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Facilitator's Scaffolding Strategies in a Design-based Learning Context

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ABSTRACT

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Design-based learning (DBL) is a pedagogy grounded in inquiry towards generating artefacts to solve a real-life issue through an iterative engineering design process. Completing a design task is challenging. Scaffolding is necessary for supporting student learning in a DBL context. However, a review of the literature revealed that there are still significant implementation issues related to scaffolding student learning in this context. The roles played by facilitators in scaffolding student learning in a DBL context are also under-researched. This study aimed to investigate facilitator's scaffolding strategies which could be used to help students integrate knowledge in a DBL context. This study involved a class of 27 Form 1 students in a national school. The students learned how to integrate knowledge from Science, Technology, Engineering, Arts and Mathematics (STEAM) subjects to design and construct a water filter. They were scaffolded by the facilitator throughout the implementation of this design task. Video recordings, student interviews and researcher's notes were used for data collection. Several vignettes were presented to illustrate how these scaffolding strategies were used to help students integrate knowledge. The research findings showed that the facilitator used various types of scaffolding strategies to support student learning based on their emerging learning needs. The scaffolding strategies were categorised into six types in terms of cognitive, linguistic, metacognitive, motivational, social, and strategic scaffolding. This study highlighted how multiple facilitator's scaffolding strategies could work as a system to help students develop a coherent understanding of the design task. This study provides guidance for teachers in pre-designing scaffolding into their instructional practice. This study also opens new lines of research which establish connections between application of scaffolding knowledge integration and interdisplinary learning context.

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1. INTRODUCTION

Scaffolding refers to temporary support provided by more capable individuals to help students move progressively towards independent learning (Maybin, Mercer, & Stierer, 1992). Two broad categories of scaffolds are fixed and adaptive scaffolds (Azevedo, Cromley, Winters, Moos, & Greene, 2005) or hard and soft scaffolds (Saye & Brush, 2002). Hard or fixed scaffolds are static support planned in advance of implementing a lesson (Azevedo et al., 2005; Saye & Brush, 2002). Soft or adaptive scaffolds are dynamic and situational support provided to students based on their progressive development in learning (Azevedo et al., 2005; Saye & Brush, 2002). Adaptive scaffolds are essential in a constructivist learning environment, such as design-based learning (DBL) (English, 2016; Puente, Eijck, & Jochems, 2013a, 2013b).

However, in the research on DBL, the roles played by facilitators are not well researched (Puente, Eijck, & Jochems, 2013a). A synthesis of the existing literature shows that facilitators use six main types of scaffoldings to support student learning: cognitive, linguistic, metacognitive, motivational, strategic, and social scaffolding (Belland, 2017; Belland, Kim, & Hannafin, 2013; Baxter & Williams, 2010; Smit & Eerde, 2013). Yet, there is a lack of research in identifying how facilitators can adopt these different types of scaffoldings in a DBL classroom (Puente et al., 2013a). Furthermore, there are still many open questions about how different types of teacher's scaffolding strategies interact and work as a system to support student learning. This study aimed to close these research gaps by exploring facilitators' scaffolding strategies to help students integrate knowledge in a DBL context.

This study has practical implications on teaching and learning. It can extend facilitators' understanding of students' different learning needs in constructivist learning environments such as DBL. This study can also help facilitators plan different types of scaffolding strategies to cater to their students' diverse learning needs to explore their investigation path. Besides, the research findings can provide an insight into how different scaffolding strategies work synergistically to support student learning in a DBL context.

2. LITERATURE REVIEW

2.1 Types of Scaffoldings

Research on scaffolding student learning in inquiry-based learning environments divided scaffolding into six main types: cognitive, linguistic, metacognitive, motivational, strategic, and social scaffolding (Belland, 2017; Belland, Kim, & Hannafin, 2013; Baxter & Williams, 2010; Smit & Eerde, 2013). Making a distinction between different types of scaffolding does not mean that scaffolding strategies fall neatly into one specific category. Indeed, researchers recognise that students need scaffolding from the cognitive, language, social, and emotional aspects. Cognitive scaffolding helps students construct cognitive structures such as identifying evidence, analysing and interpreting data and, justifying the proposed solution (Baxter & Williams, 2010). It also helps students focus on *"things to consider"* (Belland, 2017, p. 109) when they solve a problem. Cognitive strategies such as highlighting critical features (Baumgartner & Reiser, 1998; Penner, Lehrer, & Schauble, 1998), providing hints (Cunningham & Lachapelle, 2016; Penner et al., 1998) and, unpacking scientific knowledge underlying a design solution can help students narrow down alternatives to focus on a more productive solution (Hmelo, Holton, & Kolodner, 2000). Linguistic scaffolding helps students achieve desired academic language output (Smit & Eerde, 2011). For instance, facilitators help students use correct scientific terminology to explain their design solutions (Puente et al., 2013a), restate their correct utterances and, reformulate their answers using precise terms (Smit & Eerde, 2013).

Metacognitive scaffolding helps students self-reflect on their knowledge and skills and monitor their progress (Belland, 2017). Asking reflective questions (Hmelo et al., 2000; Penner et al., 1998) can trigger students to reflect on their design solutions. Motivational scaffolding triggers students' interest and enhances their motivation to keep them engaged in the activities (Belland, Kim, & Hannafin, 2013). This can be achieved by giving students autonomy to make design decisions (Puntambekar & Kolodner, 2005), developing a shared task goal, and establishing task value (Belland et al., 2013; Puntambekar & Kolodner, 2005). These strategies can develop students' ownership of a design task (Belland et al., 2013).

Learning in a DBL context is collaborative in nature (Puente et al., 2013b). Social spaces allow students to share ideas with their peers and support or rebut each other's ideas to co-construct knowledge (Puntambekar & Kolodner, 2005). Thus, social scaffolding is necessary to guide students to work with each other (Baxter & Williams, 2010). Teachers need to highlight group rules or bootstrap collaborative learning skills to help students work with their peers (Baxter & Williams, 2010). Strategic scaffolding suggests strategies or processes students can use to solve a design task (Belland, 2017). This strategy opens an opportunity for students to apply their knowledge, revise and modify their plans based on feedback received for better outcomes (Belland, 2017).

Some studies have investigated facilitator's scaffolding strategies in light of a particular type of scaffolding. For instance, Mackiewicz and Thompson (2014) reported that the tutors in their study used motivational scaffoldings such as reinforcing student's ownership and control over their work, using humour, and showing empathy towards their students' unpleasant learning experience. In terms of cognitive scaffolding, the tutors read aloud the students' drafts, linked new knowledge to a prior topic, prompted and hinted at the students (Mackiewicz & Thompson, 2014). In a research that explored social scaffolding, Baxter and Williams (2010) found that teachers used questions to invite responses from the students and encourage them to look for alternative solutions during whole-class discussions. However, research into the six aforementioned scaffoldings and how they work together to support learning is scarce. In this study, we examined how the facilitator scaffolded learning using different scaffolding strategies that were chosen based on the student's emerging learning needs in a DBL environment.

2.2 Scaffolding Design-based Learning

Design-based learning (DBL) is an instructional approach in which students solve ill-structured, real-life issues through an iterative cycle of the engineering design process (English & King, 2015; Puente et al., 2013b). The design processes involve identifying design problems, designing, testing, justifying, and redesigning a design solution (English & King, 2015; Puente et al., 2013b; Puntambekar & Kolodner, 2005). DBL emphasises making connections between design activities, concrete artefacts, and relevant conceptual knowledge (English & King, 2015). However, students tend to treat DBL tasks as craft activities and pay less attention to the concepts underlying their designed artefacts (Puntambekar & Kolodner, 2005). For example, Berland, Steingut, and Ko (2014) found that students could suggest multiple solutions for designing and refining their designs, but they did not associate them with disciplinary knowledge. Students also face many challenges such as obtaining unexpected design outcomes, misinterpreting data and, identifying imprecise variables which affect their results (Baumgartner & Reiser, 1998). DBL can only become a productive context for student learning if appropriate facilitator scaffolds are provided to them (English & King, 2015; Hmelo et al., 2000; Puente et al., 2013a, 2013b; Puntambekar & Kolodner, 2005). For instance, the students in the research by Puntambekar and Kolodner (2005) were able to develop scientific reasoning and argumentations when they were involved in designing a solution to solve a real-world corrosion issue, with the support from hard scaffolds (i.e., written prompts) and facilitators. In a study by Hmelo et al. (2015), young students were able to learn the complex scientific ideas about the respiratory system as they were constructing an artefact resembling human lungs with support from the facilitator.

Previous studies have indicated that facilitators play a pivotal role in supporting student learning in a DBL learning context (Penner et al., 1998; Puente et al., 2013a; Puntambekar & Kolodner, 2005). Scaffolding maximises the full affordances of DBL for fostering students' knowledge construction, metacognition skills, and scientific reasoning (Puntambekar & Kolodner, 2005). For example, facilitators ask appropriate questions to help students notice and connect knowledge from multiple disciplines to develop a design solution (English & King, 2015; Hmelo et al., 2000; Penner et al., 1998). Facilitators also stimulate students' inventive thinking by focusing their attention on main design issues and making connections between various design stages (Baumgartner & Reiser, 1998; Puntambekar & Kolodner, 2005).

Hmelo et al. (2000) designed a study to support sixth graders' understanding of the complex human respiratory system by constructing a working model of an artificial lung. Hmelo et al. (2000) recommended a few strategies to enhance students' knowledge and systematic thinking in designing artefacts. These strategies include introducing scientific terminology explicitly to develop early causal mechanisms; conducting reflective discussions and whole-class discussions seamlessly to promote idea-sharing and self-reflection; planning and structuring activities based on a time constraint and available resources; providing timely feedback; and connecting new tasks to students' prior knowledge (Hmelo et al., 2000). Puente et al. (2013a) elaborated that facilitators encouraged students to formulate arguments and explore alternative solutions for a design problem by asking reflective questions.

Puntambekar and Kolodner (2005) argued that planning whole-class discussions and small group discussions at appropriate intervals for idea articulation are necessary to unpack students' design ideas. They also suggested other strategies to facilitate student learning during DBL, such as chunking complex tasks into more manageable pieces, providing suggestions to help students focus on important knowledge and eliciting information to make connections between different design stages more explicit. Students also need help from facilitators to conduct good experiments for testing prototypes and justify results for emergent learning problems (Baumgartner & Reiser, 1998). Besides, facilitators problematised students' designs to help them revise their conceptual understanding of a subject area (Morgan, Moon & Barroso, 2013; Puente et al., 2013a). Problematising student work can further develop students' ability to solve a problem (Reiser, 2004). Through this strategy, students focus their attention on an aspect that needs a solution and learns to elicit their ideas (Reiser, 2004).

3. METHODOLOGY

3.1 Participant

The first author of this study played the role of the facilitator in the DBL context. The first author has 10 years of experience in teaching secondary school science in Malaysia and Brunei Darussalam.

3.2 Research Context

In this study, the facilitator implemented a DBL task with a class of Form 1 students from a Malaysian national school located in the suburban area in Johor state. There were 27 students of different ethnicities in this class. Among these students, 14 were male. The students were randomly divided into a group of three students, forming nine student groups (Group A to Group I). This is the minimum number required for a small group discussion (University of Minnesota, 2021). It is also a good number for a small team to prototype a new idea (Corrigan, 2021).

This DBL cycle was divided into 16 one-hour lessons. A real-life design task drove the DBL challenge (English & King, 2015). The DBL lessons focused on designing and constructing a water filter that could provide clean water to villagers inhabiting remote areas based on the design criteria (i.e., filter 100ml water in two minutes, produce clear water, economic). The students were required to use knowledge from STEAM (Science, Technology, Engineering, Arts and Mathematics) subjects to solve this design task in groups.

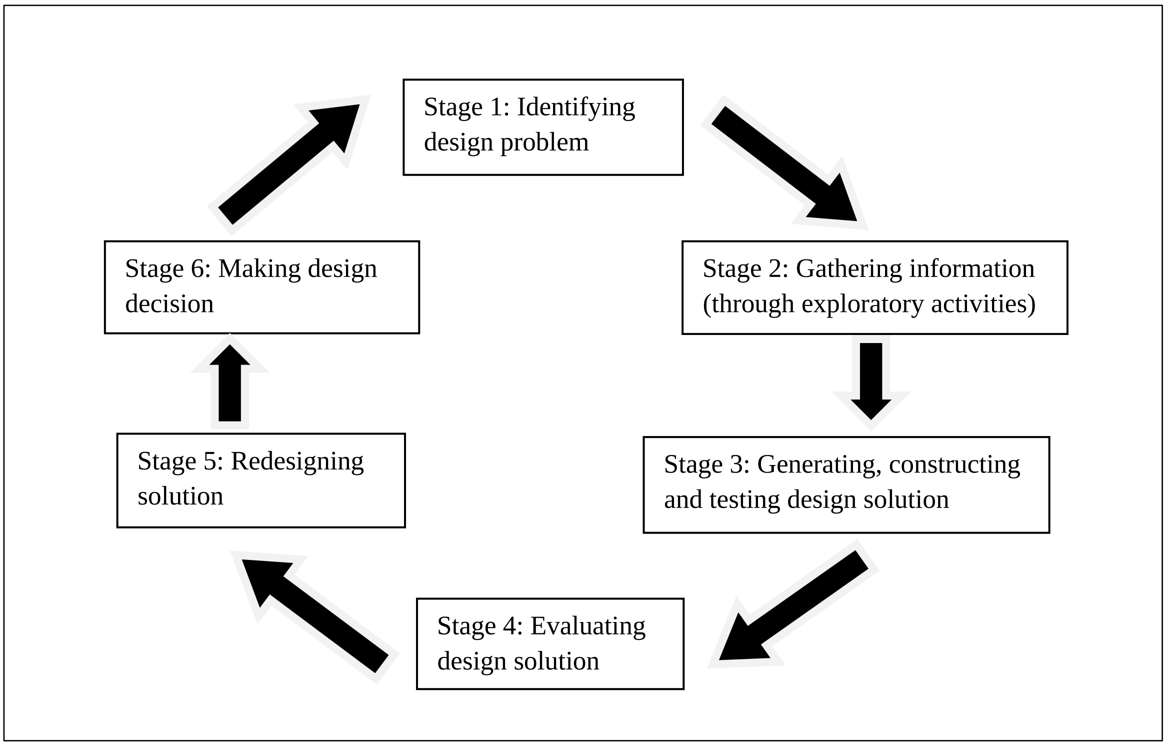

Figure 1. The Design-based Learning Cycle. Adapted from Hynes et al. (2011) and Puntambekar and Kolodner (2005)

The pedagogical framework of DBL was modified from the previous studies (Hynes et al., 2011; Puntambekar & Kolodner, 2005). As shown in Figure 1, the DBL cycle was divided into six major design stages: identifying design problem, gathering information, generating, constructing, and testing design solution, evaluating design solution, redesigning solution, and making a design decision. The problem identification stage gave the students time to analyse and define the learning issues and design problems using their prior knowledge. The information-gathering stage was for the groups to explore the nature of different types of filtering and discuss the experimental results before designing a prototype. At the stage of solution generation, the students were required to complete four tasks: selecting and justifying filtering materials, deciding the arrangement materials, identifying the concepts involved in the design of the water filter and drawing a pictorial diagram for their design solutions. During the evaluation stage, students shared their findings from the design activities, listened, and provided feedback to their peers for design improvement. The redesign stage was for the students to integrate knowledge and apply what they had learned from their initial design to improve their second artefacts. At the final stage of making a design solution, the students were required to compare their initial and redesigned solutions and justify their design solutions. Each group was also provided with a worksheet containing some question prompts at each design stage.

3.3 Data Collection and Analysis

Data was collected from video recordings and student interviews. Each activity was videotaped to preserve the moments involving the scaffolding process. During whole-class discussions, a camera was placed at the back of the class to record the interactions between the facilitator and the students. A camera was pointed to the facilitator and the scaffolded groups to capture the scaffolding strategies during small group discussions. The rationale was to identify the scaffolding strategies adopted by the facilitator in response to the emerging learning needs of each student group.

Data analysis of the video recordings involved three steps: selecting critical incidents, transcribing and coding video recordings, and categorising the codes to identify facilitator scaffolds. First, critical incidents that emerged over several lessons were identified. A critical incident is "any observable human activity that is sufficiently complete in itself to permit inferences and predictions to be made about the person performing the act" (Flanagan, 1954, p. 327). It is useful for identifying crucial factors that affect a defined purpose's outcomes (Flanagan, 1954). The criterion for selecting a critical case in this study was: a case that helped the researcher gain insights into different types of scaffolds adopted by the facilitator in the DBL context. Second, the critical incidents were transcribed verbatim and coded. While there was no a priori coding scheme for the data, coding was primarily guided by the existing literature discussed in the literature review section. Third, a constant comparative method was used to categorise the codes, delineate the categories and make connections between them (Lincoln & Guba, 1985). Categories were created when the researcher grouped and clustered relevant codes together (Lincoln & Guba, 1985). Those categories changed the units of data were constantly compared and categorised to identify any emerging category relevant to the research objectives.

To ensure the trustworthiness of the research, the data were coded by two coders. The first author was one of the coders. The second coder is an academic at a US-based university with no direct involvement with this study other than a coder and peer debriefer. First, the two individuals coded the data separately. Then, the codes were reviewed and revised based on the consensus of the coders.

4. FINDINGS

Table 1 summarises the scaffolding strategies adopted throughout the implementation of DBL activities. We categorise the facilitator's scaffolding strategies into six types of scaffoldings: cognitive, linguistic, metacognitive, motivational, strategic, and social scaffolding.

Table 1. A Summary of Facilitator's Scaffolding Strategies

Scaffolding types	Scaffolding strategies	Description
Cognitive scaffolding	• Linking to prior knowledge	• Relate students' existing experiences/ knowledge/ previous investigations to the current task
	• Questioning and pushing for an explanation	• Ask what students know about a topic, their design ideas or next step; and prompt them to give a deeper explanation
	• Appropriating and recasting	• Restate students' ideas and build these ideas into facilitators' scaffolding discourses
	• Modelling	• Set an example for imitation
	• Summarising	• Recap the main points of discussion
Linguistic scaffolding	• Reformulating using precise scientific terms	• Correct students' statements using precise academic wording
Metacognitive scaffolding	• Thinking aloud	• Prompt students to reflect on their learning by speaking out their ideas
Motivational scaffolding	• Promoting success expectancy	• Enhance students' belief in success
Social scaffolding	• Creating social spaces	• Create opportunity for students to share ideas at the whole class or small group level
	• Highlighting group rules	• Make the importance of working as a team explicit to students
Strategic scaffolding	• Contrasting cases	• Compare and contrast multiple design solutions
	• Peer reviewing	• Take advantage of neighbouring students to critique a group design solution

4.1 Cognitive Scaffolding

The cognitive scaffolding strategies, which emerged from the data, were linking to prior knowledge, questioning and pushing for an explanation, appropriating and recasting, modelling, and summarising.

4.1.1 Linking to Prior Knowledge

The facilitator's scaffolding strategies were explicitly grounded in the students' prior experiences. She made references to the students' out-of-class and in-class experiences to locate the new learning issue within their existing mental schemata. An example of this scaffolding strategy can be seen in the following scenario when the students linked the design criteria with relevant core concepts from STEAM classes:

> [1]*Facilitator: We had discussed the five design criteria for the water filter yesterday. Can you name one of these criteria?*
>
> [1]*Student: We need to filter 500ml of water as fast as possible.*
>
> [2]*Facilitator: That's right. Can you relate this criterion to the science or mathematics concepts which you have learned in class?*
>
> [2]*Student: Volume and time.*
>
> [3]*Student: Filtration and filtering materials.*
>
> [3]*Facilitator: In short, each design criterion is related to some core concepts from the STEAM subjects. You are expected to apply your prior knowledge from these subjects to solve the task.*

This short exchange occurred at the beginning of the lesson. The facilitator helped the students recall the design criteria discussed in the previous lesson ([1]Facilitator and [2]Facilitator). This starting point enabled the facilitator to link the students' prior knowledge with the new learning objective to make it more accessible to the students.

For example, during the interviews, two students explained that *"At first, it was hard for me to understand how to link the concepts from different subjects. After the facilitator asked us to name some concepts from STEM subjects, I knew that those concepts could be linked."* and *"When the facilitator made us see that we could use our existing knowledge from science, arts and mathematics to design a filter, we felt more confident to complete the job."*

4.1.2 Questioning and Pushing for an Explanation

The facilitator frequently questioned and pushed the students for an explanation. An example can be seen when two students, Eiden and Eason, explained how their group arranged the filtering materials:

> *[1]Eiden: First, we arrange cotton, followed by carbon, gravels, coarse sand and fine sand.*
>
> *[1]Facilitator: Why do you arrange the materials in such a way?*
>
> *[2]Eiden: Our idea is to use cotton and carbon on the top layer to filter out the suspension so that clearer water can be produced. But cotton may cause the water to flow slowly, so we arrange gravel with a larger size on the third layer to make the water flows faster.*
>
> *[2]Facilitator: How about the coarse sand and fine sand?*
>
> *[1]Eason: The size of the materials decreases from gravel to coarse sand and fine sand. This can help filter out small size substances.*

Eiden made his thinking visible to the facilitator ([1]Eiden) by explaining his design ideas. This allowed the facilitator to gain an understanding of the students' ability to justify their solutions. The facilitator pushed the students to explain further the arrangement of different filtering materials ([1]Facilitator and [2]Facilitator). The students could link their design solution to the characteristics of the filtering materials such as water absorber, substances size ([2]Eiden) and space ([1]Eason). The facilitator never evaluated the students' responses but provided a chance for them to articulate their ideas. This set the ground for the students to investigate the outcomes of their design solution in the following DBL stages.

During the interview, the students explained that questioning and pushing for explanation stimulated their thinking. For example, they said, *"The facilitator asked many questions to trigger our ideas."* and *"When the facilitator asked questions, I started to think. Sometimes my answers were incomplete, when she asked more questions, I could add more detailed explanations."*

4.1.3. Appropriating and Recasting

Within a whole class discussion, the students were encouraged to make their thinking public. However, a variety of ideas contributed by different students were scattered around the classroom. Appropriating or uptake occurred when the facilitator took up the students' ideas and built their contributions into her scaffolding discourses. Appropriating was normally followed by revoicing, or in other terms, recasting or restating, to shape the students' knowledge. One of the examples took place when the students were identifying the causes of clean water shortage:

[1]Facilitator: Why does this problem (clean water shortage issue) happen? You may use your knowledge gained from geography lessons or general knowledge to answer this question.

[2]Student: The number of people increases.

[2]Facilitator: When the population increases, there will be rapid development. We need land to build more housing areas. How do we get land?

[2]Student: By cutting down trees in forests.

[3]Facilitator: Cutting down trees brings a lot of disadvantages to both living things and the environment. Can you name the negative impact?

[3]Student: It causes soil erosion.

[4]Student: There will be a lack of clean water.

[4]Facilitator: There is a connection between what both of you have said. Eroded soil may be carried by rainwater into rivers and make the water milky and muddy.

The facilitator prompted the students to use the knowledge gained from their formal learning or real-life experiences to identify the factors leading to clean water shortage ([1]Facilitator). She constantly restated the students' ideas such as *"population increases"* ([1]Student) and *"cut down trees"* ([2]Student) and built their discourses into her next line of elaboration to help them focus on the main learning issue. When two students provided different opinions, stating that deforestation caused erosion ([3]Student) and clean water problem ([4]Student), she pieced their fragmented ideas together by explaining how corroded land might cause the issue of murky water ([4]Facilitator). The students' contributions of ideas were appropriated into the scaffolding discourses. They became co-participants in the construction of a broader and more systematic codification of integrated ideas.

4.1.4. Modelling

Modelling was used to introduce the new DBL approaches, concepts or, skills to the novice. This strategy set an example for imitation to help the students apply the appropriate knowledge and skills to solve the design problem. In the following example, the facilitator demonstrated the appropriate way to select a filtering material:

[1]Facilitator: You must always keep the five design criteria in your mind when you select a filtering material. Let's take fine sand as an example. First, we check its cost in the price list (provided by the facilitator). How much does it cost?

[1]Student: RM2.50.

[2]Facilitator: Next, can you relate fine sand with water clarity?

[2]Student: The spaces between the fine sand are small so that it can produce cleaner water.

[3]Facilitator: Right. But choosing fine sand may have some disadvantages.

[3]Student: I think the filtering time will become longer.

[4]Facilitator: That's a good answer. Can you check the experimental results collected from the previous activities? Tell me how much time was used to filter 100ml of water.

[4]Student: It took 840 seconds.

The facilitator modelled how to use the price list as a reference source to justify selecting fine sand from the aspect of the cost ([1]Facilitator). The students were prompted to relate spaces with water clarity ([2]Facilitator). She guided the students to see that each filtering material had its strengths and weaknesses by referring to the empirical evidence ([3]Facilitator and [4]Facilitator).

The facilitator managed to model how to justify the selection of filtering materials from different aspects: cost, water clarity and filtering time.

During the interview, the students agreed that modelling gave them a guideline for integrating knowledge. For instance, a student articulated that *"The facilitator explained the questions and prompts. Then, she gave examples like how we could compare the first and second filters. She showed us how to compare the filtering time between the two filters."*

4.1.5 Summarising

The facilitator asked the students to summarise the content of the whole class discussion to ensure that the students: (a) understood the objectives or process of the design task and; (b) grasped the main concepts underlying a design task. In the following scaffolding episode, just before the next exchange, the students had read the design problem and identified the design task. The facilitator asked a student, Betty, who looked confused, to summarise the discussion:

> [1]*Facilitator: Betty, can you summarise the design task? Or, in other words, what are you going to do in these four weeks?*
>
> [1]*Betty: We need to design a water filter.*
>
> [2]*Facilitator: Can you give more details, like how should it look like?*
>
> [2]*Betty: It should filter 500ml water fast, be cheap, attractive and produce clean water.*
>
> [3]*Facilitator: Good, Betty has mentioned four design criteria. Do you have anything to add?*
>
> [1]*Clara: We can only choose five materials to build a water filter.*
>
> [1]*Frank: We need to use knowledge from STEAM subjects to explain our plan.*
>
> [4]*Facilitator: Let me summarise what you all have said: In this design task, each group needs to design a water filter, which fulfils the five design criteria, using knowledge from the STEAM subjects.*

The facilitator attempted to make sure that Betty understood the design task ([1]Facilitator and [2]Facilitator). She also provided an opportunity for the other students, Clara and Frank, to add to Betty's explanation ([3]Facilitator). This strategy helped the facilitator and the students achieve a shared understanding of the design criteria and the learning objective.

During the interviews, the students agreed that summarising helped them focus on the design task. They explained: *"The facilitator restated the important details, like what we had to focus, at the end of the discussion."* and *"The facilitator repeated what we had to do so that we would not miss any important information."*

4.2 Linguistic Scaffolding

The facilitator focused on scaffolding the content knowledge and the accuracy of academic terms rather than the grammatical errors, syntax and sentence structures.

4.2.1 Defining Terms and Reformulating Responses Using Precise Academic Wordings

The students used scientific terms such as mass and weight as well as pores and space interchangeably. The facilitator defined some academic terms to help them differentiate the terms with similar meanings and clarify their misuse of terms. In the following scenario, Frank from Group F was explaining the reason for choosing fine sand to build the filter:

[1]Frank: One of the materials we chose to build our filter is fine sand. The pores between the fine sand are small.

[1]Facilitator: The term "pores" is not suitable. Pores are tiny holes on a surface, such as the sweat pores on our skin. Can you suggest a more appropriate term?

Frank used the term *"pores"* to describe the gaps between the fine sand, but this term is inappropriate ([1]Frank). The facilitator defined *"pores"* and prompted Frank to give a more suitable term to replace this term ([1]Facilitator). Following this scaffolding session, the facilitator reformulated Frank's utterance using appropriate wording. She said, *"The space between the fine sand is small"*, which is more accurate. Space means the unoccupied area found in between objects. Pores can secrete some substances, but spaces cannot.

During the interviews, students expressed their views that this strategy was helpful. They said, *"I could understand the prompts better after the facilitator explained the terms…I learned the meaning of design criteria."* and *"The facilitator explained the meaning of terms. When we used a term wrongly, she pointed out our errors so that we could use the terms accurately."*

4.3 Metacognitive scaffolding

Metacognitive scaffolding was constantly provided to the students, especially during the evaluation stage, to help them reflect on their design solutions.

4.3.1 Thinking aloud

As the students practised thinking aloud, they internalised their thought. This strategy was frequently adopted to help the students become more self-aware of their learning. The example shown below took place when the students were reflecting on the strengths of their design solution. Gamir from Group G was reading aloud the question *"Which design criteria are fulfilled?"*. It took him a while to make sense of this prompt, and he talked to his group member:

[1]Gamir: Is this question trying to check if our filter is good or bad?

[1]Galal: I think it is to check how many criteria our filter has met.

[2]Facilitator: Good. It is to see out of the five design criteria, which criteria have your filter met. For example, could you collect 150ml of water within 6 minutes?

[2]Gamir: Yes, we could…We only used 2 minutes 20 seconds.

[3]Facilitator: Okay…Which question haven't you understood yet?

[2]Galal: This one, "How can it fulfil the design criteria?"

The facilitator attempted to assess the students' understanding of the question ([1]Facilitator). Gamir had a vague understanding of this prompt as he merely knew that the students had to evaluate their designed artefact ([2]Gamir). Galal built on his team member's explanation, relating this question to the five design criteria ([1]Galal). The facilitator recognised Galal's ideas, stating and elaborating his statement to further clarify the question ([2]Facilitator). She also prompted them to self-evaluate their understanding of the prompts to help them aware of their knowledge gap ([3]Facilitator). As a result, Galal voiced out his confusion ([2]Galal).

4.4 Motivational Scaffolding

The facilitator motivated the students to keep their interest in the task and build their confidence in achieving the targeted learning goal.

4.4.1 Promoting Success Expectancy

The students' expectations for success were promoted by establishing their perceptions of belongingness, building their confidence, and praising them for their hard work. In the following example, Ilham from Group I was demotivated by the complex questions:

> [1]*Ilham: Name the weaknesses of your water filter. Which criterion is not met? What is the evidence? (Reading out loud the questions). So many questions! We can't do it!*
>
> [1]*Facilitator: Do you have any problems?*
>
> [2]*Ilham: I cannot understand this question.*

Ilham was overwhelmed by the complex questions and lost his interest in solving the question ([1]Ilham). The facilitator attempted to understand the challenges he faced ([1]Facilitator). She then explained that *"What you need to do is to compare your experimental outcomes with each criterion."* This helped the students identify two weaknesses of their water filter: unattractive and long filtering time. She praised the students for boosting their confidence, saying that *"Good job. You have identified two weaknesses from different aspects: attractiveness and filtering time. Be confident and voice out your ideas."*

4.5 Social Scaffolding

Social scaffolding, which included highlighting group rules, helped the students congregate fragmented ideas from different individuals into more comprehensive knowledge.

4.5.1 Highlighting Group Rules

Highlighting group rules to bootstrap positive collaborative learning helped the students develop scientific knowledge as a group. The facilitator explicitly described how she wanted the students to work together by saying, *"Each of you has designed an individual water filter. Each of you must take turn to share your individual design with your group members. Then, discuss among yourselves to design a group water filter."*

The facilitator created social spaces to optimise student interactions to negotiate with their group members before achieving consensus on their group design solution. She encouraged group interaction and tried to facilitate so that less vocal students could contribute their ideas. The facilitator noticed that Cantina, one of the members of Group C, had been very quiet. She was a passive participant who merely listened to her peers' arguments. The facilitator asked, *"Cantina, do you have a different way of thinking about how to design your water filter?"* Cantina explained her individual design idea in detail, an indication that she understood the design task. The facilitator highlighted the importance of collaboration, saying that *"All activities are group-based. So, each of you must contribute some ideas. Discuss among yourselves to come up with a new group design solution."* This strategy provided an opportunity for all group members to negotiate a shared meaning of the design solution.

4.6 Strategic Scaffolding

Strategic scaffolding was adopted to help the students design and then improve their solutions. In this study, strategic scaffolding was provided in the form of contrasting the students' design solutions and peer-reviewing.

4.6.1 Contrasting Cases

Contrasting cases helped the students notice (a) the dimensions of information that they might miss if only one single example were presented to them and (b) the general rules and significant design features which might affect the outcomes of their design solutions. An example of contrasting cases took place when the facilitator asked the Group E students to compare their designed artefact with Group F's. The facilitator asked, *"Can you state the similarities between the design from Group F and your group (Design E)?"*.

> [1]*Elagovan: Both groups used 2 cm cotton and arranged it on the top layer.*
>
> [1]*Eason: We all used cotton, coarse sand and fine sand.*
>
> [1]*Facilitator: How about the differences between the two designs?*
>
> [1]*Eiden: The filtering materials…Group F used 1cm of carbon, but our group (Group E) did not use carbon.*
>
> [2]*Elagovan: The arrangement of filtering materials…the position of coarse sand and fine sand is different…Our group arranged fine sand on top of coarse sand, but Group F arranged these materials in the opposite way.*

The facilitator prompted Group E to identify the similarities and differences between Design E and Design F ([2]Facilitator). The students named the similarities, such as the amount and types of filtering materials used ([1]Elagovan and [1]Eason). They also identified the differences in the types of filtering materials ([1]Eiden) and their arrangement ([2]Elagovan). Contrasting cases led the students to conclude that different factors, including the type, the arrangement, and the number of filtering materials, affect the design outcomes.

During the interviews, a few students explained that *"From the group presentations, I knew that there are many ways to design the water filter. Many factors affected the outcome of our designs such as the arrangement of the materials."* and *"When I listened to my friends' ideas, I compared my group design with theirs. I asked myself, 'How can their water filter produce such clear water? How can they filter the water so fast?'. It made me rethink my design so that I could improve my water filter."*

4.6.2 Peer reviewing

Each group was in charge of giving written feedback to one assigned group during the peer review session. The aims of the peer review session were two-fold: (a) to help the students reflect on their own designed artefacts while providing comments to their peers, and (b) to broaden the students' horizon of knowledge integration through critiquing their peers' designed artefacts. The facilitator distributed a peer review sheet to each student group, followed by demonstrating how to use this sheet during a whole-class discussion. A sample of the peer review sheet given by Group D to Group E is shown in Table 2.

Table 2. A Sample of Group D's Peer Review Sheet

The filtering time is 297 seconds, less than 600 seconds.
(1) The mass is high, 410g; (2) High cost, RM66.05; (3) The filtrate is still murky; (4) No arts element.
(1) Add decorative elements; (2) Reduce the cost by using less expensive materials or coloured stickers; (3) Reduce stone because it is heavy and has big spaces, so water might not be filtered well.

The evaluated group received their peers' comments, which helped them reflect on their design solutions from different aspects. For example, two students said that *"We could not see all bad* *things about our design. The comments from Group I gave us more ideas to improve our filter."* and *"Peer review gave us more ideas to modify our water filter."*

4.7 A System of Facilitator's Scaffolding Strategies

This study found that the students' performance in knowledge integration was not the result of one particular scaffold but a combination of different strategies, which worked as a system to support student learning. In this vignette, the facilitator provided scaffolding to a group, Group G, which consisted of Gafar, Galal and Gamir, who were in the process of identifying the weaknesses of their water filter. The facilitator joined Group G when the students showed a lack of enthusiasm to complete the task. The small group scaffolding ensued:

> [1]*Facilitator: Are you facing any problems? (Motivational scaffolding: Showing concern)*
>
> [1]*Gafar: I have no idea how to answer this question.*
>
> [2]*Facilitator: Let's look at this question: What are the weaknesses of your filter? (Cognitive scaffolding: Focusing attention)*
>
> [3]*Facilitator: In other words, "what is not so good about your water filter". (Linguistic scaffolding: Paraphrasing)*
>
> [1]*Galal: I think our design has a long filtering time.*
>
> [4]*Facilitator: It is a good idea. (Motivational scaffolding: Positive feedback)*
>
> [5]*Facilitator: We have talked about the strengths and weaknesses of your water filter in the previous activities, right? What are the causes of the long filtering time? (Cognitive scaffolding: Linking to prior knowledge)*
>
> [2]*Galal: The cotton blocked the mouth of the bottle.*
>
> [1]*Gamir: I think it is due to the arrangement of the filtering materials.*
>
> [6]*Facilitator: Good try. I am glad that you still remember what we had discussed in the previous sessions. (Motivational scaffolding: Positive feedback)*
>
> [2]*Gamir: Our design is not attractive...*
>
> [7]*Facilitator: Why do you say so? (Cognitive scaffolding: Pushing for explanation)*
>
> [3]*Galal: I think there are two reasons. Its mass is high…and we didn't decorate the filter. We didn't have time that day.*
>
> [8]*Facilitator: See, each of you may have a different idea. Voice out your opinion. This can help you evaluate your filter from different aspects. (Social scaffolding: Promoting collaboration).*

In this vignette, the facilitator adopted different types of scaffoldings to help the students identify the weaknesses of their filter. Cognitive scaffolding such as pumping ([7]Facilitator) prompted the students to elaborate their explanations. The facilitator motivated the students by providing positive feedback such as *"it's a good idea"* ([4]Facilitator) and *"good try"* ([6]Facilitator). She paraphrased the *"weakness of the filter"* to *"what is not so good"* to help the students comprehend the question ([3]Facilitator). She promoted collaboration among the students to help them solve the task as a team ([8]Facilitator). Each strategy was calibrated based on the diagnosis of the students' responses to cater to their different learning needs.

5. DISCUSSION

Creating a strong connection between knowledge from different disciplines in the DBL context is a challenging process for students at any level. In this study, the facilitator flexibly adapted a variety of scaffolding: cognitive, linguistic, metacognitive, motivational, strategic, and social scaffolding to support student learning in this learning context. The facilitators continuously diagnosed the progressive development of each student group to calibrate the type of scaffold, which could support the student learning. For example, cognitive scaffolding strategies such as questioning, pushing for an explanation and, linking to students' prior knowledge were used to remind the students of the relevant information and trigger their deeper thinking. Instructional strategies that utilise students' unique learning experiences can reduce their cognitive load by storing relevant information in their working memory (Kirschner et al., 2006). In addition, modelling set an example for imitation to help the students achieve the intended learning objective (Wood et al., 1976).

From the aspect of scaffolding students' language, the facilitator helped these students comprehend the question prompts by defining terms, paraphrasing sentences, and reformulating their discourses into more precise academic wordings (Smit & Eerde, 2013). Facilitators must help students articulate their ideas using scientific terminologies (Puente et al., 2013a). In terms of motivational scaffolding, conducting design activities with clearly defined goals, appropriate learning sources and, connections to students' interests can motivate them to integrate knowledge (Barron et al., 1998; Puente et al., 2013). Besides promoting students' expectancy for success, Belland et al. (2013) suggested that establishing task value, creating a sense of belonging and providing autonomy for students can enhance their motivation in learning. With high motivation, students will strive to achieve deep learning, such as solving a problem and utilising different approaches to gain knowledge (Belland et al., 2013).

Metacognitive scaffolding such as thinking aloud moved the students towards deeper thinking by saying out loud their understanding about the question prompts. This strategy created cognitive dissonance and pushed the students to reflect on the root problems of their design solutions (Reiser, 2004). From the aspect of social scaffolding, Hsi and Agogino (1995) advocated that small group discussions can help students make their mental models visible. Puente et al. (2013a) suggested facilitators provide feedback on teamwork as students need to collaborate with their peers throughout the DBL process. This study showed that creating social spaces for group interactions encouraged the students to merge the ideas of different individuals and collaboratively develop coherent, integrated knowledge. Kirschner, Sweller, Kirschner, and Zambrano (2018) explained that when a complex task with a large amount of highly interacted elements is distributed between multiple working mental models, cognitive load can be reduced if students know about working as a group.

This study indicated that multiple types of facilitator scaffolds, including cognitive, language, metacognitive, motivational, strategic and social scaffolding, worked as a system to facilitate student learning. This study concluded that student performance in learning is not a result of a single type of scaffold. Different types of scaffolding strategies work in concert to help students achieve a learning objective (McNeil, 2006; Tabak, 2004). Different scaffolding tools and agents can help students develop various knowledge and skills in a complex, open learning environment (Tabak, 2004). Thus, facilitators need to integrate different types of scaffolds seamlessly to support student learning in the DBL context.

6. CONCLUSION

The power of scaffolding lies in the interactions between different types of scaffolding strategies to complement the affordances and constraints of each other (Tabak, 2004). It is hard to differentiate the boundary of various types of scaffolding (e.g., cognitive, metacognitive, and strategic scaffolding) as they are intertwined to support a learning objective that a single scaffolding strategy cannot achieve (McNeill, 2006; Tabak, 2004). Thus, a system of facilitator scaffolds can be designed into the DBL environment to support student learning. It is necessary to prepare teachers to scaffold student learning in the DBL context (Puente et al., 2013a). Researchers found that teachers play a limited role in facilitating student learning in the DBL context (Puente et al., 2013a). For instance, they rarely use the essential scaffolding strategies suggested by the past literature, such as providing feedback on work progress, triggering students to think of a problem from different perspectives and, encouraging students to explore alternative solutions (Puente et al., 2013a).

This study provides teachers, especially inexperienced pre-service teachers, with guidelines in shaping their new roles in scaffolding. Teachers need to have positive views on teacher scaffolds' legitimacy and crucial roles (Van de Pol, 2012). They need to provide adequate scaffolds to students while still recognising and promoting their active roles in learning, as the ultimate goal of scaffolding is to transfer the learning responsibility to students. Scaffolding may require entirely different orchestration of learning activity, classroom environment and teaching approaches (Talley, 2014). Teachers need to equip themselves with pedagogical and content knowledge and mental agility (Van de Pol, 2012) to gain expertise on scaffolding student learning. Careful planning of scaffolding strategies can help students move step-by-step along the iterative design stages towards a more in-depth understanding of knowledge.

Future studies can investigate the synergy between peer interaction and facilitator scaffolds to enhance students' knowledge integration. Collaborative learning reduces students' cognitive load as interacting elements are distributed between few students (Kirschner et al., 2018). Future research can also investigate collaborative cognitive load issues when students are scaffolded in groups with synergistic scaffolds. This can help teachers make informed decisions concerning the design of an effective collaborative learning environment for promoting knowledge integration. There are multiple zones of proximal development in a classroom (Smit & Eerde, 2013). Students may respond differently to the same type of scaffolding due to their different levels of understanding and their ability to interpret and use scaffoldings (Berland et al., 2014). It is often unclear how the facilitator's scaffolding strategies lead to students' progressive development in learning (Smit & Eerde, 2013). Thus, future studies can explore the impacts of using particular scaffolds such as cognitive scaffolds and social scaffolds on student learning in a DBL context.

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APPENDIX

Appendix 1: Interview Protocol

The researcher described the research, telling the interviewee about the (a) purpose of the interview, (b) the methods that would be taken to protect the confidentiality of the interviewees and data sources, (c) what would be done to the data sources, and (d) how long the interview would take.

1. What have you learnt from this design-based STEAM activity?

2. Did you face any challenges throughout your involvement in these activities? If yes, can you give examples of these challenges?

For the past three weeks, you had learned to link the knowledge or concepts from various STEAM subjects to design your water filter. We had also discussed that knowledge integration means linking different concepts from the STEAM subjects to solve a problem.

Scaffolding is the support provided by the facilitator to help you complete your tasks. In your case, scaffolding means "how the facilitator help you integrate knowledge to design and build your water filter". For example, the facilitator gave examples of how you could evaluate your water filter based on the experimental results.

2. Did you need facilitator's scaffold or support when you learned how to integrate knowledge throughout this design-based learning activity?

If the response is "yes",
(a) Why did you need the facilitator's scaffold?
(b) What types of scaffolds the facilitator provided to you?

If the response is "no",
(a) Why didn't you need the facilitator's scaffold?
(b) Did you receive support from other sources?

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