and learning [26]. It is evident from the research cases that prototypes and solutions have to be presented in the design thinking classroom. The emerging technologies were regarded as the tools used by the children to design the solution plans and make prototypes.

The review found, however, that despite some studies emphasizing Makerspaces as a pedagogy for early childhood STEM education, Makerspaces are more commonly used with adolescents and adults and not widespread in early childhood classrooms [27]. In recent years, Makerspace education has been hailed as a means to empower young people to make a difference in their communities [28]. With Makerspaces, teachers can enhance children's problem-solving, creativity, and collaboration skills through design thinking. Despite the fact that many early childhood education approaches emphasize creativity and construction, only a few studies have explored how Makerspace can be introduced to young children [29].

V. CONCLUSION AND FUTURE WORK

This study reviewed, organized, and analyzed existing approaches to the application of design thinking in early childhood integrated STEM education through a systematic literature review. The review of research cases summarized the multiple forms in which design thinking is currently taught. The study took these forms and characteristics of application by corresponding to the five principles in Thibaut *et al.*'s model, and found that the application of design thinking in early childhood STEM education is mostly implemented in the form of children-centred small group activities, Makerspaces, integrated use of technology and engineering, problem-based and inquiry-based learning.

Furthermore, this study identified a research gap in the literature on the application of design thinking in early childhood STEM education, which has been implemented but has not been extensively studied. This also implied that design thinking has not yet been highlighted as a pedagogical approach in early childhood education, and therefore, it was not yet widely used. As such, it is suggested that future researchers could conduct more

research on the application of design thinking in early childhood STEM education, and also draw the attention of early childhood educators to new teaching methods by exploring the role of design thinking in promoting the development of 21st century skills in young children, which would contribute to the popularization of design thinking in early childhood STEM education.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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