‘Which cup is the best?’: Encouraging children to act like scientists when investigating the properties of materials

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Abstract

This paper describes an enquiry-based science teaching sequence that was designed to teach about the properties of materials, and implemented with primary school children (aged 9 to 10 years) in Malaysia. The sequence consisted of three activities: ‘Naming the cups’, ‘Defining the properties of the cups’, and ‘Grading the cups’. The first activity aimed to develop children’s scientific literacy by encouraging them to observe and classify cups based on the materials that they were made of. The second activity aimed to develop children’s critical thinking skills, by enabling them to engage in processes such as grouping and classifying, analysing, visualising and synthesising information. The third activity aimed to challenge children’s understanding of the scientific method. The evaluation of the implementation revealed that the enquiry-based science teaching sequence was successful in enhancing the scientific literacy and critical thinking skills of the children. The teacher’s facilitation of open discussion among the children, coupled with opportunities to correct their misconceptions, contributed greatly to the success of the sequence.

Keywords: Enquiry-based science teaching, properties of materials, teaching sequence, primary science

Introduction

The aim of this study was to assess the impact of a university- and industry-led STEM Academy model of multi-level partnership working on teacher and pupil confidence in and attitudes to STEM.

Enquiry-based science teaching is a strategy that encourages children to think, act and be like scientists (Hollingsworth & Vandermaas-Peeler, 2017). By building on children’s natural curiosity and engaging them in authentic science practices, this approach aims to foster in children a deep understanding of the world around them (Kuhn, 1993). Through hands-on opportunities to explore and seek answers to important questions, children are able to develop critical thinking skills and learn how to draw conclusions based on evidence (Deboer, 2006). Additionally, enquiry-based science teaching encourages children to share their new knowledge through various means, including informal class discussions and more formal presentations (Duran & Duran, 2004). This approach to primary school science education is designed to inspire a lifelong love of learning and curiosity about the natural world (Kamarudin *et al,* 2022).

Despite its benefits, enquiry-based science teaching requires significant teacher preparation and a shift from traditional teaching methods, demanding more time and resources for the implementation of hands-on activities (Baroudi *et al,* 2021). The delivery method also poses challenges in diverse classrooms, where children’s varying abilities must be accommodated, necessitating differentiated instruction (Bresser & Fargason, 2023). For teachers, there is a tension between the breadth of the curriculum content, which needs to be covered in its entirety, and the depth required to implement enquiry-based teaching (Abd-El-Khalick *et al,* 2004).

Moreover, assessing student learning through this approach can be difficult, as standard tests may not fully capture the skills developed (Mat Noor, 2021). These challenges highlight the need for strategic planning and resource allocation to effectively implement enquiry-based teaching.

Addressing children's misconceptions about the properties of materials

Research has shown that enquiry-based science teaching methods are effective in helping to address children's misconceptions about the properties of materials, and in enabling them to develop a deeper understanding of this subject matter (Hernández *et al*, 2015). Enquiry-based science teaching encourages children to act like scientists and to investigate the properties of different materials through hands-on investigations and activities (Inan & Inan, 2015). This approach allows children to discover new information through observation and experimentation, rather than simply being told what to believe (Harris, 2012). In addition, Barbara (2007, 2014) argues that in enquiry-based teaching, unlike other science practices, children grapple with sense-making, and the teacher's role varies from directive to collaborative depending on the level of enquiry, thus shaping the depth of children's cognitive engagement.

One study conducted by Acher *et al* (2007) found that, when enquiry-based science teaching methods were used to teach children about the properties of materials, they were able to overcome their misconceptions and achieve a deeper understanding of the subject. Children engaged in small group activities, manipulating different materials though the construction of models to understand these manipulations. This work also involved children communicating their ideas with peers through whole-classroom discussions. The study also found that children who were taught through enquiry-based science teaching were more engaged and motivated to learn about the properties of materials. Another study conducted by Wendell and Lee (2010) found that enquiry-based science teaching was effective in addressing children's misconceptions about materials science. In the study, children worked in pairs to complete a model house investigation using LEGO to deepen their understanding of the design problem's requirements or constraints. As they generated and implemented solutions to the design problem, they increased their understanding of materials science. The study found that, when children were able to conduct hands-on investigations to observe, compare and manipulate different materials, they were able to overcome their misconceptions and understand the concept more thoroughly.

To summarise, enquiry-based science teaching is effective in addressing children's misconceptions about the properties of materials (Hernández *et al*, 2015). Enquiry-based teaching differs from traditional practical science investigations in its emphasis on the process of questioning, exploring and analysing, rather than merely following a set of instructions (Constantinou *et al*, 2018). This approach is characterised by its focus on children-led questioning and exploration, where children are encouraged to formulate their own questions, hypotheses, and methods for investigation (MacDonald *et al*, 2020). Throughout this process, teachers encourage children to act like scientists and investigate the properties of different materials through hands-on investigations and activities (Hollingsworth & Vandermaas-Peeler, 2017). This approach allows children to discover new information through observation and experimentation and helps them to develop a deeper understanding of the subject matter (Muhamad Dah & Mat Noor, 2021).

Properties of materials in the primary science curriculum

In most of the primary science curricula, the properties of materials topic is usually covered as part of the broader area of materials science (Schibeci & Hickey, 2000). The main focus is on helping children to understand the physical and chemical properties of different materials and how those properties affect their suitability for different uses. At primary level, children are introduced to the basic properties of materials, such as their shape, size, texture, weight, colour and flexibility. They are also taught how to observe, compare and classify different materials based on their properties such as density, conductivity and melting point. Hands-on activities such as sorting, matching and experimenting with different materials are often used to help children to understand these concepts.

In general, the properties of materials topic in the primary science curriculum focuses on helping children to: understand the basic properties of materials; observe, compare and classify different materials based on their properties; learn how properties of materials can be used to identify and classify materials; and be able to identify how properties affect suitability for different uses.

The properties of materials is an important topic in primary science education, and is included in both the Standards-Based Curriculum for Malaysian Primary School Science (MOE, 2018) (see Table 1) and the National Curriculum in England: Science Programmes of Study (DfE, 2015) (see Table 2). According to the Ministry of Education Malaysia (MOE, 2018), the properties topic should be taught to Year 4 children, who are aged between 9 and 10 years. Similarly, in England, the Department of Education (DfE, 2015) states that the topic should be taught to Key Stage 2 (Year 5) children, who are aged between 9 and 10 years. Understanding the properties of materials is essential for primary children, as they need to be able to understand the characteristics of different materials and how they can be used (Mat Noor, 2022b). This knowledge is useful for their everyday lives and can help them to make informed decisions when choosing materials for various tasks.

Table 1. The Standards-Based Curriculum for Malaysian Primary School Science, Year 4 (MOE, 2018).

Content Standard	Learning Standard
8.2 Properties of Materials	8.2.1 Describe the properties of materials by conducting an activity. 8.2.2 Create objects by applying knowledge of the properties of materials. 8.2.3 Reason about the selection of the type of material used in the created objects. 8.2.4 Explain observations about the properties of substances through sketches, information and communication technology (ICT), writing or discussion.

Table 2. The National Curriculum in England: Science Programmes of Study (DfE, 2015).

Year 5 Programme of Study	
Properties and Changes of Materials	Pupils should be taught to: • Compare and group together everyday materials on the basis of their properties, including their hardness, solubility, transparency, conductivity (electrical and thermal), and response to magnets. • Know that some materials will dissolve in liquid to form a solution, and describe how to recover a substance from a solution. • Use knowledge of solids, liquids and gases to decide how mixtures might be separated, including through filtering, sieving and evaporating. • Give reasons, based on evidence from comparative and fair tests, for the particular uses of everyday materials, including metals, wood and plastic. • Demonstrate that dissolving, mixing and changes of state are reversible changes. • Explain that some changes result in the formation of new materials, and that these kinds of change are not usually reversible, including changes associated with burning and the action of acid on bicarbonate of soda.

The context

The author implemented the lesson on investigating the properties of materials as part of their doctoral dissertation (see Mat Noor, 2022a). The lesson was implemented in Malaysia, and the participants consisted of 35 Year 4 children (ages 9-10) at a high-performing school in Kelantan, Malaysia. The lesson plan, which spanned a duration of approximately three weeks, was divided into three distinct activities, one for each week. The development of the lesson was thoroughly reviewed by five experts in the field of science education, including university academics and specialist subject leaders. The lesson, while specifically designed for Malaysian children, is adaptable and can be applied when working with children of the same age worldwide. The lesson sequence, implemented in a single lesson period (60 to 90 minutes), not only presents the basic activities involved in the lesson, but also seeks to integrate them with scientific enquiry (Deboer, 2006).

The development of learning objectives and learning outcomes

The author made the decision to develop the learning objectives and learning outcomes of the lesson by using the 'Structure of the Observed Learning Outcome (SOLO)' model (Biggs & Collis, 1982). This decision was based on the realisation that the stages of the SOLO model were compatible with the enquiry-based science teaching goals that he sought to implement. Hattie (2012) has described SOLO as a '*powerful model*' for setting learning intentions and accessing learning objectives and learning outcomes (p.54). By using the SOLO model in many of his works (e.g. see Hattie, 2012), Hattie has demonstrated how the model could be used in evaluating learning intentions and success criteria. Therefore, this body of scholarly literature inspired me to use this approach.

The SOLO model includes five levels of understanding: pre-structural, uni-structural, multi-structural, relational, and extended abstract (Biggs *et al*, 2022). These levels represent a progression from a lack of understanding to a deep understanding of a concept. In the current lesson, the decision was made to focus on the latter three levels – multi-structural, relational and extended abstract – as they were deemed more appropriate for the abilities of 10 year-old children. Using these levels, learning objectives and outcomes were carefully crafted, which are presented in Table 3.

Table 3. Utilisation of the SOLO model in the construction of learning objectives and learning outcomes.

SOLO	Learning Objectives	Learning Outcomes – at the end of the lesson children will be able to:
Multi-structural (Use two or more discrete and separate pieces of information contained in the stem.)	Recognise that cups are made up of different materials.	Name the material that each cup is made from.
Relational (Use two or more pieces of information, each directly related to an integrated understanding of the information in the stem.)	Know that the cups made from different materials have different properties.	Explain that the properties of cups are based on what materials they are made of.
Extended abstract (Use an abstract general principle or hypothesis that can be derived from, or suggested by, the information in the stem.)	Understand what properties make the material/cup the best for drinking.	Discuss which material/cup is the best for drinking based on their properties.

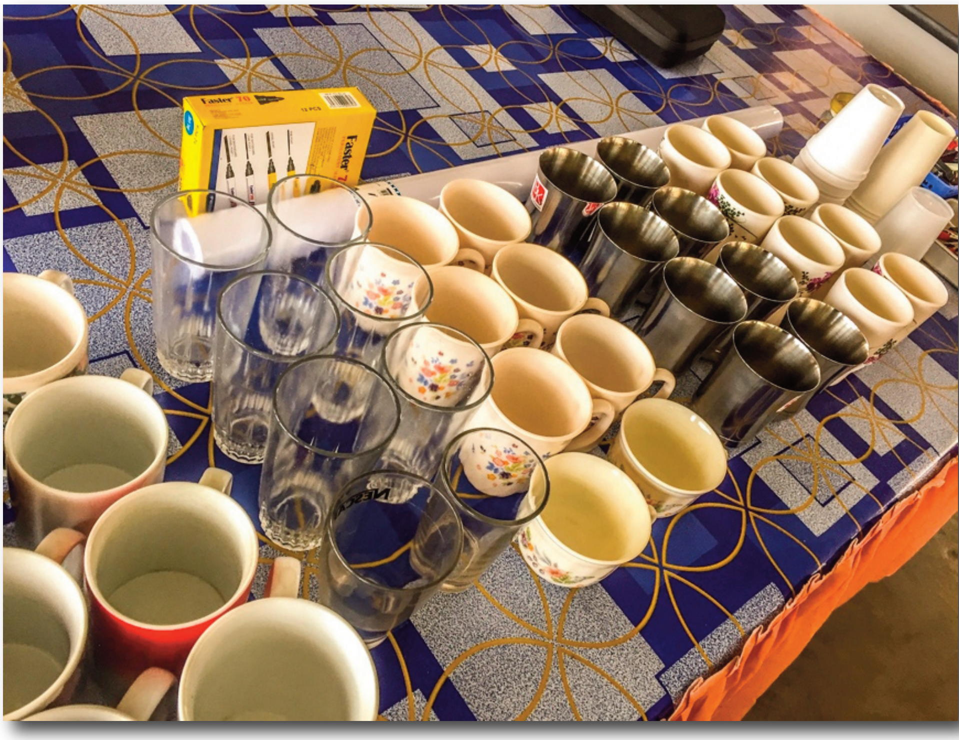
The lesson plan focused on addressing two key areas of the curriculum standards: conceptual understanding of key scientific ideas related to the properties of materials, and enquiry-based science teaching. Through the use of the SOLO model, the activities were designed to target the multi-structural, relational, and extended abstract levels. The first activity aimed to identify and correct children's misconceptions about the materials used to make the cups, while the second activity encouraged children to explore and identify the properties of different materials. Finally, the third activity challenged children to make evidence-based decisions about which cup was the best for drinking purposes and to present their arguments.

The enquiry-based science teaching sequences

Activity 1 – 'Naming the cups' (multi-structural)

Children entered the science classroom and sat in the groups of six that they had chosen. They brought cups from home and shared them with their peers. The teacher also provided several types of cup as a reserve to ensure that each group had a diverse selection, with a similar number of cups (n=8) for each group (see Figure 1). The first activity was to name the materials that the cups were made from and to write these names on the sticky notes provided. Within their groups, the children discussed and named the cups based on their existing knowledge. The teacher facilitated the children's discussion, checked groups' answers and corrected any misconceptions identified. This process is crucial in enquiry-based teaching, as it encourages children to use their higher-order thinking skills. Volunteer groups were also given the opportunity to present their findings to the class and a whole-class discussion was facilitated. The groups made corrections to the labels if they discovered any errors. The teacher explained that the children were beginning to investigate the eight cups like scientists. In the subsequent activities, the children were encouraged to work like scientists, by engaging with a series of activities that led to various conclusions. Thus, children discovered that science is a tentative activity that relies on experimentation.

Figure 1. Eight different types of cups were prepared for groups of children to investigate.



Materials:
1. Polystyrene cup
2. Melamine cup
3. Porcelain cup
4. Ceramic cup
5. Plastic cup
6. Stainless steel cup
7. Glass cup
8. Paper cup

The integration of scientific enquiry

In this activity, the children were required to name a variety of cups. This activity aimed to develop the children's science literacy by encouraging them to observe and classify the cups based on the material that they were made from (Mat Noor, 2021). The children used their sense of touch to identify the material that the cups were made from and grouped them according to similarities or differences. They also used their past experiences to make inferences about the cups and to name them. This activity aimed to develop the following thinking skills in children: attributing, comparing and contrasting, grouping and classifying, generating ideas, and making inferences (Zimmerman, 2007).

Activity 2 – 'Defining the properties of the cups' (relational)

The teacher provided a sheet of white flipchart paper with a prepared table template to each group and instructed the children to discuss in their respective groups the properties of each cup in front of them. The children shared ideas and engaged in a discussion with their friends. The teacher also instructed each group to come up with at least five variables, and they were told that each variable must be testable through investigation. Each group completed the task by suggesting 'the properties of the cups' (see Figure 2) and writing them in the first column of the table, as shown in Table 4. The teacher then offered the groups the opportunity to volunteer to present the outcome of their discussion in front of the class. The children were encouraged to justify why they had chosen certain variables. It was important for the teacher at that time to accept children's views and facilitate the discussion openly. The teacher would intervene if anything was incorrect, asking the children to justify their chosen properties of materials and correct any misconceptions.

Table 4. Example of the 'properties of materials' in the first column of the table that the children were expected to come up with.

	Cup 1	Cup 2	Cup 3	Cup 4	Cup 5	Cup 6	Cup 7	Cup 8
Waterproof								
Light/Heavy								
Insulator								
Recyclable								
Reusable								
Durable								

Figure 2. In their respective groups, children discuss the properties of the cups' materials.

The integration of scientific enquiry

The children collaborated as a team to generate ideas and prepare arguments for their scientific investigation (Muhamad Dah *et al*, 2023). By doing so, the children engaged in argumentation, a crucial social process where they co-operatively aligned their intentions and interpretations through a verbal rationale, thereby enhancing their understanding of scientific content and processes (Evagorou *et al*, 2020). They used their senses of hearing, touch, smell and sight to observe and identify the properties of the cups provided. They controlled variables by naming the manipulated variable and the different properties of the cups. They used a prepared template (table) to communicate their findings and explain their chosen variables. Through this activity, the children were able to practise the processes of grouping and classifying, analysing, visualising and synthesising information.

Activity 3 – 'Grading the cups' (extended abstract)

The groups carried out practical activities based on the chosen properties of materials (see Figure 3) and scored the cups that were the most practical to drink from on a scale of one to three, with one being the lowest and three being the highest (see Figure 4). They carefully discussed and determined the score for each cup based on its properties and materials. Through this process, the children determined which cup was the best based on the highest score achieved, as shown in Table 5. Each group then prepared arguments to justify their choice of the best cup for everyday use.

Figure 3. Children carried out practical activities to test the properties of the cups.

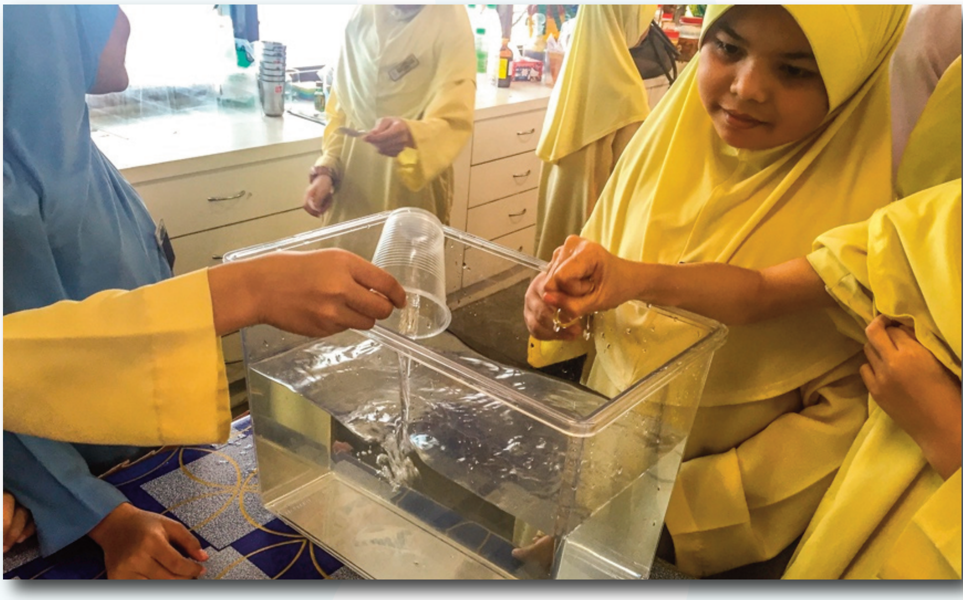
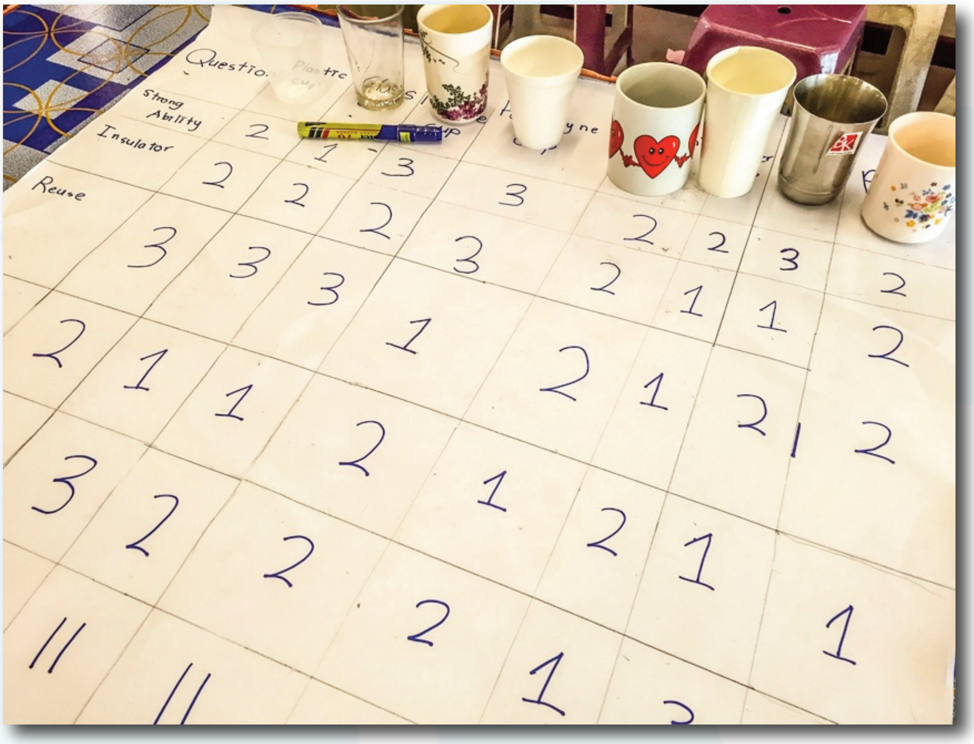


Table 5. Example of the score graded by one of the children's groups: Cup 4 is considered to be the 'best' cup.

	Cup 1	Cup 2	Cup 3	Cup 4	Cup 5	Cup 6	Cup 7	Cup 8
A	1	2	3	3	2	1	3	2
B	3	1	2	3	3	3	1	3
C	3	2	1	2	1	3	1	1
D	1	3	2	2	1	1	1	1
E	1	2	2	3	3	1	2	3
Total	9	10	10	13	10	9	8	10

Figure 4. Children discussed and scored the properties of each cup.



The teacher facilitated the children's discussion and reviewed each group's answers as they shared them with the class. At the same time, the teacher corrected any misconceptions and mediated the children's conceptual understanding of the properties of materials. The class then engaged in a discussion to explore and challenge the groups' various thinking strategies and to understand why each group had different answers and chose different cups as the best. After all groups had drawn their conclusions, the teacher emphasised that, in science, scientists continually test and challenge previous assumptions and findings.

The integration of scientific enquiry

In this activity, the children learned about the nature of science, specifically that scientific knowledge is tentative and always open to interpretation (Cleminson, 1990). As part of the activity, they used their past experiences to make inferences about the properties of different cups. They also measured different variables and used numbers, making quantitative observations by comparing each cup to a non-conventional standard. Additionally, they interpreted the data they collected by offering rational explanations about their choice of best-scoring cup. All groups also drew conclusions about the other cups, providing reasoning for why their scores were lower than those of the 'best cup'. Through this activity, the children also practised key science skills such as sequencing, prioritising, evaluating and making conclusions (Zimmerman, 2007).

Conclusions

Research indicates that the implementation of enquiry-based science teaching sequences in the classroom was an effective way to engage children in hands-on, interactive learning experiences (Kamarudin & Mat Noor, 2023). In the study, the use of various materials, such as cups, allowed children to observe and classify objects based on their properties, and to develop their science literacy and thinking skills.

The first activity, 'Naming the cups', provided children with the opportunity to observe and classify cups based on the materials that they were made from, using their sense of touch and their prior knowledge to identify and name the cups. This activity aimed to develop children's thinking skills, including processes such as attributing, comparing and contrasting, grouping and classifying, generating ideas, and making inferences. In the study, most of the children were initially unaware of the variety of cups differentiated by their properties. They learned about different types of cups and the materials that they were made from. The second activity, 'Defining the properties of the cups', allowed children to work in groups to discuss and generate ideas about the properties of the cups, such as whether they were waterproof or durable. Children were asked to come up with at least five testable variables, and were given the opportunity to present their findings to the class and justify their choices. This activity aimed to develop children's skills in grouping and classifying, analysing, visualising and synthesising information. In the study, most groups identified numerous variables, some of which were incorrect. However, they were given opportunities to explain their choices, and the teacher corrected their misconceptions along the way. The final activity, 'Grading the cups', enabled children to observe the cups, determine their properties, and then score the cups on a scale of one to three, with the highest score indicating the best cup for everyday use. Children were then asked to justify their choice and engage in a class discussion to challenge and understand different perspectives. This activity aimed to help children to understand the scientific process of continually testing and challenging previous assumptions and findings. In the study, all groups arrived at different results, and they were guided by teachers to draw conclusions. Most importantly, the children learned indirectly that science is tentative, and that the methods and results of investigations can vary, often leading to diverse outcomes.

Overall, the implementation of enquiry-based science teaching sequences in the classroom provided children with opportunities to engage in hands-on, interactive learning experiences, and to develop their scientific literacy and thinking skills. The use of materials such as cups allowed children to observe and classify objects based on their properties, and to work collaboratively and effectively to communicate their findings. These skills included dialogic exchanges, where children actively engaged in meaningful discussions, enhancing their understanding through verbal reasoning and an exchange of ideas. Argumentation played a significant role, enabling students to present and evaluate arguments, a process crucial for scientific reasoning. Social constructivist aspects, such as the 'power of the group brain' as highlighted by Vygotsky (see Erbil, 2020), were evident in the collaborative group dynamics. Working in these groups was relevant as it mirrored the collaborative nature of scientific enquiry and allowed children to learn from and with each other, thereby building a collective understanding and advancing their individual cognitive development.

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