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Outcomes of an integrated STEM with design thinking module on preschoolers' engineering practices

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Abstract

Research indicates that utilizing engineering design processes such as design thinking (DT) to integrate science, technology, engineering, and mathematics (STEM) disciplines yields positive outcomes. However, there is limited study on the effects of STEM education on preschoolers' engineering practices. This case study evaluation examined the outcomes of an integrated STEM with DT module on preschoolers' engineering practices in a private preschool in Malaysia. Two preschool teachers facilitated the learning of twenty preschoolers in two classes daily over four weeks. Data was collected through interviews and direct classroom observations, including fieldnotes, students' artefacts, photos, voice, and video recordings. The qualitative data were analyzed inductively through thematic analysis. The findings indicated that the preschoolers engaged in numerous engineering practices while they actively participating in learning tasks. During their efforts to solve problems using DT process, they showed compassion for the characters in the stories and successfully defined the problem. The findings also highlighted the preschoolers' ability to design and sketch their ideas. They demonstrated proficiency in constructing, testing, analyzing and evaluating their designs, as well as generating ideas to improve them and solve problems. Additionally, the results provided evidence that the engineering design process fosters collaboration and communication. Through iterative testing and modification, the preschoolers exhibited persistence and very positive learning dispositions.

Keywords: design thinking, early childhood education, engineering design, STEM education

INTRODUCTION

Insights from McKinsey and Company (2020) and OECD (2018) highlight a severe shortage of science, technology, engineering, and mathematics (STEM) graduates to meet the global industry demands. Reports indicate that graduates often lack the essential skills required by the industry (World Economic Forum, 2020).

Consequently, many countries around the world have put STEM education into their national education policy and developing the students' scientific literacy and STEM skills is one of the important goals. Research in the last decade has shown that STEM curriculum or programs produce good outcomes in students' 21st century skills (Asigigan & Samur, 2021; Benek & Akcay, 2022; Chang et al., 2021).

Integrated STEM Education

As interest in STEM education has grown, many scholars have emphasized the importance of integrating STEM disciplines and encourage educators to embrace integrated STEM education. Studies have shown many diverse benefits of an integrated curriculum (Drake & Burns, 2004; Drake & Reid, 2018, 2020). Many advocates for the use of the engineering design process to integrate STEM disciplines contextually (Cook & Bush, 2018; McCurdy et al., 2020; Moore et al., 2015). The iterative and reflective practices in the engineering design process not only develop students' essential 21st century skills (English, 2018; Johnson et al., 2015) but also provide opportunities for them to practice the engineering practices (Fan & Yu, 2017; Sanders, 2008).

Design thinking (DT) is a systematic engineering design process in which students solve real-world

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Contribution to the literature

- The findings have implications for the design, development, and implementation of STEM education in early childhood education.
- The study provides an exemplar module that can support preschool teachers in implementing a student-centered STEM program.
- The outcomes also provide evidence of preschoolers' ability to think and act like engineers.

problems through the five stages: empathy, define, ideate, prototype, and test (English, 2019; Fan & Yu, 2017). According to Cook et al. (2020), the inclusion of the empathy stage in DT distinguishes it from other engineering design processes. This stage allows students to focus on understanding the needs of the people for whom they are designing solutions, and such an emotional connection serves as a powerful driving force. DT process also encourages students to learn, think critically, collaborate, and innovate. It nurtures them to become creative problem solvers and develop the necessary 21st century skills (Li et al., 2019). As revealed in English's (2019) study, young children can frame the problem, generate ideas, design and construct, test and reflect, redesign and reconstruct during the design challenge project. It is no longer just about acquiring knowledge but also about applying knowledge and skills to real-life situations (Simeon et al., 2020).

Early Engineering & Design Thinking in Early Childhood Education

Studies have found that children as young as four to six years old exhibit early engineering behaviors and thinking (Ata-Akturk & Demircan, 2021; Dorie et al., 2014). Some researchers advocate exposing preschoolers to engineering early and developing early engineering curricula, which were found to produce positive learning outcomes (Bagiati & Evangelou, 2016; Cunningham et al., 2018; Dubosarsky et al., 2018). Preschoolers can identify problems, set goals, design and test solutions, collaborate with others, and apply each other's ideas in solving problems (Ata-Akturk & Demircan, 2021; Bagiati & Evangelou, 2016). In fact, Forbes et al.'s (2021) study of children aged five to seven using DT to learn STEM conceptual knowledge and competencies found that the children demonstrated capabilities in problem-solving, collaboration, communication, critical thinking and creative thinking skills.

On the other hand, researchers express concerns regarding teachers' limited experience in facilitating engineering design-based activities (McFadden & Roehrig, 2019). Campbell et al. (2018) found that the preschool teachers' STEM practices were primarily observed during mathematics and science lessons, with little evidence of integrated teaching approaches. However, these teachers' classroom practices are crucial for scaffolding students' STEM learning (Giamellaro & Siegel, 2018; Hsiao et al., 2022) and their positive attitudes toward STEM education are critical for the successful implementation of early years curriculum (Bagiati & Evangelou, 2015).

Hence, building the teachers' capacity in integrated STEM education is crucial. Boice et al. (2021) found it effective when teachers experienced integrated STEM activities firsthand and then worked collaboratively to design and implement an integrated STEM curriculum. These teachers, especially those teaching in early childhood education (ECE), need professional development in effective STEM pedagogy (Alghamdi, 2023; Park et al., 2017), high quality STEM programs (DeJarnette, 2018), and opportunities to teach STEM with an established support system (McWayne et al., 2022). According to Cunningham and Carlsen (2014), teaching engineering practices is an uncharted territory to most teachers as they were not trained engineers, and they need to acquire the skills to facilitate the student-centered learning tasks. Even when these ECE teachers showed positive dispositions and self-efficacy after attending a professional development with resources support and mentoring, DeJarnette (2018) found that STEM activities were not incorporated into the classrooms regularly. Thus, to support the preschool teachers in embracing the pedagogical transformation, having an exemplar integrated STEM module would be helpful (Ata-Akturk & Demircan, 2017; Shernoff et al., 2017).

Engineering Practices

Researchers and educators believe that using engineering design process in integrated STEM education helps students develop engineering practices that benefit their STEM learning and their lives (Fan & Yu, 2017; National Science Teachers Association [NSTA], 2014). The engineering practices involved in the inquiry and problem-solving process include questioning, problem scoping, analysis, computational thinking, designing solutions, communicating, and reasoning (Milford & Tippett, 2015; NGSS Lead States, 2013). The iterative process in DT further develops students' collaboration and communication skills as they work in groups, fostering their persistence in problem-solving. Developing preschoolers' STEM learning dispositions is a goal in many countries' STEM education (Kementerian Pendidikan Malaysia [Malaysia Education Ministry], 2018; Murphy et al., 2019). Therefore, the lead researcher

Table 1. Lesson outline corresponding to design thinking stages in each challenge

Lesson	DT stage	Description
1	Empathy	A real-world problem will be shared with children. A story will be told (through video, storytelling, &/or role playing) to evoke emotional connection with children.
2 & 3	Define	The problem will be further defined. Due to children's limited knowledge and experience, prior-knowledge activities will be conducted in these two lessons.
4	Ideate	Children will brainstorm solutions to the problem and draw or sketch the solution (idea or model) they believe is most feasible.
5	Prototype	Children will build the prototype based on their drawing.
6, 7, & 8	Test	Children will test their prototype, attempt to fix any issues identified during testing, & seek feedback from others to further improve the product. They will then present the final product to others.

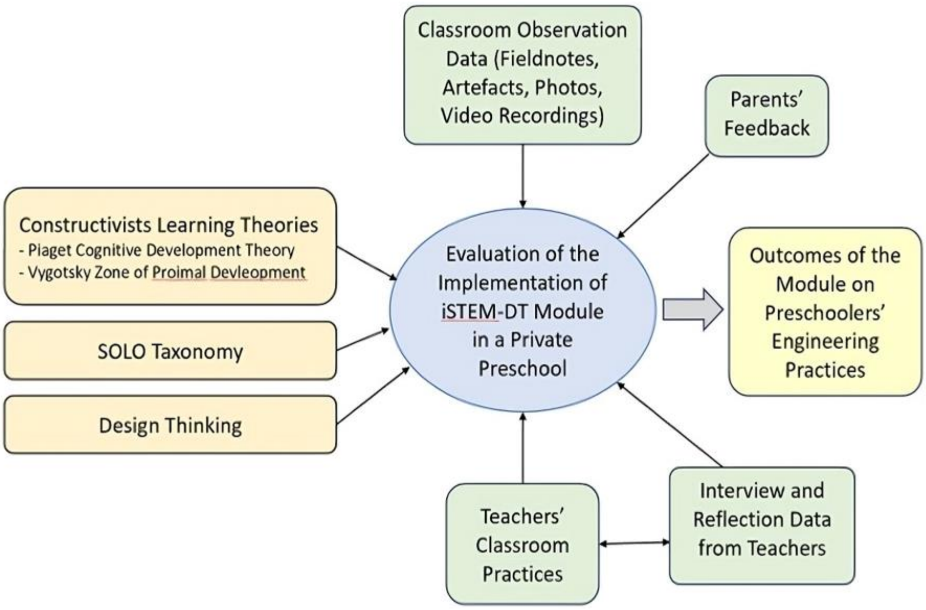

Figure 1. Conceptual framework of study (Source: Authors' own elaboration)

of this study has developed an integrated STEM with DT (iSTEM-DT) module for the preschoolers to develop their engineering practices.

Theoretical Framework

This iSTEM-DT module is grounded in constructivist theories, with the instructional design that utilizes Biggs' (1996) structure of observed learning outcome (SOLO) taxonomy to hierarchically structure the learning objectives.

The lesson plan explicitly describes instructions for teaching-learning tasks and assessment against success criteria (Biggs, 1996). Preschoolers will engage in two real-world problems, namely river crossing challenge and river cleaning challenge, collaborating using DT process. **Table 1** outlines the lessons for each challenge, each lasting an hour.

A preliminary study was conducted, and minor changes were made to the instructional materials, and the implementation process was refined (Ho & Pang, 2023). The modules received positive feedback from five STEM experts during the review process.

The conceptual framework of the study is illustrated in **Figure 1**. Throughout the implementation of iSTEM-DT module, the study aims to answer this research question, "what are the effects of iSTEM-DT module on preschoolers' engineering practices?"

METHODOLOGY

This is a single case study evaluation that adopts a social constructivists worldview (Yin, 2014). It employs an exploratory approach to investigate the preschoolers and teachers' interactions and behaviors in a natural classroom setting. The study aims to understand the multifaceted effects of implementing iSTEM-DT module on preschoolers' engineering practices. It achieves this by collecting rich and diverse qualitative data from various methods and sources to address the research questions of the study.

Participants & Procedure

This case study was conducted in a private preschool in Selangor, Malaysia, selected through purposive sampling to fulfil specific criteria: two classes of six-year-old children, two teachers with a diploma in ECE, and a willingness from the preschool to implement iSTEM-DT module daily for four weeks. The preschool caters to middle-income families and uses English as the primary

Table 2. Profile of teachers

Teachers	Qualification & experience in ECE
Teacher Mia	Diploma in ECE, degree in business & technology, three years working experience in ECE, & 30 years old
Teacher Ivy	Diploma in ECE, A-level equivalent, five years working experience in ECE, & 27 years old

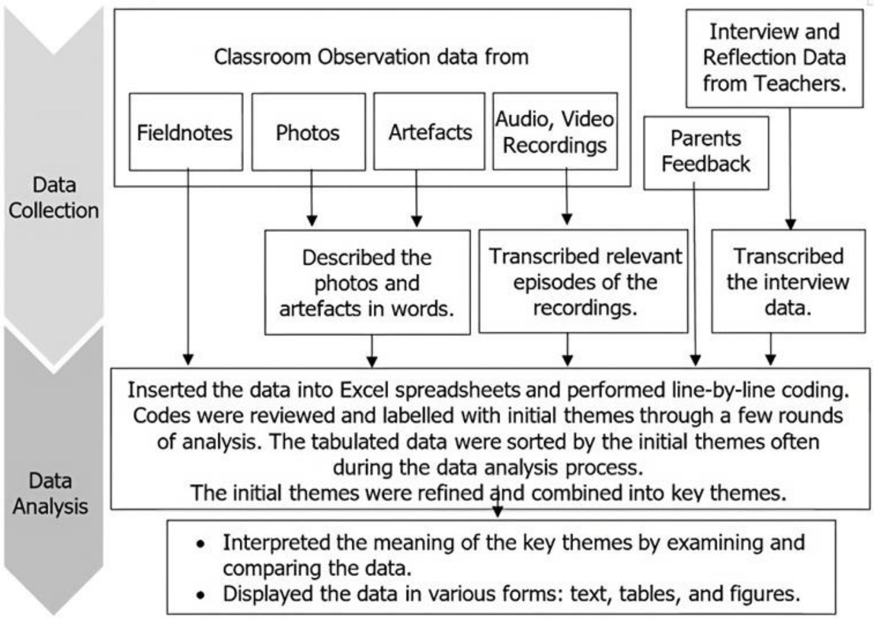

Figure 2. Data collection and analysis of this study (Source: Authors' own elaboration)

medium of instruction. Twenty preschoolers were selected based on convenience sampling, as they needed to attend iSTEM-DT classes in the afternoon during the module implementation. During the preliminary study, it was determined that it was more effective for the preschoolers to work in pairs than groups of three (Ho & Pang, 2023). Consequently, the teachers organized the preschoolers into pairs and assigned them to the two classes. The preschoolers attended either the 2.30 pm to 3.30 pm class or the 3.30 pm to 4.30 pm class daily. **Table 2** provides the profile of the two teachers.

Informed consent was sought from the adult participants during a meeting that provided an overview of the study. Following this, another meeting was held with the parents and their participating children, informing them of the confidentiality and anonymity commitments made by the researcher (Mertler, 2016). The lead researcher used simpler language and showed photos to explain the purpose of the study and what the preschoolers would be doing. She further explained that photos and videos would be taken during the activities, and she might ask them questions during or after the class, but they could stop or leave the classroom if they wanted to. This ensured they were aware of the option not to participate and not to be forced to take part due to power relations between adults and children (UNICEF, 2013). The presence of the parents allowed them to explain further to their children, and consent was obtained from all the children. During the module implementation, only one child left the classroom once when she cried and requested to leave.

Data Collection

The data for this case study evaluation was collected from multiple sources using various methods. The lead researcher conducted direct classroom observation and collected fieldnotes, students' artefacts, photos and video recordings as evidence of the participants' behaviors and practices during iSTEM-DT module implementation. This included observing the preschoolers' engagement during the activities, their interactions with others, and the questions they asked, as well as their responses to questions from others. The entire hour of each lesson for both classes was video recorded, allowing the lead researcher to view them multiple times with different focus (Blikstad-Balas, 2017). After every lesson, both teachers sat down together with the lead researcher, and their reflection was audio recorded. After the module implementation, one-to-one interviews were conducted with the teachers, and all the parents shared their feedback via Google Form. The use of triangulation of data from multiple methods and sources has increased the credibility of the study. **Figure 2** illustrates the data collection and analysis process of this study.

The lead researcher functioned as a participant-observer, providing daily support and confidence to the teachers. Her consistent presence during lessons helped them become comfortable with her observations. She spent two hours every afternoon interacting with the participants throughout the four weeks of module implementation, establishing a trustful relationship. This relationship enhances the credibility of the case study evaluation (Lincoln & Guba, 1985). To ensure dependability of this case study evaluation, a procedure was implemented to disregard the video recordings of the first two lessons of each class due to Hawthrone effect during the data collection stage (Connelly, 2016).

Data Analysis

The qualitative data collected were analyzed inductively through thematic analysis process. The lead researcher was responsible for collecting, transcribing, and analyzing the data throughout the study, which immersed her in the data and provided depth and breadth to the rich data collected (Braun et al., 2014). The collected data were stored in folders with dates, each containing more than a hundred files of photos, audio and video recordings. The audio and video recordings were transcribed into Microsoft Word files. All transcribed data and fieldnotes were then inserted into Excel spreadsheets using the In Vivo Coding method. This method allowed the original voices of the participants to be retained (Saldana, 2016). Analysis of 5,000 plus lines of data began with each line being assigned a code. These codes were reviewed and labelled with initial themes; when the lead researcher performed several rounds of analysis to identify patterns and connections. The tabulated data, sorted by the initial themes, were then refined and combined into key themes that explain the outcomes of iSTEM-DT module on the preschoolers' engineering practices.

To address the research question, the lead researcher explored descriptive data interpretively, and employed reflexivity when analyzing the data. Photos of participants and the artefacts served as evidence to support emerging themes. Detail descriptive data, as presented in the findings below, enhances the transferability (Lincoln & Guba, 1985).

RESULTS & DISCUSSION

This study demonstrates how preschoolers can engage in the engineering design process and apply their STEM knowledge and skills to solve two real-world problems. The evidence of their engineering practices is discussed below, following DT process and learning dispositions.

1. Empathy and defining problem
2. Designing, sketching, and ideating
3. Constructing
4. Testing, making improvements, and problem-solving
5. Persistence
6. Collaboration and communication

Empathy & Defining Problem

ISTEM-DT module began with the first lesson on empathy, allowing the preschoolers to empathize with the people in the stories. They found it easy to define the problem and articulate their point of view. For instance, they expressed concerns such as

> "Ramaya needs to cross the river safely."
>
> "[They] need to go to school every day."
>
> "They need to go to hospital."
>
> "Mr. Asha needs to fish in a clean river."
>
> "He needs to sell fish."

Data collected further shows that all the children understood the presented problems and wanted to build something to help Ramaya and Mr. Asha. For example, Farah said,

> "[I want to] help Mr. Asha … collect the rubbish."

Sam explained,

> "Because at Makoko, there is lots of rubbish. Water is dirty. Fish died."

Wise defined the consequences of the problem, saying

> "Fishermen cannot go to the market. They have no fish to sell."

Similarly, Kai responded,

> "No fish to sell, no money."

The excerpt below illustrates evidence of their ability to define the problem and their compassion.

> Wade: Mr. Asha is angry.
>
> Teacher Ivy: Why?
>
> Wade: Angry at the rubbish.
>
> Ara: Angry at those who simply throw rubbish.

The above findings indicate that exposing preschoolers to DT enables them to consider the ethical aspects of solutions or actions and how these might impact others or the environment (Lippard et al., 2019). This aligns with Cook et al.'s (2020) study, which highlights the Empathy stage as one of the most crucial elements in an integrated STEM curriculum.

However, the preschoolers did not ask additional questions to find out more information about the problems, except for Zoe. She asked,

> "Can pick them [the rubbish] up with hands?"

to which teacher Mia replied,

> "No."

Zoe then asked,

> "Why cannot?"

Teacher Mia explained,

> "Is not it dirty? Your hands would be very smelly."

According to Park et al. (2018), preschoolers' definition of engineering problems was rather intuitive, mostly revolving around their daily experiences. Sometimes, young children would express their desires to do something rather than to solve a problem, as seen in English's (2019) study. The study found that more than half of the grade-four students proposed shoes designs that they desired without identifying the problem that they could solve.

Designing, Sketching, & Ideating

The collected data revealed the preschoolers' ability in designing and sketching their ideas. Some of the sketches were simple and could be interpreted by the teachers, but some were difficult to understand. This finding on the diverse quality of the sketches is echoed by teacher Mia, who said,

> "I was having a hard time trying to understand what he [Finn] drew".

According to McFadden and Roehrig (2019), When the sketches were difficult to interpret, it could be an issue for others, including partners or other group members, to understand and collaborate effectively during the building process, as well as difficult for others to contribute ideas for the design.

Some sketches can be easily comprehended the moment the preschoolers give a simple explanation. For example, Farah and Iris explained their sketch to the lead researcher,

> "When the boat moves, the net will collect the rubbish."

They sketched a boat made of aluminum foil hauling a net below it. The artefacts revealed that the sketches drawn by the preschoolers looked like the physical model built or were representative of it. The lead researcher reflected,

> "It [the prototype built] was exactly what they drew in the booklet".

This finding suggests that preschoolers can sketch the design ideas they have in mind. Examples of sketches drew by the preschoolers are shown in **Figure A1** and **Figure A2** in **Appendix A**.

Teacher Mia shared her observations on how the preschoolers were copying ideas from their friends when needed,

> "Farah's design was using net, with no holder. So, when she saw Kai group's design, she said she wants to add a holder."

This finding echoed Park et al.'s (2018) study, which found peers influenced the design ideas in the classroom.

In addition to the positive effects seen above, fieldnotes captured the teachers' consensus when the lead researcher reflected on the effects of the first challenge the preschoolers experienced with the normal arts and crafts lessons in the normal classroom.

> "In school, you have carried out many creative arts and crafts work with the children. The difference of this type of project is that the children must design for functionality … not to design to make it looks nice aesthetically. Many children can design a boat that looks beautiful, but it may not serve any purpose."

The above finding is supported by the reflection shared by teacher Mia,

> "She [Amy] already drew her sketch, but she was focusing on the artistic aspect. She drew a tree."

> "Kathy's design is more on arts and crafts. Her boat has no function, cannot work."

The boat design by Amy's group used lots of sponges, which has no function in solving the problem presented to them. They explained that the sponge was to act like the carpet on the boat, to provide comfort to the passengers. Thus, the findings reinforce the importance of engineering design process in STEM education for young children. It truly trained them to create purposeful sketches, rather than just drawing "attractive drawings" (English, 2019).

Despite the above challenges, all groups managed to change and improve their designs after a few iterations. It indicates that when preschoolers engage in design-based STEM programs, they can define the problem, brainstorm possible solutions, explore available materials, sketch ideas, build model and modify sketches (Ata-Akturk & Demircan, 2021).

Constructing

In addressing the research question, "What are the effects of iSTEM-DT module on preschoolers' engineering practices?", the collected data further revealed the preschoolers' ability to construct. Many managed to construct their prototypes according to what they had sketched. Examples of their sketches along with the prototypes built can be found in **Figure A3** and **Figure A4** in **Appendix A**. The data showed that all of them managed to modify their prototypes after testing. The lead researcher observed that most of them were quite confident when constructing their prototype, even though they displayed different levels of mastery. As they constructed, they practiced fine motor skills such as cutting, threading, holding and taping.

Additionally, the data revealed that the idea the preschoolers had in mind when they first started building may change as they realize potential problems in the design or when they discuss or are challenged during the construction process. The data further showed that this often happened when the teachers facilitated the learning tasks, asking them questions about their design as they constructed. Consistent with Park et al.'s (2018) study, the changes made by the preschoolers were usually a small part of the whole design, and not a dramatical change in the design.

During the construction of the prototypes, the lead researcher and teachers observed a common challenge among the preschoolers when they tried to join the pieces together. Most of them tried to use tape for this purpose. However, they encountered difficulties when the strip of tape was too long, as it became entangled with itself. Additionally, they often taped it only once and did not press it down to ensure that it was securely attached. As a result, the lead researcher heard Teacher Ivy reminding the preschoolers to tape it many times or wrap it around many times, just to make sure that the tape could hold the items tightly.

The data also revealed that the preschoolers needed help when building the prototypes, and that sufficient time must be given for this task. Teacher Ivy remarked,

> "[We] need to help them a lot,"

while Teacher Mia noted,

> "They took a long time to build."

According to Park et al. (2018), preschoolers learn at different paces, so teachers need to provide them with enough time to complete their tasks when engaging in design-based STEM programs.

Testing, Making Improvements, & Problem-Solving

During iSTEM-DT module implementation, the preschoolers were given opportunities to test the prototype they had built. This process was iterative, involving testing, modification, and further testing until the prototype met the design requirements. The data collected revealed that this stage was crucial, as it allowed preschoolers to experience failures. Teachers asked questions to help them analyze and evaluate what had happened, and they scaffolded the preschoolers to propose modifications to their prototypes. Excerpts below illustrate Henry applying his evaluating skill by keeping the same design on both cups when he attempted to improve the design, rather than making a dramatic change (Park et al., 2018).

> Teacher Ira: Your one cup can only get one piece of rubbish. How can you make it get more than one?
>
> Henry: Oh … can add one more cup.
>
> Teacher Ivy: How many holes do you want to add to this cup?
>
> Henry: Two also.

In river crossing challenge, two groups of preschoolers had designs with the same flaw: a weak joint between two pieces of board or plates. This design flaw caused the bridge to collapse in the middle during testing. With some guidance from the teacher, both groups managed to improve their designs by adding another plate or two overlapping pieces of board to their initial design.

In another instance, the lead researcher observed Amy and Issac identifying the cause of their failure in their boat design. The prototype they built had a hump–an uneven space–intended for placing weight during testing. This hump was the result of the edges of two foam plates being joined together. They decided to remove the plates, replace them with a plastic container on top of the bottles, and add a plastic board on top of the container. The improved design successfully passed the test.

During the testing of river cleaning challenge, we continued to notice preschoolers enacting the engineering practices during the iteration process of testing and modifying. In the second project for iSTEM-DT module, the increased level of difficulty made the preschoolers experience struggles and failures compared to the first project. Many of them experienced a few rounds of testing and modification before they could pass the test successfully.

Another piece of evidence of preschoolers enacting the engineering practice of testing and making improvements was demonstrated by Wise and Sara. They had tested their prototype, which used two bottles as handles at the sides. However, after a quick test, Wise said,

> "I've got to do it again!"

They then discussed and discarded the two bottles, secured the plates with chenille stem (acting like twisted wires), and attached popsicle sticks as the handles. Wise and Sara then carried out another test. Unfortunately, it failed to scoop out the rubbish effectively again. Wise evaluated their design and told teacher Ivy,

> "The handle is not strong enough."

as he pointed to the part of the handles that needed to be strengthened.

Both Wise and Sara modified their prototype again, and Wise was heard explaining to teacher Ivy that,

> "The ice-cream sticks were broken … so we changed to chopsticks."

He also explained that they cut the front part of the plate away so that it can work like a dustpan. They finally succeeded in building a sieve that can filter the rubbish from the water. Examples of their design changes are shown in **Figure A5** in **Appendix A**.

One of the groups that faced tremendous challenges during testing was the group Farah and Iris. They started off by constructing this net around a ring made of chenille stems. However, it was too flimsy and thus failed to collect any rubbish during the testing. They decided to solve the problem by using a plastic container as the frame, by cutting out the middle section, and attaching two handles at the sides. Unfortunately, the improved prototype failed again. The handles were not secured firmly, and one of the handles came off and could not be used anymore. They tried to repair their prototype, and with some guidance from teacher Mia, they opted for a simpler design, which worked in the final testing. Examples of their prototypes are shown in **Figure A6** in **Appendix A**.

Beside Farah and Iris's group, the other group that faced repeated failures is group Sam and Sofie's group. Their prototype, built mostly with bottles and cups, was secured together with cling wrap film and failed during testing. The handle almost came off in the first attempt, and they struggled with two other handle designs. Finally, they discovered that even without the handle, they could still hold the whole prototype by the hole created earlier, with their fingers positioned at the hole, and it worked during testing.

The above findings indicate that preschoolers think and work like little engineers; they can practice the iterative process of testing and modifying and apply basic science process skills as they problem-solve. This is consistent with other studies involving preschoolers in design-based STEM curriculum (Ata-Akturk & Demircan, 2021; Park et al., 2018; Yalcin & Erden, 2021), which found that young children can generate ideas, work with available materials, test and modify their models, and solve the issues they face.

Persistence

Persistency is an important attitude necessary in engineering design process. The evidence described in the earlier sections reveals that these young preschoolers were persistent when working on their projects, attempting to make their prototypes work even after experiencing repeated failures during the testing process. For example, Sam and Sofie's prototype underwent five design changes. At one point, Sofie gave up and replied to Teacher Ivy's question about how to improve it,

> "Make a new one."

Similarly, Sam also shared his frustration with the lead researcher. Fortunately, they persisted and finally managed to produce a working prototype.

The lead researcher also noticed persistence in Farah and Iris when they were constructing their prototypes. Although it may seem simple with only three different prototypes built, the first prototype required a lot of patience and fine motor skills when they tried to thread and sew the net. In building the second prototype, they needed to attach the flimsy net onto a soft frame. Unfortunately, they had to discard the idea and worked on a fresh idea after the second prototype failed during testing.

The lead researcher empathized with Farah and Iris's frustrations and recognized the growth mindset they displayed during the engineering design process. The evidence below was captured in Teacher Mia's interview and researcher's fieldnotes.

> For Farah and Iris, they really did not give up. Even though their prototype was damaged, all broken, the handle broken, the plate broken, but they keep fixing it.
>
> In their second trial, they added a frame to strengthen the design, and failed again. But they did not give up. Even when they were building it, they needed to thread strings to sew the net together, which takes a lot of time, but they were patiently doing it and they have good motor skills. When asked, how do they feel when their prototype failed, they replied, 'It's OK, we can try again.'

The lead researcher managed to ask many of the preschoolers about their feelings when their prototypes failed during testing, and how they responded to this feeling. For example, Sam and Luca told the lead researcher,

> "It's easy, if we fail, we will make it again."

They have this growth mindset all the time. When they were sketching, Luca said,

> "Never mind-lah, we sketch first, if my idea cannot work, we use your idea, ok?"

and Sam replied,

> "OK."

When teacher Mia asked Issac and Amy if they were afraid of failure during testing, Issac shook his head while Amy replied,

> "No, I try again."

The above is consistent with the reflection that teacher Mia shared with the lead researcher,

> "The children did not give up when their prototype failed … many showed persistence when doing the projects."

Studies have shown that a STEM curriculum that uses engineering design process develops students' perseverance and nurtures their positive attitudes towards STEM (Allen et al., 2019; Park et al., 2018). They are not afraid of failures and possess a growth mindset (Dweck, 2012).

Collaboration & Communication

The effects of iSTEM-DT module on preschoolers' engineering practices are evident in their collaboration and communication skills. The collected data also revealed that, during the module implementation, these preschoolers actively engaged in DT process, collaborating and communicating with their peers and teachers.

As the preschoolers were paired up to work on the projects, this study gathered ample evidence of the synergy between them when collaborating. For example, the lead researcher noted on the fieldnotes that Issac yielded to Finn, which aligns with Teacher Mia's observations,

> "He sacrificed-lah, let Finn build Finn's design."

The data revealed that many of these preschoolers were highly accommodating. For instance, whenever Fabian suggested adding new elements to the design, Kai would respond with

> "OK-lah."

and offer his support. Similarly, fieldnotes showed Issac yielded to Amy and supported her idea, even though both initially insisted on building their own designs. The lead researcher also noted that Sara collaborated effectively with Wise, as she was heard telling Teacher Ivy,

> "I follow Wise's instruction."

Ara was observed playing a supportive role; data indicated that she was comfortable working with someone else's idea and was willing to collaborate with Wade to build the prototype.

When preschoolers collaborate, they listen, communicate, take turns, share ideas, and strive to problem-solve with a common goal. For instance, the lead researcher pointed out to the teachers that,

> "Mary and Henry are working together, not individually. They keep on trying their ideas with the materials they want to use together and discuss as they do it … for a long time."

The teachers shared their observations on the preschoolers' behaviors in this aspect below:

> Henry is like not able to choose the right item, and Mary helped him, she suggested ideas… but their teamwork was good.

> Farah talked a lot, telling Daisy what to do.

> Issac and Finn agreed to try out Finn's idea first. If it failed, they would then try out Issac's idea. I am glad that they could discuss and did not fight or argue over it.

The lead researcher inferred from her observation that the effects were greater and more visible in group Fabian and Kai, as they were the only ones of the two groups that had the same partner for both projects during iSTEM-DT module implementation, hence having a longer time to work together. The collected data revealed that they worked very well together; often when one person talked, the other person would listen, and they would also demonstrate their idea to each other so that they could understand better. Teacher Mia commented,

> "You see them talk talk talk all the time … and sometimes even whisper to one another."

It became evident that their collaboration and communication improved in the second project, and they even expressed a desire to work as a group in the future. According to Teacher Mia, Fabian shows good improvement in terms of collaboration, which is consistent with the lead researcher's observations. Below are the excerpts.

> During the first project, he was very quiet and very dependent on Kai. We see their roles switched and equal now, with neither being more dominant than the other. Now, Fabian knows more about one thing, Kai knows more about another. There was this one time when there was a lot of discussion going on. They really poured their heart into it, even when they were sitting, they were still discussing their designs.

Sometimes, conflicts arose during the collaboration. Data collected shows that some of these preschoolers were inexperienced in resolving conflicts. For example, in the first project, Fabian almost cried after they agreed to use Kai's design for their group. He was fine after the teacher's intervention, but then at the end of the lesson, he proposed a better idea to resolve their conflict, i.e., to combine both of their design ideas. Teacher Mia reflected,

> "It was a brilliant idea … Fabian's design was using lots of popsicle sticks, combined with Kai's design on plastic boards; it would really make a strong bridge."

The data also revealed some preschoolers who were more passive partners during collaboration. For example, Luca was actively building the prototype while Zoe watched or helped a little. On the other hand, collaboration was found to be dependent on the partner the preschooler was paired with. Amy, for instance, collaborated well with Issac on the first project. However, when she paired with Harry, the lead researcher noticed that she did not allow Harry to build the prototype. This may be attributed to Harry's personality traits as he is quiet and a passive learner. Thus, the lead researcher intervened to encourage more collaborative learning.

Similar group dynamics were observed in Yliverronen et al.'s (2018) study on the nature of preschoolers' collaboration. For these young children, the concept of working together to solve a problem without any help from the adults was new. It was found that in each group, different children assumed different roles, such as leader, follower, or observer. Thus, teachers play an important role in facilitating learning in groups, and the concrete materials used in the activities support collaborative learning.

Positive Learning Dispositions

Overall, the data collected indicates strong evidence of the preschoolers displaying positive learning dispositions during the learning process. The lead researcher observed that almost all the children showed great interest in the learning tasks, responded actively to the questions asked by teachers, engaged actively in the activities, and demonstrated responsibility in the learning process.

The collected data further revealed that the preschoolers were eager to attend the next class, as seen in Issac's response when Teacher Mia told him at the end of the class on Friday that they would continue the testing next week. He replied,

> "Oowwh … I want to test tomorrow. Why cannot we test tomorrow?"

This is consistent with the classroom observation data collected by the lead researcher. For examples,

> "Farah is very curious … when the teacher says something, she is very responsive in the class."

> "Harry is very motivated to do the activity, he wants to participate, wants to build things."

> "Daisy and Farah were quite confident. They build (their bridge) with one row of tissue rolls, then they added the 2nd row and finally ended with three rows … they did it with excellent teamwork."

> "Wise responded well in the class, actively answering questions the teacher asked. Sara is more like a doer. She will 'do' things."

The positive outcome was also seen by Wise's father, who gave feedback in the Google Form survey,

> "It is (yielding) positive results. Wise is more curious… about almost everything!"

This concurs with numerous studies on STEM curriculum that have reported enhanced students' STEM interest, engagement and motivation levels (Asigigan & Samur, 2021; Guzey et al., 2017; Holmes et al., 2021). Such positive learning experiences in the engineering design process could develop how preschoolers think and act like engineers (Lippard et al., 2019). Additionally, it nurtures optimism in children, which includes perseverance and motivation to learn. Through engagement in design-based STEM activities, preschoolers are given the opportunity to learn how to respond to problems and enhance their confidence in dealing with them. According to Katz (2010), STEM education in ECE would provide preschoolers with intellectually engaging and stimulating experiences, giving them an active role, making them take responsibility for their learning, and hence allowing them to achieve their intellectual potential.

CONCLUSIONS

The above findings have implications for the design, development and implementation of STEM education in ECE. With iSTEM-DT module as the exemplar, hands-on experiential training workshops for preschool teachers, and support from the lead researcher through daily discussions and reflections during module implementation, all have helped teachers become more confident in facilitating student-centered integrated STEM learning activities. This has resulted in positive outcomes for preschoolers' ability to practice and develop engineering practices, including defining problems, generating ideas, designing, constructing, testing, collaborating, communicating, and persisting.

However, iSTEM-DT module is limited to two problems or challenges that preschoolers are required to solve. Expanding the module with more real-life problems to allow the preschoolers to engage in such an integrated STEM module throughout the year would enrich the present findings and enhance the trustworthiness of the study. As this study is limited to the effects of the module on the preschoolers' engineering practices, a focus on the teachers' reflecting on their experiences and using these reflections to improve their classroom practices, can be part of the capacity building for these teachers (Boz, 2023; English, 2019; McWayne et al., 2020). The support given by the lead researcher to the teachers throughout the module implementation could be modelled and enhanced. For example, providing the teachers with high quality STEM program (Alghamdi, 2023), implementing a long-term professional development program to support teachers in embracing the changes in their STEM teaching practices (Boice et al., 2021; Way et al., 2022), ensuring all the training workshops are hands-on experiential learning (DeJarnette, 2018; McWayne et al., 2022) and having experts' support throughout their transformative journey (Giamellaro & Siegel, 2018).

In addition, the above results were limited to one private preschool. The effects of iSTEM-DT module could not be generalized due to the limited sample size, convenient sampling of the preschoolers, time and duration of the study. A comprehensive study on a bigger scale, with more preschools, including public preschools, and implementation during the normal school hours as part of the core curriculum, is recommended for the future.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A

This section consists of figures relevant to study, which serve as evidence collected to support findings.

1. Simple sketches, which could be interpreted by the teachers (**Figure A1**).

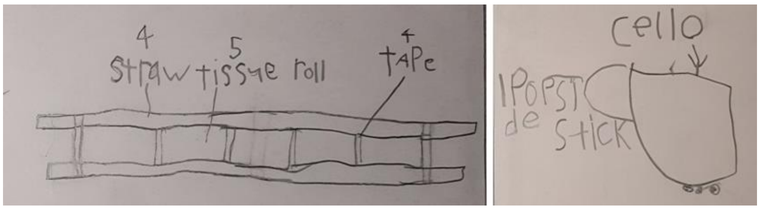

Figure A1. A bridge & a cup design (Source: Authors' own elaboration)

2. Sketches that were difficult for others to interpret (**Figure A2**).

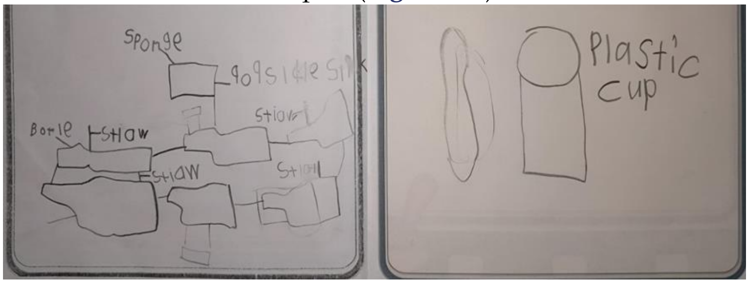

Figure A2. Sketches drawn by Sofie & Sam (Source: Authors' own elaboration)

3. The design ideas sketched by Daisy and Kathy, along with the prototypes shown in **Figure A3** and **Figure A4**. Both figures demonstrate that the sketches closely resemble physical models.

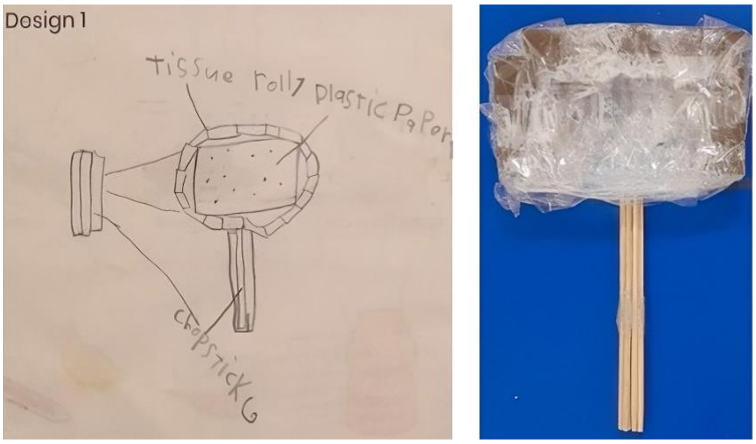

Figure A3. Daisy & Kathy's original design & prototype (Source: Authors' own elaboration)

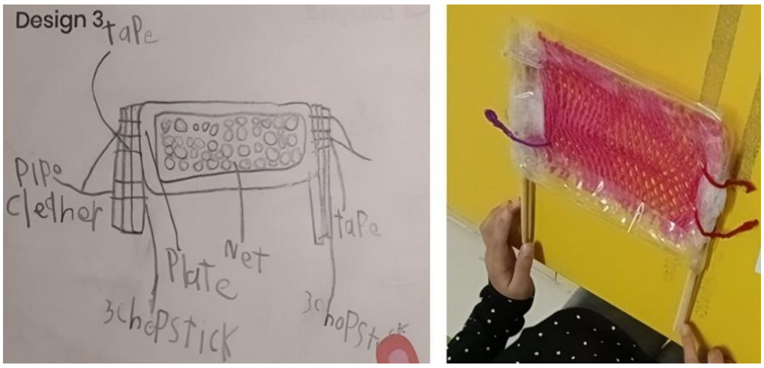

Figure A4. Daisy & Kathy's final sketch & prototype (Source: Authors' own elaboration)

4. Design changes in Wise and Sara's prototype (**Figure A5**).

Figure A5. Design changes in Wise & Sara's prototype (Source: Authors' own elaboration)

5. Farah and Iris's prototypes were very tedious to construct and required lots of patience. **Figure A6** shows the three design changes in their prototypes.

Figure A6. Farah & Iris's prototypes (Source: Authors' own elaboration)