Project-Based Inquiry in STEM Teaching for Preschool Children

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Abstract
This study explored the research question: How can project-based inquiry (PBI) in STEM teaching be designed, planned, and implemented in two preschool settings? A case study was conducted, using a collaborative action research approach. This research was conducted with 11 teachers and 300 children from 11 classes at two preschools in Taiwan. The data sources included research logs, observations, interviews, and documents. The collected data were analyzed qualitatively (e.g., iterative coding). The results indicate that PBI in STEM teaching can be integrated successfully into preschool curricula. Children can engage enthusiastically in STEM activities in a well-planned learning environment. We provide some suggestions for readers who have an interest in STEM teaching or research at the preschool level.

Keywords: STEM education, preschool, early childhood education, project-based inquiry

INTRODUCTION

Problem Statement

Science, technology, engineering, and mathematics (STEM) education has become a major topic in education research worldwide. STEM education integrates knowledge from across the four disciplines and cultivates cross-domain abilities in individuals, which they can use to explore, think about, and solve problems (Akturk & Demircan, 2017). Although STEM education is widely promoted in the United States and is becoming popular in other countries, most STEM research focuses on elementary school and above, and few studies have been conducted on STEM teaching in the early education stage.

Currently, uncertainty remains regarding the optimal approach for implementing a STEM curriculum in the early years of education (Tippett & Milford, 2017). However, STEM education for preschool children is recognized as crucial for developing a foundation for their future STEM knowledge and abilities, such as curiosity, creativity, cooperation, and thinking skills. Therefore, it has been recommended that STEM education be implemented as early as preschool (MacDonald et al., 2020). Taiwan preschools have begun to attach increased importance to the implementation of

STEM education; however, appropriate methods for implementing STEM teaching in preschool classrooms remain unknown

Research Objective

The present study explored how to conduct STEM teaching at the preschool level. The two main objectives were, as follows:

1. to encourage the development of young children's STEM skills and content knowledge and

2. to support preschool educators' planning and integrating of STEM in their teaching.

Research Question

The main research question was: How can project-based inquiry (PBI) in STEM teaching be designed, planned, and implemented in two preschool settings?

CONCEPTUAL FRAMEWORK

The conceptual framework for this study consists of five considerations for early childhood STEM education: age-appropriate teaching, drawing from everyday experiences, scientific inquiry, PBI, and questioning strategies (see Figure 1). STEM activities for pre-schoolers need to be age appropriate and connected to

Contribution to the literature

- This study is unique in an early childhood STEM education context and assists in the understanding of the complex connection between STEM concepts and preschool teachers' pedagogical practices in inquiry.
- The study has described directions of providing enriched STEM learning experiences where children could be meaningfully guided to discover their STEM problems arising from their daily lives.
- The study has identified possible advantages and challenges of implementing the inquiry-based of STEM education in the preschool setting. Readers can use it as the stepping stones to understand children's STEM learning trajectories and preschool teachers' professional development in the near future.
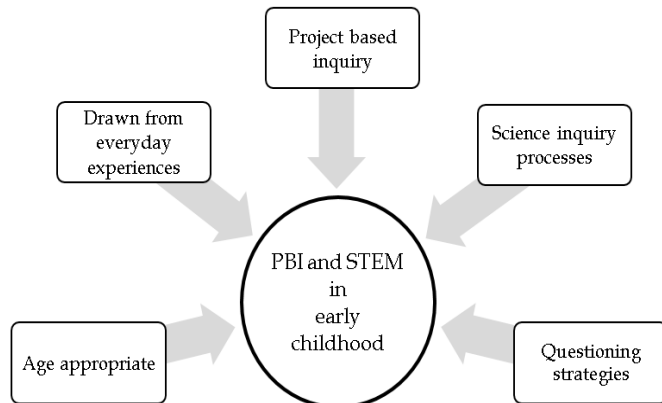

Figure 1. Conceptual framework

children's everyday experiences. Using questioning strategies and adopting a PBI approach to STEM teaching can provide opportunities for young children to engage in integrated STEM activities that can foster the development of science inquiry processes.

Age-Appropriate Teaching

In preschool, general teaching strategies are developed mainly on the basis of Dewey's (1997) "learning by doing" theory and Vygotsky's (1980) social construction theory. Dewey (1997) indicated that the content of teaching themes must be representative of real life so that the themes are meaningful to young children. Vygotsky's (1980) theories emphasize the role of collaborative teaching and learning. Therefore, STEM teaching in early childhood education should integrate children's life experiences, with educators making effective use of children's prior knowledge and experience to provide children with relevant STEM learning opportunities (Corlu et al., 2014).

In early childhood education settings, the environment serves as a teacher, enabling young children to explore. Thus, teachers can reconstruct the environment to strengthen children's understanding of STEM concepts (Krogh & Morehouse, 2014). Fredericks and Kravette (2014) suggested that a suitable STEM learning environment should provide children with tools, spaces, and materials (i.e., technology) for testing predictions. For example, if a child wishes to test a ramp, the learning environment must have sufficient space and materials (e.g., building blocks and boards) for the child

to investigate their ideas. If a child wishes to explore the color effect of various light overlays, the learning environment must contain flashlights and different types of cellophane so that the child can conduct investigations.

The learning environment should contain sufficient materials, which must be easy to access and return, as well as scaffold clues (e.g., small books, finished products, or exploded-view drawings) to encourage children to explore freely. Research suggests that the early learning experience of young children should involve the hands-on exploration of materials (Follari, 2015).

Drawing from Everyday Experiences

Research has revealed that many opportunities are available in daily life for young children to learn STEM (Sahin et al., 2013). National Science Teachers Association (2014) suggested that teachers can guide children's learning as they explore their own STEM questions about daily life experiences. For example, when children enter an air-conditioned classroom during summer, they might ask the following STEM-related questions: What is the difference between the outside and inside air? And why is it cooler inside than outside? The teacher can begin a discussion that focuses on the children's experiences with cooling and air convection. The STEM teaching content in this example is as follows:

- S: exploring the factors that affect the temperature inside and outside;
- T: making use of different tools to measure temperature and to design cooling solutions;
- E: designing a method or product to solve the problem of reducing indoor temperature; and
- M: measuring, comparing, counting, or calculating techniques used during the problem-solving process.

The crucial aspect of early childhood STEM education is not the answers obtained but the opportunities for children to explore concepts and conduct investigations of their ideas. Therefore, it is suggested that STEM teaching content comes from the common problems in children's daily lives.

PBI

In addition, problems in daily life are often interconnected; therefore, researchers have suggested that integrated project-based learning should be used for STEM teaching among young children (Corlu et al., 2014). PBI entails four phases, namely inquiry, exploration, invention, and reflection. Research indicates that children's intellectual capacities can be enhanced when children engage in PBI in which they conduct investigations around their personal questions (Johnson et al., 2019). Sanders (2009) defined project-based STEM education as an inquiry-based and student-centered learning model that links at least two STEM fields in the exploration of the environment. Kelley and Knowles (2016) further elaborated that integrated project-based STEM education can cover multiple classes with multiple teachers and students from diverse backgrounds as well as link non-STEM subjects, such as music and art, with STEM subjects. Ong et al. (2016) indicated that the project's theme should be based on the children's interests and the problems that they face. Through exploring these projects, children's abilities to identify problems, plan solutions, solve problems, create works, and work in a team are promoted.

Science Inquiry Processes

Dejonckheere et al. (2016) observed that inquiry learning can significantly improve children's reasoning ability. Inquiry-based teaching strategies are mainly based on constructive learning theory, which emphasizes that learners can develop higher-order thinking skills through the inquiry process (Dewey, 1997; Vygotsky, 1980). Gerde et al. (2013) suggested that scientific inquiry can be used as a guide for creating comprehensive and meaningful science experiences for young children. Scientific inquiry comprises processes and skills including: observing, questioning, predicting, investigating, summarizing data, communicating findings, and identifying new questions.

For observing, teachers can ensure that children have ample time to observe, interact, and investigate a variety of science materials. Teachers can also encourage children to represent and document their observations in multiple ways, such as drawing, writing, describing, or even taking photos.

For questioning, teachers can build on children's interests to help students develop and refine their own testable questions. For investigating, teachers can provide children with multiple opportunities to conduct hands-on explorations related to their testable questions.

For predicting, teachers can activate children's prior knowledge and encourage children to draw on their experiences to predict the answers to their testable questions.

For summarizing data, teachers can scaffold children's efforts to represent the results of their investigations, using similar approaches as in documenting observations.

For communicating findings, teachers can provide children with opportunities to share their findings with classmates, family members, and other authentic audiences.

For identifying new questions, teachers can use questioning strategies to encourage children to develop new testable questions that might extend or build on their findings.

In the scientific inquiry process, children should play the leading role, whereas adults should take the lead in the questioning and guidance processes, intervening when appropriate. Moreover, adults can use questions or environmental preparations to help the children develop systematic inquiry skills (Harlen, 2013). Colburn (2000) indicated that the inquiry teaching method comprises three teaching approaches: structured inquiry, open inquiry, and guided inquiry.

In structured inquiry, teachers establish inquiry paths and procedures and provide guidance through questions, procedures, and materials. Students aim to determine the relationships between different variables, make inferences from the collected data, and find solutions to problems.

In open inquiry, students identify problems, develop problem-solving procedures, and interpret the results of their inquiry.

In guided inquiry, teachers provide inquirers with the materials required to explore relevant questions and ask them to develop problem-solving procedures. Structured inquiry limits learners' creative and inquiry potential. Moreover, open inquiry may be excessively difficult for young learners who lack basic knowledge and inquiry ability (Harlen, 2013). Therefore, the teachers in this research adopted a guided inquiry approach to conduct STEM teaching.

Questioning Strategies

One key finding from research is that teachers should use multiple questioning strategies to support young children's inquiry learning and to scaffold the development of new science and STEM understandings (Chen et al., 2017; Gerde et al., 2013; Kawalkar & Vijapurkar, 2013). Teacher questioning plays a major role in supporting students' learning, through fostering discussions around that learning and enabling assessment (Crawford, 2000). To foster student discussions, teachers can use different questioning strategies to encourage student engagement, direct student attention, support the flow of information, recognize student thinking, help students compare ideas, and integrate new ideas into discussions (Chen et al., 2017; Kawalkar & Vijapurkar, 2013). Chin (2007) also noted that teacher questioning plays an important role in scaffolding student argumentation, an important

dialogic pattern even for young children (e.g., NGSS Lead States, 2013). To assess student understanding, teachers can use questions to elicit student responses, challenge students' thinking, encourage a broader range of responses, and stimulate reflective thinking (Chen et al., 2017; Kawalkar & Vijapurkar, 2013). For example, open-ended questions can be used for assessment of student thinking allowing the teacher to explore students' prior knowledge and experiences, and to encourage students to articulate newly developed understandings (Ruiz-Primo & Furtak, 2007). In this study, teachers were encouraged to utilize a variety of questioning strategies as they supported the development of young children's inquiry processes and STEM learning.

STEM in Early Childhood Education

STEM education is a major feature in international education reform as well as part of innovation policies for facing a new era and strengthening national competitiveness (Cohen & Waite-Stupiansky, 2019). STEM education is also an emerging topic in research on teaching early childhood education (MacDonald et al., 2020). Before an exploration of STEM education can be undertaken, the four components of STEM need to be articulated. Widely accepted definitions of the four disciplines are, as follows:

1. Science refers to the exploration of the natural world to understand, or answer questions about, how the natural world works.

2. Technology refers to the modifications made to the natural world and the innovations achieved to meet human needs and desires.

3. Engineering refers to solving problems through systematic methods or designs to meet human needs and desires.

4. Mathematics refers to the concepts of quantity, space, and logic (Corlu et al., 2014).

Sharapan (2012) clarified the definition of STEM in the field of early childhood education, as follows:

1. Science refers to the curiosity of and problems faced by children in their daily lives. For example, children may be curious about why ice cubes melt or why shadows form.

2. Technology refers to young children's use of tools, such as crayons, magnifying glasses, or experimental materials, to find answers to problems.

3. Engineering refers to the systematic problem-solving process, which includes identifying the problem, and imagining, creating, testing, and improving solutions. An example of such a process is the entire design and problem-solving process of children who attempt to create a paper boat that floats steadily on water.

4. Mathematics refers to mathematical thinking in children's learning, which includes the processes of measuring, comparing, sorting, and calculating. For example, children may compare different sizes of paper planes and measure how far these planes can fly. This nuanced definition of STEM in early childhood was the foundation for our study of PBI and STEM at the preschool level.

METHOD

Case Study of Collaborative Action Research

A case study was conducted as part of this research because this method offers a detailed understanding of the studied phenomenon (Creswell & Poth, 2017). Study participants, who had no experience with STEM teaching were selected by the first author using purposive sampling (Creswell & Poth, 2017) In the development of the STEM teaching process, a collaborative action research method was adopted in which we, the teachers, and the school director collaborated to explore how to conduct STEM teaching for young children from various age groups. The action research team discussed and designed teaching strategies together. Through practice and reflection, continual improvements were achieved related to STEM teaching problems. The purposes of this research were to obtain solutions for and achieve improvements to STEM teaching as well as to improve the STEM professional knowledge of the teaching team.

Evaluation of Learning

Because preschool children are limited by their language development and literacy skills, using written tests to assess their learning is difficult. Research has suggested the use of diversified, interactive, and activity-based tools to conduct assessments with young children and these types of authentic assessments are widely used in early childhood education to assess children's learning outcomes (Wortham & Hardin, 2015). Authentic assessments involve understanding children's needs, abilities, and interests through the observation, recording, and systematic collection of their works. In these assessments, children's real-life events are considered the main evaluation context as well as observations are made to determine whether children can apply the learned knowledge and skills in real life. In the present study, observations, anecdotal recording, interviews, documenting teacher and student artefacts, and checklists, which are commonly used in authentic assessments, were used to evaluate children's STEM-related abilities. The observations and evaluations in this study were analyzed according to the "real inquiry" characteristics of Chinn and Malhotra (2002). The following questions were analyzed (Dubosarsky et al., 2018):

Table 1. Information about the research setting and participants

Research duration	Preschool	Location	Participating classes	Participants
March 2019-March 2020	School U	Urban area	Eight classes (three classes each of children aged 3-4, 4-5, and 5-6 years)	8 teachers 225 children
September 2020-June 2021	School R	Rural area	Three classes (one class each of children aged 3-4, 4-5, and 5-6 years)	3 teachers 75 children

Table 2. STEM teaching themes in the two preschools

School	Age (years)	Class themes (teacher)	STEM-related teaching content
U	3-4	Class A: Blowing bubbles (TUa) Class B: Water (TUb) Class C: Sinking & floating (TUc)	S: Activities encouraging the children to explore their problems & curiosity related to the theme. For example, the children explored the factors affecting whether an item floated.
	4-5	Class D: Wind-driven car (TUd) Class E: Shadows (TUe) Class F: Spinning tops (TUf)	T: All the materials used by the children to solve problems during their explorations, including the materials & tools used to design a spinning top (e.g., paper plates, pencils, marbles, & compact disc).
	5-6	Class G: Paper planes (TUg) Class H: Constructing a boat for animals (TUh)	E: Systematic problem-solving & design thinking. For example, the children hypothesized about how paper planes can fly far.
R	3-4	Class I: Rabbit & eggs (TRa)	Subsequently, the students engaged in design, testing, reflection, & design revision repeatedly until their paper plane could fly a relatively long distance.
	4-5	Class J: Fish & cloth (TRb)	
	5-6	Class K: Cricket & paper (TRc)	M: Mathematical thinking during the learning process. For example, the children compared the sizes of shadows by measuring the distance between an item & the light source.

1. How do children develop STEM inquiry questions?
2. How should STEM-related learning be expressed?
3. How should STEM information be organized and collected?
4. How should the findings of this study be presented and explained?

Participants

This research was conducted in two preschools in Pingtung County, Taiwan: one school is located in an urban area, whereas the other is located in a rural area. Table 1 presents some information on the participants of this study.

These two preschools were selected because of their high quality and favorable reputation in Pingtung County, and teachers at these preschools have won various teaching excellence awards. Classes from both preschools, comprising students of different age groups, participated in this study.

All 11 participating teachers had a minimum of three years of teaching experience. We obtained written informed consent from the teachers and the parents of 300 students to comply with ethical considerations and safeguard all participants. Because none of the participating teachers had experience with STEM teaching, we provided them with basic information about STEM education through a six-hour workshop, in which we introduced the relevant theories, approaches to curriculum planning, and recommended teaching strategies of STEM education.

Action Strategy

On the basis of relevant literature, STEM teaching was conducted using a theme-based teaching model. The teaching content was mainly related to the problems encountered by children in their daily lives. The teachers used scaffolding questioning strategies to guide children's STEM exploration. Moreover, during the study learning centers were created to facilitate individual or small-group investigations by the children. Finally, authentic assessments were used to evaluate the children's STEM abilities and performance. The STEM teaching curriculum was child-centered and could be modified to meet children's interests and curiosity. STEM teaching activities were modified each week according to the children's interests and curiosity; the STEM teaching themes undertaken during the study are listed in Table 2.

Data Collection

In this study, data were collected using field notes during teacher seminars and classroom observations, recorded interviews, and artefact review. We also used research logs, which are one of the most crucial data collection methods in action research. The purpose of the collected data was to explore the change in STEM teaching in the course of action research and the crucial influencing factors from the perspectives of the researchers and the teachers. The teacher seminars, which included discussions about teaching situations, helped the teachers clarify and reflect on any problems and plans of action. During observations we recorded the thinking process during the design and development

Table 3. Coding the data: Main codes, sub codes, & themes

Main code	Sub-codes	Themes
Origins of STEM themes	▪ Previously developed curricula ▪ Picture books ▪ Learning centers ▪ Children's free play	Planning for STEM
Integrated STEM projects	▪ Integrated STEM projects ▪ Original themed curricula ▪ Emerging opportunity ▪ Use of picture books	
Inquiry processes	▪ Observing ▪ Developing questions ▪ Predicting ▪ Investigating ▪ Summarizing data and communicating findings	Teaching STEM
Constructivist teaching approach	▪ Using questioning strategies ▪ Providing adequate time and material for investigations ▪ Drawing from everyday experiences and focusing on children's ideas ▪ Providing diverse means of communicating results ▪ Prompting for additional questions	
Evaluation of learning	▪ Development of inquiry skills ▪ Understanding of scientific concepts	

of teaching strategies as well as the reflections on the results of STEM teaching with field notes and video recording. We observed the STEM classrooms every week, focusing on the teachers' STEM planning and teaching strategies and the children's STEM performance. Teacher interviews were conducted because of the utility of interviews in capturing participants' views regarding a phenomenon (Kuteeva, 2020). After the classroom observations, we interviewed the teachers to understand their teaching methods and any challenges they faced. Each interview lasted approximately 10-15 minutes and were recorded for subsequent transcription. In addition to face-to-face conversations, online discussions were periodically conducted through social media (i.e., LINE). Finally, we collected artefacts like teaching plans, aids, assessment sheets, materials, and photographs of children's work.

Data Analysis

We conducted a thematic analysis (Creswell & Poth, 2017) that involved transcribing, coding, categorizing, and establishing themes as well as reporting the data for each research objective. First, audio-recorded data transcripts were transcribed. Second, the transcribed data were coded and the overall amount of data was reduced and relevant text identified by focusing on this study's purposes (Auerbach & Silverstein, 2003). Data coding involved initial coding and synthesizing codes among the codes (Saldaña, 2021). Third, the data were further categorized into meaningful units to obtain distinguishable patterns in them. Finally, the coded and categorized data for each theme were combined. The main codes, sub codes, and themes are listed in Table 3.

We sorted, organized, and structured codes to conceptualize claims. Next, we reviewed our provisional claims through the analysis of various data sources. We constantly reviewed the data classification and the appropriateness of the aforementioned claim in an iterative process of back-and-forth deductive thinking about themes, categories, temporary propositions, and discussions. Member checking of the transcriptions was performed to ensure the validity of the data analysis (Yin, 2015). Moreover, we used several triangulation strategies to increase the reliability of the study's findings, which included: (i) different settings (i.e., multiple classrooms in two preschools), (ii) multiple sources of data (e.g., observations, interviews, artefacts), (iii) multiple coders (i.e., two researchers analyzed data and reached coding agreement), and (iv) theoretical triangulation (i.e., we analyzed other research in early childhood STEM education and presented a literature review to support our claims). We also verified the reliability of the collected data through self-reflection and continual discussions and dialogue with the teachers.

RESULTS

Our data analysis led to the development of two main themes, each of which had two or more main codes: planning STEM themes (origins of STEM themes, integrated STEM projects) and teaching STEM (inquiry processes, constructivist teaching strategies, evaluation of learning). Although not a separately coded theme, we also observed that teachers used questioning strategies extensively. Examples of each subtheme are provided in the following sections.
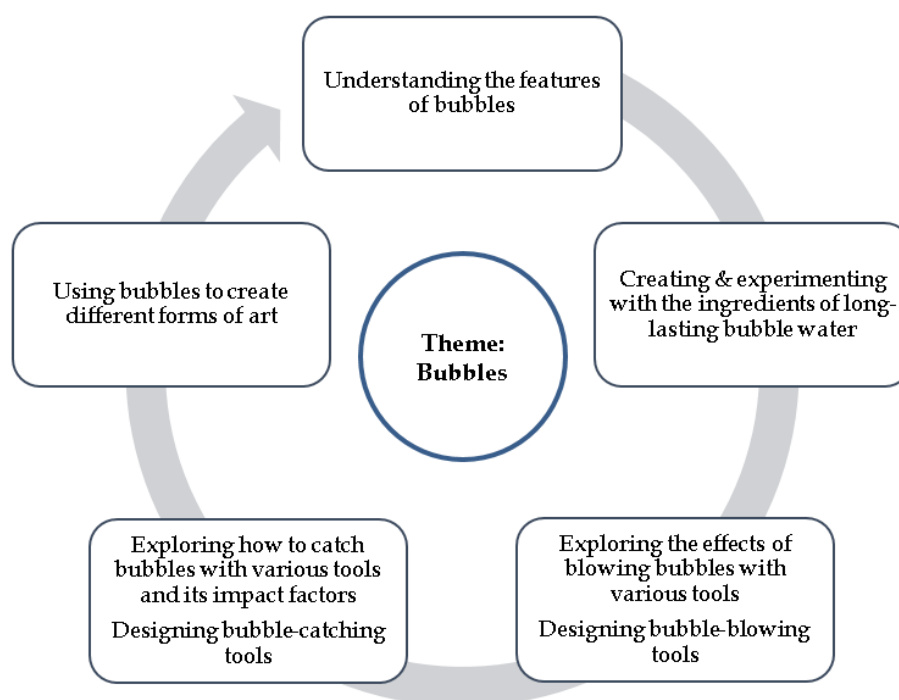
Figure 2. Sample of a STEM theme curriculum

Origins of STEM Themes

Participating teachers planned their STEM themes with inspirations from previously developed curricula, picture books, learning centers, and children's free play. The two preschools where this study took place had developed their themed curricula (see Figure 2) before our arrival. After discussions with the participating teachers, the action research team (i.e., the participants and the researchers) decided to develop STEM teaching strategies for these themes according to emerging opportunity.

In addition to designing STEM themes based on previously planned teaching themes, we observed that some teachers used picture books to stimulate children's STEM interests and initiate integrated STEM activities. For example, teacher TUc used the picture book *Stone Soup* to stimulate children's interests in a sink and float STEM activity. "Do you see… what fruit or vegetable floats or sinks in the stone soup?" (Observation-TUc -20190507). After the story and observation, the children had many thoughts about the factors that affect sinking or floating. One child stated, "I think that small fruits will float, and I think that big vegetables will sink" (Observation-TUc-20200319). To allow the children to verify the factors that they predicted would affect sinking and floating, the teachers provided several materials to explore their assumptions (e.g., grapes, beans, and bananas). The children then made conclusions regarding the factors affect sinking or floating.

Learning centers were another approach that teachers used to stimulate STEM interest and provide opportunities for integrated STEM projects. For

example, teacher TUd developed a learning center for a wind-driven car. In this learning center, different materials and scaffolding pictures were provided to children to enable them to construct cars. Teacher TUd spoke about her observations as follows: "The children were arguing that wind can help the car move. A sail may be necessary to help wind drive the car. Then, the children discussed the designs of the sails and cars" (Interview-TUd- 20190510).

STEM teaching ideas were also obtained by observing the children's free play. Teacher TUa provided an example of how they developed a STEM theme after observing 3- to 4-year-old children blowing water bubbles:

> The children tried to blow water bubbles with straws. But, they failed several times. First, they did not know how to make bubble water. Then, they did not know how to blow bubbles with their mouths and different tools. Next, they wanted to catch the bubbles with their hands and other tools. I found that the children were fascinated with this activity [bubble blowing]. So, I used water bubbles as a STEM theme to guide them to conduct in-depth STEM activities (Interview-TUa-20190508).

Integrated STEM Projects

The teachers supported children's engagement in STEM by planning integrated projects that would include two or more of the four disciplines, a PBI approach. Teacher TRb spoke about how they developed PBI STEM teaching, as follows:

Table 4. The scientific inquiry stages involved in the paper plane STEM theme (Observation-TUg-2019)

Observing & questioning	Variable of interest	Predicting	Investigating	Summarizing data	Communicating findings
How might the plane's nose affect the distance a paper plane travels?	Plane's nose	The shape of the nose will affect flight	Folded jet nose versus no folding	The presence or absence of folding makes no difference	Use different jet nose shapes
			Pointed versus wide nose	Planes with pointed nose fly better than those with wide nose	Use tape to sharpen the nose
		The weight of the nose will affect flight	Weighted versus non weighted nose	Superior flight is achieved with a moderately heavy nose	Use tape or a clip to make the nose heavier
How might the plane's wing affect the distance a paper plane travels?	Plane's wings	The shape of the wing will affect flight	Reel versus flat	Planes having wings with small reels can fly far	Design wings with a small reel
		The size of the wing will affect flight	Large wings versus small wings	Planes with larger wings can fly farther	Design large wings
Does it make a difference how the plane is released?	Release method	A run-up before release will enable the plane to fly far	Run-up versus no run-up	A run-up before release helps the plane to fly far	A run-up should be taken before releasing the plane
Does the direction of the plane make a difference?	Flying direction	The plane would fly farther when moving straight than when moving upward	Fly up versus fly straight	Straight movement results in a longer flying distance than an upward movement does	Straight movement results in flying a flying distance

Our original theme is "fish." After observing the first teaching [process], the action team suggested that we explore the features and habits of different fishes [science] Then, following the children's discussion and interests, the children decided to raise fish in the learning center. So, we explored the living environment of the fish and began to design a fish tank to raise the fish. In these observations and design processes, the children gained related STEM abilities (Interview-TRb-20210320).

Several teachers adopted the picture book strategy to cultivate a stimulating STEM environment. This strategy led to a number of integrated STEM activities in addition to the sink and float activity, such as paper building or bridge construction, cloth bag or parachute design, egg-protector design, paper plane design, and spinning top design (Observation-School U, R, 2019-2021).

Teacher TUd observed the problems encountered by the children in the wind-driven car learning center and used these problems as the starting point for intentional STEM teaching. In the exploration process, the children found that the weight and size of the car, the position and shape of the sail, and the direction and force of the wind affect the movement of the wind-driven car. Subsequently, the teacher guided the children to repeatedly test the effects of these factors. Finally, the children confirmed the variables affecting the movement of a wind-driven car and designed a wind-driven car

with the knowledge and experiences acquired through the exploration (Observation-20190517).

For the water bubble STEM theme, the teacher drew on an emerging opportunity to plan an integrated STEM project. The children explored the factors affecting the formation of bubbles [science], categorized items that can and cannot be used to blow bubbles [mathematics], and designed tools [technology] that can blow bubbles [engineering]. Subsequently, the children combined their knowledge and skill to create various types of bubbles (e.g., grape bubbles, turtle bubbles as well as three-layer bubbles), which indicated their STEM competence (Interview-TRb- 20210320).

Inquiry Processes

The PBI teaching of STEM themes involved the following inquiry processes: observing, questioning, predicting, investigating, summarizing data, and communicating findings. In Table 4, we briefly illustrate how these processes might be enacted by young children in a single integrated STEM project, based on our observations of the children's exploration of the paper plane theme.

In the following subsections, we provide more detailed examples of how the participating teachers supported the children's inquiry processes in their PBI approach to STEM.

Supporting children in making observations

The teachers offered various scientific materials (e.g., collections of papers, clips, tapes, and plane pictures) that the children could observe and manipulate, enabling them to acquire multiple experiences of engaging in observations. In discussions, the teachers asked the children to describe their observations to peers during free play. The describing of observations enabled children to understand scientific concepts. For example, for the paper plane theme, the teachers provided the children with various types of paper and invited them to construct paper planes that could fly a long distance. Subsequently, the teachers led the discussion by asking the following questions: "Which paper plane flew the farthest?" "Which factors caused the plane to fly the farthest?" and "What is the difference between the planes that flew long and short distances?" (Observation-TUg-20190506). In the aforementioned discussions, the teachers' questioning strategies enabled the children to become more adept observers and to develop understanding of scientific concepts.

Developing questions

After children had shared their observations, teachers summarized those observations and helped children to develop questions about what they had observed. Teachers scaffolded question formulation by asking probing questions (e.g., "Do you remember the shape of the paper plane that flew the farthest?"). Teachers linked children's observations to concrete objects in order to demonstrate those observations and make them clearer to other children (e.g., "Why do not you fold your plane's nose so that they know what you mean by increasing its weight?"), which also helped children to generate additional questions. Subsequently, the teachers used the raising questions (Chin, 2007) strategy to stimulate the children to develop questions that they would wish to explore further. For example, the children wanted to know "whether folding the plane's nose can let it fly farther" (observation-TUg-20190320).

For the wind-driven car theme, the children raised the question of "whether the weight of the wind-driven car affects its speed" (Observation-TUd-20190420). For the spinning top theme, the children raised the question of "whether the size of the surface affects the extent of its spinning effect" (Observation-TUf-20190523). Most of the questions raised by the children were based on their interests and what they had previously observed. However, not all the children's questions were testable, and teachers sometimes had to help the children generate testable questions. For example, the children raised the following question: "Does the position of the sail on the boat affect its movement speed?" The teachers guided the children to refine this question by asking: "Where the sail should be placed (to the left, right, up, down, or center?" (Observation-TUd-20190504). When

the children raised their questions, the teachers recorded them on a poster to attract the children's attention and summarize the children's further exploration direction. The children were developing skills for recognizing and asking questions.

Leading children to develop predictions

During the introductory workshop, we suggested that teachers record the children's prediction on a large paper and display them to provide the children with a visual reference for exploration and discussion. According to our observations, children often made predictions regarding the answer to their questions. For example, for the spinning top theme, the children observed that "the length of the axis of the top affects the rotation time" (Observation-TUf-20200325). Subsequently, the children predicted that "the shorter the axis of the top is, the longer the rotation time would be" (Observation-TUf-20200325).

Engaging children in investigating their ideas

Children were reminded of their predictions so that they could test them. The teachers encouraged the children to find patterns in their predictions, develop ways to test out those patterns, compare results, and organize data, drawing on science process skills such as communicating, measuring, and sorting. For example, the teachers instructed the children to design a bag that could carry a heavy object. First, the teachers asked the children questions: "What type of cloth can be used to make a bag?" and "Can you organize (or sort) different types of cloths in the descending order of the weights that they can support?" (Observation-TRb-20210322), "What are the appropriate locations for placing eggs in the bag?" and "What are the effects of different positions on the bearing of weight?" (Observation-TRa-20210329).

Teachers needed to scaffold activities that would support children's investigations, and to ask guided questions to encourage reflective thinking about their results. For example, the teachers asked the following questions to the children after the egg-related investigations: "Did you notice which egg placement locations had a high weight that can be borne by the bag?" "What did you find?" and "What are the similarities and differences observed for the different egg placement locations?" (Observation-TRa-20210426). Investigating and testing ideas helps the demonstration of phenomena in a concrete manner and facilitates the clarification of ideas as well as concept development (Gelman & Brenneman, 2004).

Helping children to summarize data & communicate findings

The teachers helped the children combine their findings from their investigation journals. For example, the children had drawn and labelled objects that sunk or

Table 5. Questions asked during the inquiry process for the paper plane STEM theme (Observation-TUg-20190427)

Question purposes	Example of questions asked
Recall information	What do you notice here?
	Does anything unexpected occur when you put a clip on the plane's nose?
Generate ideas	Is there anything that you are puzzled about?
	What else would you like to know about?
Make comparisons	How are the two planes similar or different?
	What is the difference between the distance traveled when you release the plane from the bottom or the top?
Predict outcomes	What would happen if you take a run-up?
	What would happen if we fold the plane's wings in a triangle shape?
Provide explanations	Why cannot this plane fly farther?
	What are some possible reasons for the plane's poor flight performance?
Analyze data	What is the relationship between the shape of the plane's nose and its flying direction?
	What are the variables affecting the flying distance?
Make inferences	How can you make a plane fly farther? Why?
	Are there any conditions under which the plane would fly farthest?

floated. Then the teachers encouraged the children to discuss their discoveries by asking them to share their observations. For example, the children spoke about observing objects that sunk and floated as follows: "I think a light object will float" and "I think a small thing will float."

However, some children stated, "a grape is small but it sinks" and "a watermelon is big but it floats" (Observation-TUc 20200326). After several trials, the children concluded that "if the items have holes or inside the object, they will float. Seeds' inside look dense, they will sink. Watermelon and cabbage look loose inside. They will float" (Observation-TUc 20200326). Children concluded "the density" of an object, not its size or weight, affects whether it sinks or floats.

Constructivist Teaching Approach

The participating teachers followed a constructivist approach to teaching STEM. They used questioning strategies, provided adequate time and materials for investigations, drew on children's experiences and focused on children's ideas, and asked children if they had additional questions.

Using questioning strategies

Chin (2007) indicated that different question types serve distinct purposes, such as prompting the student to recall information, generate ideas, make comparisons, predict outcomes, provide explanations, analyze data and make inferences. The role of a teacher is to use different forms of questions to bridge the cognitive gap between children's questions and their current knowledge base. Throughout the study, participating teachers frequently used questioning as they supported the development of young children's STEM knowledge, skills, and abilities, as can be seen in the previous examples; here we focus on the teachers' perspectives on questioning strategies and their rationale for using questions in STEM teaching. Table 5 presents some of the

question types asked by teacher TUg during the PBI for paper planes.

When teachers were asked about their questioning strategies, they mentioned several points. First, TUf mentioned that:

> I must have a thorough understanding of the STEM content to ask appropriate questions that can help children integrate different concepts into a conceptual framework. For example, "are there any conditions under which the spinning top will spin longer?" is this kind of question (Interview-TUf-20190527).

Second, TUg indicated that:

> Teachers must select appropriate questions that build on children's previous knowledge and experiences. For example, "How are the two planes similar or different?" and "What is the effect of increasing or decreasing the size of the plane's wings?" are the questions that stimulate children to further their investigation (Interview-TUg-20190530).

Third, TUd suggested that:

> We need to use a series of question sequences to stimulate children to test their assumptions through investigation. For example, "What is the evidence to support your view of the wind-driven car?" "Do you want to make a triangle sail to examine whether the effect is different?" are questions that can stimulate to test their assumptions (Interview-TUd-20190530).

In our study, all teachers agreed that various forms of questioning have different learning functions and thus can be used to guide children toward the path of developing STEM knowledge.

Providing adequate time for children to interact with materials

The teachers ensured that there was ample time for children to observe and explore a range of materials related to their questions, a requirement noted by Gelman (2009). In this study, we set up a STEM learning center in which the children could manipulate materials and test their ideas. For example, the teachers established a learning center related to spinning tops in which the children could test their assumptions on the spinning effect on spinning tops of various shapes and different axial lengths as well as on various other materials (observation-TUf-20190326). Furthermore, the teachers offered the children various STEM exploration tools (e.g., rulers, magnifying glasses, and scales) to expand the children's opportunities to discover interesting phenomena. The STEM learning center allowed the children to explore their ideas freely by using the materials in this center. For example, one teacher stated, "The children used different materials from the STEM learning center to construct and modify a boat for animals for a whole month" (Observation-TUh-20191121). This learning center enabled the children to understand how to obtain information that would help them to answer their questions (Dejarnette, 2018). The children participated in the investigating process and did not simply observe a teacher conducting a test; thus, the children could develop a deeper understanding of complex scientific phenomena. The materials in the center remained accessible for several days to ensure that all the children had multiple opportunities to conduct exploration with the materials.

Drawing from children's experiences and focusing on children's ideas

The STEM activities were often drawn from children's experiences. For example, the shadow STEM activity began with children's play with their shadows outside. After that, the teacher asked the children questions: "How can we create a shadow in the classroom? What do you want to play with a shadow?" Children suggested: "We can use a flashlight to create a shadow when the light is off. We can have a shadow room where we can hide in the dark to play with shadows" (Observation-TUe-20190923). Then, the teacher set up a shadow learning center to stimulate children's explorations based on their ideas. Children were encouraged to bring different materials or objects (e.g., different transparencies, sizes, shapes) to play with in the center. While playing, children became interested in more questions: "Why can some children can create a shadow but some cannot? Why do some objects have bright shadows/dark shadows in the center? Why is a shadow different in sizes? How can we create different kinds of shadows?" (Observation-TUe-20191012). Focusing on these interests, the teacher encouraged children to investigate their ideas. For example, the

teacher suggested that children shine their flashlights in different positions with an object (i.e., above, below, behind, in front) to see whether they could create a shadow (Observation-TUe-20191012). After several weeks' exploration, the children had the idea of using shadows to tell a story. Thus, they made up a story and used their knowledge of shadows to create a tabletop shadow theater.

Providing children with diverse means for communicating their results

Children in this study were provided with diverse means for sharing their results. For example, one teacher in this study asked each child to explain to the others why "one paper plane flew farther than the other." (Observation-TUg-20190415). The teachers documented images of the children's work, prediction charts, and design sheets (see Table 6). The children were also encouraged to draw representations of their findings (e.g., a summary chart of the findings regarding shadows) or to explain their conclusions to others. For example, "the children designed and produced animal boats, wind-driven cars, handbags, and egg protectors. The children used their language and literacy skills to communicate their ideas about STEM design in a meaningful manner" (Observation-School U, R, 2019-2021). This sharing process could enhance children's ability to think critically about their STEM exploration. Gelman (2009) indicated that children's communication of their scientific findings enhances their ability to talk about and understand a range of STEM concepts.

Asking children if they had additional questions

The teachers facilitated continued investigations by asking the children if they had additional questions about what they had just learned or by following up on the children's observations during the investigation and summarization steps. For example, after the children created a paper plane that could fly a relatively long distance, they observed that the planes created by some children turned during movement. Thus, the children identified the following new question: "How does one construct a paper plane that has the ability to turn?" (Observation-TUg-20190401). Moreover, in the scientific inquiry process for the wind-driven car, the children were interested in adding additional sails to the card to examine how the number of sails affected the car's speed (Observation-TUd-20190424). Building upon children's curiosity is crucial because it allows children to follow their interests and use their emerging knowledge to continue learning (Worth & Grollman, 2003).

Evaluation of Learning

The teachers used authentic assessments (e.g., observations, interviews, documenting artefacts) to evaluate children's STEM-related abilities (i.e.,

Table 6. Examples of artefacts from STEM activities

Description	Example 1	Example 2
Design sheets and products 1. A child's design of a wind-driven can and their final product 2. A child's design of a spinning top and their final work		
Hypothesis and testing charts 1. Children's predictions (left column) and testing results (right column) for catching bubbles (with bubble water vs. without bubble water) 2. Children's predictions and testing results using different tools with and without bubble water		
Discussion chart Teacher's summary of children's discussion about the influence of different parts of a paper airplane on its flying distance.		
Representations of findings 1. Fastest speed of wind-driven cars with sails of different shapes. Children placed a sticker in the column showing their results. 2. Sinking/floating/semi-floating. Children put objects in front of the pictures (red dot represents item position in bucket of water)		

development of inquiry skills, understanding of scientific concepts). For example, the spinning top STEM activity began when the teacher noticed "children make a competition to compare the rotational durability of different spinning tops." (Observation-TUf-20200316). Building on this interest, the teacher asked, "What factors do you find affecting the rotational durability?" The children predicted, "The shorter the axis of the spinning top is, the longer it spins". Then, the teacher asked, "How are you going to know whether your prediction is true?" The children answered, "We can compare two spinning tops, one has a longer axis, the other has a shorter axis, to see which one spins longer" (Interview-TUf-20200316). The teacher encouraged the children to investigate their prediction and during the explorations, observed and evaluated the children's development of inquiry skills. After investigating, the children concluded that the shorter the axis of the spinning top, the longer it would spin. However, during the investigation process, the children noticed other

variables (e.g., the size of spinning top's body, the way you spin the spinning top) that may affect the spinning top's spinning. Therefore, the teacher asked each child to design their own spinning top that might spin the longest. Each child sketched a design (i.e., an artefact) and the teacher interviewed the children to evaluate their understanding of the scientific concepts. Next, children created real spinning tops (i.e., more artefacts) based upon their design sketches to test whether their spinning tops met their predictions, which was another opportunity for the teacher to observe and evaluate the development of inquiry skills.

CONCLUSIONS

The development of children's STEM competences will help to adequately prepare them for the challenges of a society driven by science and technology (National Research Council, 2011, 2012). In this study, we used a collaborative action research approach to design, plan, and implement PBI in STEM teaching in two preschools. The purposes of this study were to support the children's skills and knowledge in STEM and to improve preschool teachers' abilities to plan and integrate STEM teaching in their teaching strategies. The STEM curriculum and PBI practices implemented in this study were regularly reviewed by the action research team to ensure their quality. This study is our first step in documenting PBI in STEM teaching with young children. Our findings are valuable for other scholars and preschool educators who are interested in implementing PBI in STEM teaching, and we provide several suggestions.

First, we suggest that teachers who have an interest in conducting PBI in STEM teaching participate in a research team to gain the necessary support from relevant professionals. STEM education is a new educational trend; PBI is a new teaching approach; and most preschool teachers are unfamiliar with and uncertain about the implementation of STEM teaching and PBI. Thus, preschool teachers must be mentored by researchers to help them overcome any difficulties that they may encounter. Therefore, assistance from a cooperative action research team can be crucial for preschool teachers who have just begun to conduct PBI in STEM teaching.

Second, scaffolding strategies are key for successfully implementing PBI in STEM teaching. The results of our study indicate that young children often do not have sufficient ability to explore STEM projects (e.g., to test their predictions) independently and that teacher guidance was needed to advance their level of scientific inquiry. Questioning was the major scaffolding strategy we observed in this study. Teachers can refer to the questioning strategies documented here and apply them to their STEM teaching contexts as required.

Third, teachers should vary their activities in response to children's STEM exploration needs. In this study, PBI was conducted in large groups, small groups, and at learning centers. In large groups, teachers offered opportunities to children to discuss their problems, interests, and predictions to advance their follow-up exploration. In small groups, children engaged in discussions and cooperated with each other to conduct various investigations to verify their predictions. At learning centers, children were allowed to explore their ideas at their own pace and in their free time. Therefore, the daily school schedule must accommodate a range of learning activities so that children can engage in various types of learning and in-depth exploration.

Fourth, the professional development of preschool STEM teachers should begin with undergraduate teacher education programs. The Early Childhood STEM Working Group (2017) recommended that preservice early childhood programs and teacher accreditation requirements should include STEM teacher training to ensure that professionals are well equipped to conduct high-quality STEM teaching in early childhood education. The preschool teachers who participated in this study reported an increased level of self-esteem and confidence in conducting STEM teaching in their classrooms after receiving relevant training. These teachers understood that STEM education can be integrated into early childhood classrooms. Thus, with appropriate training and sufficient experience, teachers can gain the knowledge, self-efficacy, and confidence required to conduct PBI in STEM teaching. Consequently, undergraduate teacher education programs should include courses that provide student teachers with theories, methods, and practical experience regarding the implementation of STEM education in preschool settings. On-site support and monitoring are also highly helpful for student teachers in the process of developing STEM competence.

Fifth, STEM education in early childhood is a suitable domain for future exploration. A limitation of our study is the inability to generalize across contexts since the participants are limited. The participants of this study were from private preschools in urban areas in which children are mostly from middle and high socioeconomic status families. Studies that explore the implementation of STEM education in various preschool settings (e.g., public, urban, rural, and suburban) and with more diverse students are needed. In addition, we provided ongoing support to teachers through regularly classroom visits, observations, and discussions. Without this support, teachers might have had difficulty implementing a PBI approach to STEM education. Thus, future research might investigate which supports are most beneficial for teachers learning to employ PBI in STEM.

In conclusion, this study shows when teachers purposefully nurture curiosity and support learning, children can meaningfully engage in activities that involve inquiry and STEM learning. The themes of

STEM learning in this study were based on the questions and observations generated by participating children according to their interests. Participating children appeared enthusiastic about STEM activities, exhibited an appropriate understanding of STEM concepts, and articulated questions related to the conducted STEM activities. Our findings also suggest that PBI in STEM teaching can be successfully integrated into preschool curricula. If appropriate scaffolding strategies are adopted, children can engage in STEM activities in a well-planned, stimulating, and age-appropriate learning environment.

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