

Research Article:

The Engagement of Jahai Indigenous Pupils in Integrated STEM-EDP Learning through the Kombucha Tea Fermentation

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ABSTRACT

This scholarly work delved into the integral role of engineering in STEM (Science, Technology, Engineering, and Mathematics) education, particularly focusing on the contemporary emergence of the Engineering Design Process (EDP) within the landscape of science education reform. The EDP is identified as a catalyst for fostering active engagement in science learning, encompassing cognitive, behavioural, and emotional dimensions, though a prevailing lack of information among science teachers regarding its effective application persists. This study investigated the integration of STEM-EDP learning using kombucha tea fermentation aimed to enhance pupils' engagement, particularly for Orang Asli pupils. The purpose is to bridge modern educational strategies with indigenous traditions to boost engagement and learning outcomes in STEM. A one-group pre-test-post-test design was employed to craft a unified STEM learning experience for Jahai tribe pupils in a rural school within the Royal Belum Rainforest, Perak, Malaysia. The study involved 16 pupils and utilised a STEM Learning Experience Survey and reflective journal to gather data on teacher observations and pupils' work. Results showed that STEM-EDP Kombucha effectively immersed pupils in the learning process, facilitating a deeper understanding of life processes and the factors influencing microorganism growth and use. Despite its promising outcomes, the study is limited by its small sample size. Nonetheless, it introduces an innovative instructional approach that is uncommon in Malaysian primary schools today. Teachers may use this approach to create a more captivating and engaging educational setting, thereby enhancing pupils' enthusiasm for STEM disciplines.

Keywords: STEM education, engineering design process, kombucha tea fermentation, pupil engagement, indigenous education

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INTRODUCTION

Science education has seen remarkable global advancements through the fusion of dynamic teaching innovations, seamless technology integration, and a steadfast commitment to enhancing scientific literacy (Saro et al., 2023). Pupils are now actively producing innovative products and solutions as part of their science education, fostering a culture of creativity and problem-solving. Integrating innovative pedagogical approaches has been a driving force behind the advancements in science education. These approaches include where the pupils are given with solving real-world problems or designing innovative products, which encourages them to apply their scientific knowledge and develop critical thinking skills (Suradika et al., 2023).

The recognition of the need for stronger scientific literacy and competency has marked a pivotal moment in addressing the challenges of today's rapidly changing world. Traditional science education, however, has often emphasised rote memorisation over the cultivation of critical thinking and problem-solving skills (Fitriani et al., 2020; Jamil et al., 2021). This limitation leaves many pupils ill-prepared to apply scientific knowledge to real-life contexts. As Tang et al. (2020) emphasise, focusing on higher-order skills is essential for equipping learners to navigate complex and dynamic issues, thereby enabling them to contribute meaningfully to society.

To address this, integrating STEM education with the Engineering Design Process (EDP) has been proposed as a promising approach. The EDP provides a structured methodology for problem-solving, encompassing steps such as defining the problem, selecting solutions, modelling, analysing, and iterating designs (Berland et al., 2014). Placing pupils at the centre of this process has been shown to strengthen engagement (Struyf et al., 2019; Yata et al., 2020), while also enhancing their ability to apply science and mathematics to practical challenges (English & King, 2015). Through systematic cycles of prototyping, testing, and refinement, pupils develop critical competencies in research, innovation, and decision-making (Bartholomew, 2017).

In this study, the EDP-STEM Kombucha experiment was implemented to nurture innovative thinking in STEM. While kombucha-making is traditionally artisanal, applying EDP principles highlights how systematic design can optimise processes and outcomes, linking scientific concepts with hands-on, culturally relevant experiences. Such an approach resonates with Sustainable Development Goal 4 (SDG4), which calls for inclusive and equitable quality education for all (Bansal et al., 2024).

Nonetheless, ensuring inclusivity requires particular attention to indigenous pupils, who often face significant barriers in STEM education. In Malaysia, *Orang Asli* pupils, especially those from the Negrito sub-ethnicity, continue to experience disparities in participation and achievement (Jin, 2021; Idrus & Nan, 2023). Although STEM

initiatives have been introduced in indigenous communities, many have struggled with issues of cultural relevance, sustainability, and alignment with formal curricula. Some were externally driven or short-term, limiting their long-term impact. Moreover, research by Magee et al. (2024) and Ganesan (2020) highlights challenges in teacher leadership, historical perspectives, and gaps in culturally relevant pedagogy, while very few documented interventions directly address indigenous STEM education in Malaysia.

To move forward, it is critical to embed indigenous knowledge and perspectives within STEM programmes in ways that are culturally responsive and curriculum-aligned (Tapia et al., 2018; Shukri et al., 2020). Engaging *Orang Asli* pupils in hands-on activities such as EDP-based experiments allows them to connect local practices with scientific principles, fostering both understanding and engagement. This integration reflects a holistic view of science that recognises the interconnectedness of human life, culture, and the environment, while valuing indigenous contributions to scientific knowledge (Zidny et al., 2020).

LITERATURE REVIEW

Theoretical Underpinnings: Constructivism and Culturally Responsive Pedagogy

This study is anchored in constructivist learning theory, which views learners as active participants in building their own understanding rather than passive recipients of information (Piaget, 1970; Vygotsky, 1978). From this perspective, meaningful learning happens when pupils engage directly with tasks, experiment with ideas, and collaborate with others to solve problems. In STEM education, this approach is particularly relevant because it aligns with inquiry-based and hands-on learning, such as the EDP. Through the EDP, pupils test out solutions, learn from mistakes, and refine their ideas—processes that mirror the iterative nature of knowledge construction (Bartholomew, 2017; McKinney, 2023).

In parallel, culturally responsive pedagogy (CRP) stresses that pupils' cultural backgrounds are not peripheral but central to learning. CRP highlights the importance of drawing on learners' cultural knowledge, values, and practices to make learning experiences more engaging and meaningful (Ladson-Billings, 1995; Gay, 2010). In the context of Indigenous education, this approach ensures that learning is not only academically rigorous but also affirming of pupils' cultural identities, which has been shown to strengthen participation and motivation in STEM (Bang & Medin, 2010; Kanu, 2011).

Taken together, constructivism and CRP provide the theoretical backbone for this research. Constructivism explains why problem-based, iterative approaches like the EDP can deepen understanding, while CRP explains why integrating practices such as kombucha-making can make STEM more relevant to Indigenous pupils. This combined lens guides the study's design, linking integrated STEM education, the EDP framework, and culturally meaningful activities like kombucha production, which are further elaborated in the following sections.

Integrated STEM Education and Indigenous Pupils

Integrated STEM education can be meaningfully understood through the lens of constructivism and CRP. Constructivism highlights the importance of pupils actively constructing their knowledge through hands-on experiences, while CRP emphasises connecting learning to pupils' cultural backgrounds (Piaget, 1970; Vygotsky, 1978; Ladson-Billings, 1995; Gay, 2010). For Indigenous pupils, STEM learning that acknowledges their lived realities and local practices has been shown to foster stronger engagement and deeper understanding (Bang & Medin, 2010; Kanu, 2011). Thus, integrated STEM education provides not only the content knowledge but also the opportunity to design culturally relevant learning experiences that can close existing equity gaps.

STEM Education in Malaysia is frequently incorporated into the teaching and learning of science and mathematics subjects. Moore et al. (2014) define integrated STEM education as an approach that combines some or all the four disciplines: science, technology, engineering, and mathematics into a single unit or lesson. This integration is based on the connections between the subjects and is aimed at addressing real-world problems. Kelley and Knowles (2016) further explain that STEM practices are best situated within authentic contexts, which serve to link these subjects together in a way that enhances pupil learning.

The Ministry of Education (MOE) Malaysia has been instrumental in shaping STEM policies and frameworks through the development of curriculum guidelines and the implementation of teacher training programs. The ministry has also introduced numerous initiatives to promote effective science education practices, particularly in primary and secondary schools. As outlined in the Malaysia Education Blueprint (MOE, 2013). MOE Malaysia has implemented a series of initiatives to bolster STEM education. These include integrating STEM-focused curriculum elements that promote the application of scientific and mathematical concepts in real-world scenarios, establishing STEM clubs and extracurricular activities for hands-on learning, incorporating technology in the classroom with educational software and digital resources, forging partnerships with industry and higher education for career exposure and real-world applications, and providing professional development for teachers to

enhance their STEM inclusion teaching skills and stay current with educational trends. These initiatives reflect the MOE's commitment to fostering a culture of innovation and scientific literacy among pupils, preparing them for the challenges of the 21st century and the demands of a knowledge-based economy.

In Malaysia, the integration of indigenous perspectives into STEM education is a growing initiative aimed at creating a more inclusive and culturally responsive learning environment. Indigenous pupils, who are part of the diverse cultural fabric of the country, bring unique knowledge and experiences that can enrich STEM education. By incorporating indigenous wisdom, practices, and worldviews into the STEM curriculum, educators can foster a sense of belonging and relevance among indigenous pupils, encouraging their engagement and success in STEM fields (Ghani, 2021). This approach not only respects and values indigenous cultures but also promotes a holistic understanding of science and technology that is grounded in local contexts and global perspectives.

As Malaysia continues to develop its STEM education system, the of indigenous voices and knowledge will be crucial in building a more equitable and diverse scientific community. To modernise teaching methods and equip pupils with 21st-century skills, STEM educators are encouraged to innovate their science curriculum delivery. The aim is to cultivate inquiry, critical thinking, teamwork, and prepare pupils for innovative careers. Global organisations like the Organisation for Economic Cooperation and Development (OECD) and National Science Teacher Association (NSTA) endorse this approach. Integrating indigenous perspectives into STEM education, as seen in countries like Australia, India, Indonesia, the United States, Canada, and Europe, can enrich learning and foster inclusivity. Malaysia can draw from these international examples to create a more diverse and culturally responsive STEM education system that acknowledges indigenous knowledge and experiences.

Engineering Design Process (EDP)

The EDP reflects the principles of constructivist learning, as it engages pupils in iterative cycles of problem-solving, testing, and refining ideas (Bartholomew, 2017; McKinney, 2023). In constructivist terms, pupils learn best when they actively construct meaning by doing, reflecting, and revising—precisely what the EDP requires. At the same time, EDP can be implemented in ways that are culturally responsive, for example by framing design challenges around issues that are relevant to pupils' local communities and cultural practices. This dual alignment positions the EDP as a powerful pedagogical tool to build both STEM competency and cultural relevance in the classroom (Winarno et al., 2020; Struyf et al., 2019).

The EDP is a systematic, iterative approach that enables pupils to tackle complex problems by developing and refining solutions through defined stages (Bartholomew, 2017). The process begins with problem identification, where constraints and contextual needs are clarified (McKinney, 2023; Studer et al., 2018). From there, pupils generate multiple ideas, often through brainstorming and modelling, before narrowing down the most feasible options (Bartholomew, 2017; Studer et al., 2018; Winarno et al., 2020). Evaluation and prototyping provide opportunities to test, simulate, and gather feedback, while the iterative cycle of revisiting earlier stages encourages resilience and ongoing improvement (McKinney, 2023).

Research has consistently highlighted the benefits of EDP in STEM learning, including the development of critical thinking, creativity, and collaboration (Winarno et al., 2020). Pupils gain practical experience in applying scientific and mathematical concepts, building prototypes, and making evidence-based decisions (Bartholomew, 2017; Studer et al., 2018). However, despite its pedagogical value, existing studies often emphasize short-term classroom outcomes and provide limited evidence on scalability or long-term impact. Winarno et al. (2020) also note that implementing EDP can be time-intensive, resource-heavy, and difficult to assess due to the subjective nature of evaluating design processes and outcomes. Additionally, not all pupils thrive in open-ended and ambiguous problem-solving environments, raising concerns about equity and differentiated support. These gaps indicate the need for further research on sustainable implementation, assessment strategies, and context-sensitive adaptations of EDP in diverse educational settings.

Building on the principles of the EDP, which emphasises iterative problem-solving, creativity, and contextual application, this study positions kombucha-making as a culturally relevant medium through which these skills can be cultivated. While prior research highlights the strengths of EDP in fostering critical thinking, teamwork, and innovation, less attention has been given to how such processes can be localised and made meaningful within Indigenous learning contexts. The kombucha product, therefore, is not merely a scientific activity but a culturally grounded entry point that situates STEM-EDP within everyday practices, enabling learners to see the relevance of abstract concepts in tangible, community-based experiences.

Kombucha Production

The inclusion of kombucha production as a STEM activity reflects the principles of both constructivism and CRP. From a constructivist perspective, brewing kombucha provides pupils with an authentic, hands-on opportunity to investigate biological and chemical processes, moving beyond rote memorisation into applied scientific inquiry (Antolak et al., 2021). At the same time, kombucha-making can serve as a culturally responsive practice, as it connects science learning to traditional and community-based

knowledge of fermentation and food practices (Campos Costa et al., 2023; Zidny et al., 2020). By integrating such practices into STEM education, pupils are encouraged to view science not as abstract knowledge but as something interwoven with daily life and cultural heritage.

Kombucha is a fermented tea beverage traditionally made from black or green tea and a symbiotic culture of bacteria and yeasts (SCOBY). Its origins can be traced to ancient China, and it has since acquired various cultural identities—for example, Mut-mut water or Mecca mushroom water in Malaysia, Kocha Kinoko in Japan, and Manchurian mushroom tea in other regions (Antolak et al., 2021). During fermentation, SCOBY produces a cellulose mat on the tea surface, offering a vivid example of microbial activity that pupils can directly observe (Antolak et al., 2021). For education, kombucha provides a tangible entry point into concepts such as symbiosis, microbial ecology, and biochemical transformation, making science learning more engaging and contextually meaningful.

In addition to its cultural and scientific relevance, kombucha has been studied for its health benefits. Research reports positive effects such as lowering cholesterol and blood pressure, inhibiting cancer cell growth, and improving liver, immune, and gastrointestinal function (Campos Costa et al., 2023; Motafeghi et al., 2023). Probiotic content supports gut health and nutrient absorption, while antioxidants help counter free-radical damage (Campos Costa et al., 2023; Vargas et al., 2021; Leal et al., 2018). However, much of this literature is grounded in biomedical or laboratory studies, which may not be directly applicable to classroom learning contexts. While these findings highlight kombucha’s broader relevance, more research is needed on how fermentation-based activities can be adapted into formal curricula in ways that are sustainable, culturally responsive, and pedagogically effective. The concept of STEM integration in the kombucha making process is shown in Table 1.

Table 1. Concept of STEM integration in kombucha making process

Discipline	Explanation
Science	Understanding of types of microorganisms (bacteria and yeast); understanding of the life process of microorganisms (breathing, moving and growing); application of the use of microorganisms; and the application of factors that affect the growth of microorganisms (temperature, air, acidity and nutrients).
Technology	Testing kombucha through observation in terms of taste quality, the presence and condition of SCOBY, acidity, and sugar content so that the kombucha produced is of the right quality to be used as a health product.

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Table 1: (Continued)

Discipline	Explanation
Engineering	Designing and producing kombucha through fermentation 1 and fermentation 2 which involves the suitability of equipment and materials; the location of fermentation; in addition to the factors that affect the growth of microorganisms.
Mathematics	Measure the mass of filtered water and sugar; measure acidity using a pH meter; measure the sugar content using a Brix refractometer (ignoring the acidity and sugar content can cause the SCOBY to die from being overgrown with fungus which eventually slows down the kombucha fermentation process).

Based on Table 1, it is important to relate the STEM concept to the T&L approach and strategy to ensure that pupils completely understand the interdependence of science, technology, engineering, and mathematics in real-world applications. Integrating STEM into the T&L process enhances the overall educational experience by fostering critical thinking, problem-solving skills, and creativity.

METHODOLOGY

Research Design

This study employed a convergent mixed methods design by integrating survey data (quantitative) and reflective journals (qualitative) to evaluate indigenous pupils' understanding and experiences with the kombucha making process. A one-group pre-test-post-test design was employed in this study. The survey served as a structured method to assess pupils' knowledge acquisition after the intervention. To complement the survey, reflective journals were used as a qualitative tool to explore pupils' experiences, challenges, and engagement with the kombucha process. The pupils expressed their opinions verbally and the researcher recorded the observations. These include the pupils' learning experience, emotional engagement, and cultural relevance of kombucha-making. The qualitative data was analysed thematically to identify patterns. The integration of these two methods ensures a holistic understanding; while the survey provides structured, measurable results, the reflective journals offer contextual insights into how and why pupils engaged with the learning process. This mixed approach strengthens the study by validating findings across different data sources, enhancing both reliability and depth of analysis (Creswell & Creswell, 2017).

Participants

This study included 16 *Orang Asli* primary school pupils from Royal Belum Rainforest area, Gerik, Perak, Malaysia. All respondents ($N = 16$) were *Orang Asli* pupils from the Jahai tribe's Negrito sub-ethnicity. The participants were selected using purposive

sampling. In educational research, purposive sampling involves selecting participants or samples deliberately based on specific criteria to ensure they are particularly relevant or informative for the research question at hand (Creswell et al., 2006). For the content, Microorganisms topic was selected. To deliver a content syllabus, the teacher utilised hands-on activities in their lesson so that the topic is presented in a more engaging manner (Shukri et al., 2020). The pupils involved were not proficient in reading and participated in activities through observation and led by the group leader who is proficient in reading.

Instrument

This study employed two main instruments for data collection: the STEM Learning Experience Survey adapted from Charteris and Thomas (2021) and teacher observations through a reflective journal. These instruments were selected to provide a comprehensive view of the project's outcomes with rich data, as they offer unique perspectives on the study's objectives. According to McNiff (2010), using multiple instruments enhances the study's credibility by offering different perspectives on the same issue.

The STEM Learning Experience Survey was designed to collect pupils' perceptions on STEM learning experiences via EDP. The survey is structured into three sections, comprising a total of 14 items and two open-ended questions to capture a comprehensive range of pupil perceptions. The first section is dedicated to capturing pupils' perceptions of STEM learning experiences, the second focuses on their perspectives on the hands-on activities, where before introducing the kombucha making process, the hands-on activities were those found in the science textbook, such as Grow Molds on Bread and Blow Up Balloon with Yeast and the third section provides an opportunity for detailed feedback through open-ended questions. The survey instrument underwent validation by three experts, with two experts evaluating the content validity and one expert assessing the language clarity and appropriateness. Pupils were instructed to provide binary or dichotomous responses to streamline the data collection process and improve the quality of the data, aligning with recommendations by Coskun et al. (2020).

The validation method confirmed that the survey instrument was trustworthy and appropriate for evaluating pupils' perspectives with overall validity index, CVI = .87. The experts provided valuable suggestions, particularly on enhancing question phrasing to improve clarity and ensure alignment with the study's objectives, demonstrating the iterative improvement process of the survey instrument. The content validation method validated that the survey items accurately reflected STEM learning and hands-on activities in general, and the language expert guaranteed that the questions were understandable to the target respondents. Minor changes were made based on the experts' advice to increase readability while maintaining the original message. In addition, a pilot test with a small sample of pupils ($N = 15$) was done to evaluate the

instrument's usefulness. The instrument demonstrated acceptable internal consistency, with $\alpha = .77$, indicating that pupils responded to the items with clarity and without misunderstanding. This supports the reliability and usefulness of the instrument in measuring the intended constructs (Nunnally & Bernstein, 1994).

Besides, this study used a reflective journal, which functioned as a tool for teachers to document detailed observations on pupil engagement and progress, serving as a valuable resource for capturing insights and reflections on the educational intervention. It has two main purposes: to enable teachers to record and reflect on pupils' activities and to understand the intervention's impact on pupil engagement. Thus, the journal is divided into two sections as outlined by Charteris and Thomas (2021). The first involved frequent notes and observations by the teacher. Observations provided insights into pupils' practical abilities and potential to make kombucha as a product from the *Orang Asli* Jahai community. The reflective journal also served as reflective practice, such as emphasised by McNiff and Whitehead (2006), where it involves the teacher keeping a journal throughout the project. The reflections were based on teachers' observations on pupils' engagement and achievements in making kombucha.

To analyse the qualitative data, thematic analysis was employed, following Kushnir (2025) six-phase framework; (i) familiarisation with data, (ii) generating initial codes, (iii) searching for themes, (iv) reviewing themes, (v) defining and naming themes, and (vi) producing the report. Coding was conducted manually and focused on identifying patterns related to pupil engagement and emotional responses. To enhance the trustworthiness of the analysis, intercoder reliability was established by involving a second researcher who independently coded a subset of the data. The level of agreement was discussed and refined to ensure consistency and credibility in theme development.

By combining these approaches, the teacher gained a holistic understanding of pupil participation and engagement, providing valuable insights for current teaching practices and showcasing pupils' learning and innovative abilities. This comprehensive approach ensured a thorough evaluation and understanding of the educational intervention's impact.

DATA COLLECTION

Kombucha Production

This part explains the production of kombucha following EDP steps. The elements of STEM are also presented. The integration of STEM in the kombucha making process was done through the five phases of the EDP (Bartholomew, 2017), which are detailed in Table 2.

Table 2. Five phases of EDP

Phase	Activity	Notes								
<p>Problem Identification</p> <table border="1" style="margin-left: 20px;"> <tr> <td style="text-align: center;">S</td> <td style="text-align: center;">/</td> </tr> <tr> <td style="text-align: center;">T</td> <td></td> </tr> <tr> <td style="text-align: center;">E</td> <td></td> </tr> <tr> <td style="text-align: center;">M</td> <td></td> </tr> </table>	S	/	T		E		M		<p>1. Pupils were shown a video about the situation during and after the COVID-19 pandemic in Malaysia.</p> <p>https://www.youtube.com/watch?v=vhkGAdG4CHA</p> <p>https://www.youtube.com/watch?v=c5axWyWD22Y</p> <p>2. Based on the video, pupils' questions and answers with the teacher guided by Socratic questioning as follows.</p> <p>Questions to determine why: What is the cause of COVID-19?</p> <p>Questions related to views:</p> <ul style="list-style-type: none"> - In your opinion, will we continue to live with COVID-19 forever? - Can someone refuse vaccines? - In addition to wearing a face mask and taking care of personal hygiene, does nutrition play an important role? <p>Questions related to implications:</p> <ul style="list-style-type: none"> - What will happen to individuals who refuse vaccines? - Is there a good effect if we take care of our diet to avoid COVID-19? <p>Question for qualifications:</p> <p>Do you try to explain why a healthy diet can curb the spread of COVID-19?</p>	<p>First, accept all pupil responses. Collect as much information as you can about COVID-19.</p> <p>Encourage each pupil to express their opinion by offering awards to daring pupils.</p>
S	/									
T										
E										
M										

(continued on next page)

Table 2: (Continued)

Phase		Activity	Notes
Idea Exploration		1. Pupils and teachers have an in-depth discussion about the Socratic questions that have been asked.	Show a video of the benefits of kombucha according to a medical doctor
S	/		
T		2. All answers received from pupils are corrected and explained further.	https://www.youtube.com/watch?v=zMCcA1pNQ1s
E			
M		3. The teacher stressed that taking care of personal hygiene and taking vaccines is still not enough. Our body needs a strong defense system because viruses are becoming increasingly varied. A healthy diet can strengthen the body's immune system. By practicing kombucha (infused tea water) can reduce cholesterol and blood pressure levels and strengthen the liver, gastrointestinal tract and immune system.	In addition to fruits and vegetables that not all individuals eat or eat in small quantities, an easy way is to practice kombucha.
Planning and Development		1. Materials such as tea powder (black tea), SCOBY, sugar, filtered water, glass jar, glass bottle, spoon, Brix refractometer, pH meter, gloves, and face mask are provided.	Mature kombucha contains about 2–6 grams of sugar (1/2 teaspoon) in 240 ml of kombucha.
S	/		
T	/		The fermentation process must start with 6 °Bx sugar and above.
E	/		
M	/	2. Pupils are guided to carry out investigative activity based on the instruction cards and demonstrations shown.	For pupils to know the types of microorganisms that exist in SCOBY – bacteria and yeast) along with the name of the bacteria (acetic acid bacteria and lactic acid bacteria).
		<ul style="list-style-type: none"> • Prepare tea water. • Dissolve the sugar in the tea water. • Let the tea cool at room temperature. • Put tea water into a glass jar. • Add the SCOBY with some kombucha. • Cover the mouth of the glass jar with gauze or muslin cloth. • Store the glass jar with its contents in a place that is not exposed to sunlight for 10–14 days (fermentation 1). • Every two days, record observations on the presence of new SCOBY, acidity (pH meter) and sugar content (Brix refractometer). 	Relate the life processes of bacteria and yeast. Microorganisms breathe – briefly cover the glass jar with an airtight lid. Note the resulting water vapor on the lid. Microorganisms move – kombucha under the microscope
			https://www.youtube.com/shorts/Dzd2BN8I2DM

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Table 2: (Continued)

Phase		Activity			Notes
Day	Presence of new SCOBY (✓ / X)	pH	°Bx	<p>Microorganisms grow – SCOBY growth from day to day.</p> <p>Factors that affect the growth of microorganisms – a good temperature of 24°C–29°C; air; acidity pH 4–4.5; nutrients - sugar</p>	
0					
2					
4					
6					
8					
10					
12					
14					

- After 10–14 days, transfer the old and new SCOBYs into another container (SCOBY hotel).
- The resulting kombucha is stored in a bottle.
- Flavor kombucha using fruit (raisin/ pineapple/strawberry/plum/kiwi).
- Store flavoured kombucha for three days in a place not exposed to sunlight (fermentation 2).
- Pupils make observations on the condition of flavoured kombucha on the first, second, and third day.

Day	Observation
1	
2	
3	

(continued on next page)

Table 2: (Continued)

Phase	Activity	Notes
Tests and Evaluation	<ol style="list-style-type: none"> 1. Pupils test the kombucha in the first fermentation process in terms of taste (gassy, sour, slightly sweet), the condition of the SCOBY (thickness and health; healthy if not overgrown with fungi), acidity and sugar content (depending on the volume of the kombucha) which shows that the kombucha has matured. 2. Pupils test the kombucha in the second fermentation process in terms of taste (does gas increase? is it sourer?) 3. If the kombucha produced is successful, guide the pupils to commercialise the kombucha product as one of the Jahai Indigenous products 	<p>Relate kombucha to the use of microorganisms in industry.</p> <p>https://www.youtube.com/watch?v=l078iZpF9wg</p>
Sharing Solution	<ol style="list-style-type: none"> 1. Pupils share the results of the products with other group members and teachers at school. 2. Pupils are guided to explain the benefits of bacteria and yeast in the process of making kombucha as well as the benefits of using kombucha for health to school members. 3. The development of STEM-Kombucha investigation activity is also documented on social media (Facebook) for mutual sharing. 	<p>Sharing on Facebook social media</p> <p>https://www.facebook.com/groups/484532227198073</p>

Making kombucha requires two fermentations steps. The first fermentation takes 10 to 14 days for the kombucha to reach maturity. This relies on the kombucha’s acidity (pH) and sugar level (°Bx). Matured kombucha is ready to drink, having a sweet and sour flavour. Not everyone can tolerate such a flavour, but the second fermentation can be extended to give the kombucha a pleasant flavour by incorporating their preferred fruits. The chosen fruit is ground with a little kombucha. Next, the pulverised components are combined in a glass bottle filled with kombucha. The second fermentation takes three days. Throughout the process of making kombucha, the four disciplines of science, technology, engineering, and mathematics are integrated together. In addition, the three life processes of microorganisms, which are breathing, moving, and growing are questioned orally to the pupils in the process. Among the questions asked are, “What are the three life processes of microorganisms?” Through this activity, how do you prove that microorganisms (SCOBY) breathe? Can you tell me how SCOBY grows? What about the movement of microorganisms? Can you see the bacteria and yeast moving?”

Functional testing is necessary for the STEM integration of the pupil-produced solution products (kombucha). Therefore, the formative assessment in the STEM-Kombucha investigative activity involves observing the first day the kombucha is left to ferment. The process of SCOBY formation was recorded, and the diagram is shown in Figure 1.

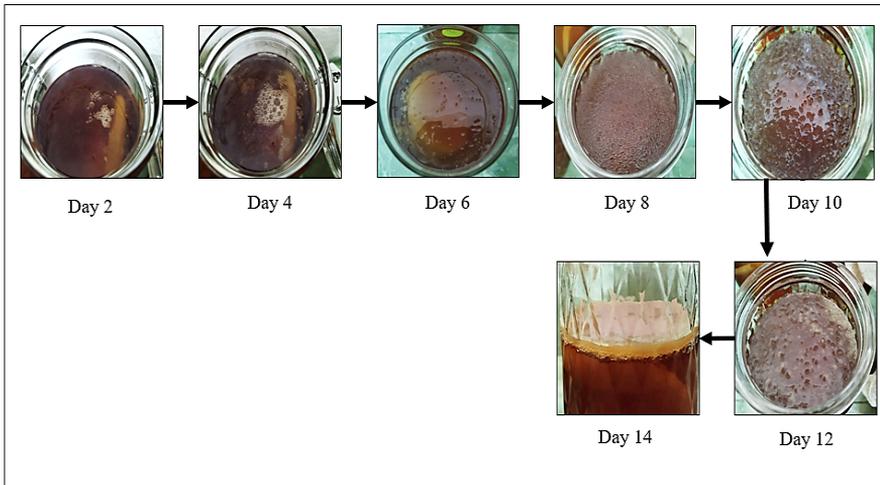


Figure 1. Formation process of symbiotic culture of bacteria and yeast (SCOBY)

Based on Figure 1, the SCOBY formation was observed for every two days interval, and the data was recorded from the aspects of SCOBY presence, acidity and sugar content every two days, starting day two until day 10 or day 14. The initial product for the first fermentation process is called new SCOBY, as shown in Figure 2.

Based on Figure 2, the fermentation of kombucha was done with the formation of a new SCOBY that was healthy and thick on the surface of the kombucha. After the new SCOBY was formed, the kombucha was then let ferment for the second part, as shown in Figure 3.



Figure 2. A matured kombucha after first fermentation

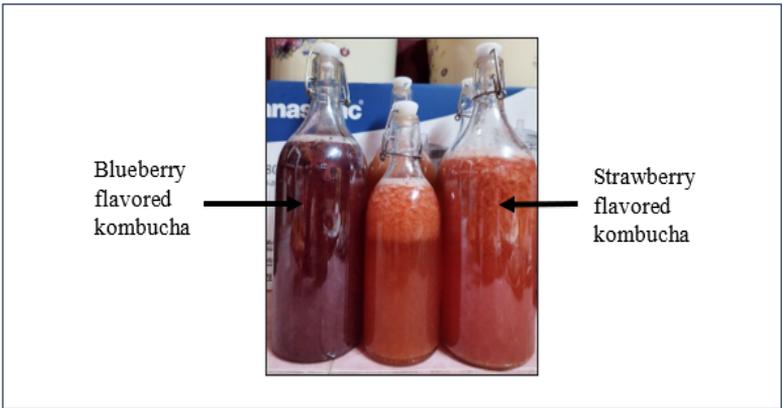


Figure 3. Flavouring kombucha using ground fruits in second fermentation

As shown in Figure 3, kombucha was let to ferment by adding flavour with ground fruits, i.e., strawberry, and blueberry. The second fermentation involves observing the condition of the kombucha on the first, second, and third days. The condition of fermented flavoured kombucha is shown in Figure 4.



Figure 4. Condition of flavoured kombucha on the third day of second fermentation

Condition of the flavoured kombucha on the third day of second fermentation was quite saturated as shown in Figure 4. Thus, the summative evaluation is related to testing the kombucha that has matured physically (foamy or gassy), taste and smell (slightly sour, sweet, and yeasty), the condition of the SCOBY (thickness and health without being overgrown with any fungi), acidity (pH 4 to pH 4.5), and sugar content (2 °Bx to 4 °Bx). In addition, the kombucha is also tested after the second fermentation in terms of condition (a lot of foam, a little, or the same as the first fermentation) and taste (gassier or not), and then the pupils make a choice between the first fermented kombucha and the second fermented flavoured kombucha, deciding which one is their favourite.

Based on the pictures in Figures 1, 2, 3, and 4, they clearly showed the success of the pupils in the process of making kombucha. The results of these pupils' work reflect the seriousness of their engagement in STEM learning through the EDP pedagogical approach. In the final phase, pupils shared the kombucha product with the rest of the group as well as school members, including teachers, clerks, school operation assistants, and cleaning workers. Through this partnership, the pupils were guided to explain to the public the benefits of consuming kombucha by emphasising the health aspects and the use of microorganisms.

Administration of Survey and Journal Reflection

STEM Learning Experience Survey was administered twice. The pre-survey assesses pupils' initial perceptions, attitudes, and understanding of STEM concepts prior to

engaging them in the integrated STEM-EDP learning experience. Post-survey on the other hand evaluates if there are any significant changes in pupils' perceptions, attitudes, and knowledge regarding how the integrated STEM-EDP learning experience through the kombucha-making is effective. The survey was administered to respondents individually after two weeks of kombucha-making. Given the literacy constraints, the survey was administered orally, with questions read out by the leader and the pupils responded using the Guttman scale with binary answer choices of yes or no. This quantitative approach provides measurable data on pupils' comprehension but does not capture the depth of their learning experience or engagement levels.

For the reflective journal, during the observation part, the teacher took the role of an observer, conscientiously recording field notes while the class was in session. The main objective was to record how the pupils interacted with the intervention at certain points in time. This included documenting the behaviours, relationships, and levels of engagement shown by the pupils during the kombucha project. The real-time observations provide a comprehensive overview of the children's activities and reactions throughout the session. The teacher critically examined the recorded actions in this reflective journal, establishing connections between them and educational ideas as well as prior studies. This kind of reflective practice facilitated a more profound analysis of the findings within a wider academic framework. The subjective character of these remarks became the journal an essential instrument for comprehending and enhancing teaching methodologies, guaranteeing a thorough and deliberate approach to gathering data.

Data Analysis

Quantitative data was gathered from respondents' ($N = 16$) responses to the 14 items of the STEM Learning Experience Survey and analysed using both descriptive and inferential statistical methods. Since the sample size was small with a single sample across two time periods and the data were categorical, the statistical test of choice would be nonparametric. The McNemar test was the right one. According to McKnight et al. (2016), the test was especially useful when the research design was a one group pre-test-post-test design in which the subjects serve as their own controls, and the dependent variable is dichotomous. This contributes to the primary goal of research, empowering teachers by establishing new theories of teaching practice (McNiff & Whitehead, 2006). An inductive method for qualitative data analysis was used, drawing data from the questionnaire's final two questions and the teacher's reflection journal entries. The qualitative data collected was sorted according to the themes found, then quantified and organised into a table (Charteris & Thomas, 2021). This method could demonstrate how incorporating STEM into the kombucha-making process using EDP affects pupil engagement. To further the STEM-Kombucha investigation activity, the teacher's reflection journal entries were formulated in narrative form along with pictures of the pupil's work.

RESULTS

In response to a growing need for understanding the perspectives of the pupils on the STEM learning experiences, the STEM Learning Experience Survey was administered to the 16 Jahai *Orang Asli* pupils. The findings for overall pupils’ perspectives on the STEM learning experiences are shown in Table 3.

Table 3. Pupils’ perspectives on the STEM learning experiences

No.	Item	Before		After		<i>p</i> -value
		%	f	%	f	
1	The STEM learning experience helped me to be a responsible person.	12.50	2	100.00	16	.000
2	I found the STEM learning experience to be highly satisfying and enriching.	0	0	100.0	16	.000
3	I enjoyed hands-on STEM learning activities.	25.00	4	100.00	16	.000
4	I learned so much about microorganisms in the STEM learning.	18.75	3	100.00	16	.000
5	The hands-on STEM learning activities should be continued in the future.	6.25	1	100.00	16	.000
6	The STEM learning experience developed skills that were essential in my life.	18.75	3	100.00	16	.000
7	I felt bored with the STEM learning.	25.00	4	0	0	.125
8	The hands-on activities in the STEM learning were difficult to implement.	100.00	16	0	0	.000
9	STEM learning was just a waste of my time.	62.50	10	0	0	.002

Note. Percentage (%) and number of pupils (f) who agree with the item

According to Table 3, most items show positive shifts especially related to how much pupils enjoyed the activities from the textbook related activities to the kombucha-making, how they perceived learning about microorganisms, and the importance of hands-on learning experiences. These changes are statistically significant as indicated by all the *p*-values of .000 across many items. Besides, Item 7 has *p* = .125, which means that the change is not significant, though there was an increase in engagement from boredom. Overall, the STEM learning experience had a significant change on pupil perspectives, with the only areas of marginal or non-significant change being difficulty of implement and boredom. Whereas the findings of the STEM Learning Experience Survey in Table 4 depicts pupils’ perspectives on the hands-on activities conducted according to the textbook before and after introducing the kombucha-making.

Table 4. Pupils’ perspectives on the hands-on activities conducted

No	Item	Before		After		<i>p</i> -value
		%	f	%	f	
1	The hands-on activity caught my attention.	0	0	100.00	16	.000
2	I managed to produce a product related to the hands-on activity.	12.50	2	100.00	16	.000
3	The hands-on activity helped me to develop collaborative attitude.	0	0	100.00	16	.000
4	The hands-on activity was highly relevant to the topic of Microorganisms.	68.75	11	100.00	16	.063
5	The hands-on activity was manageable to carry out.	62.5	10	100.00	16	.031

Note. Percentage (%) and number of pupils (f) who agree with the item

In Table 4, although the change is positive for Item 4, the *p*-value of .063 is just above the threshold for statistical significance, suggesting the shift in perception was not as strong as in other areas. Before implementing the hands-on activity of kombucha-making, most of the pupils realise that hands-on activities in the textbook are relevant to microorganisms too. However, all of them unanimously agreed that after implementing kombucha-making activity. Regarding Item 5, the kombucha-making seems to have provided a structured, clear process that allowed all pupils to succeed and feel competent in carrying out the task compared to the textbook activities. Overall, most of the changes were statistically significant, especially in the areas of enjoyment, responsibility, collaboration, and the perceived value of the activities.

Besides, this survey also asks pupils to provide comments about their experiences that describe whether they like or dislike engaging in STEM learning with kombucha-making activity. Based on their comments in writing, orally, or in sketches, Table 5 shows the themes that emerged because of coding the interesting experiences comments.

In Table 5, the interesting experiences can be categorised into four themes: skill, interest, satisfaction, and cooperation. Pupils described themselves as skilled, which is an interesting experience because they could operate equipment such as pH meter, refractometer, and specimens like SCOBYs. These activities make pupils responsible for their own learning. In addition, pupils expressed feelings of fun, excitement, and interest while making kombucha, observed the physicality of the SCOBY, and wished to make it at home. Pupils also expressed satisfaction when they were able to recognise the structure of SCOBY, which is their new knowledge, in addition to being

able to produce kombucha products as an interesting experience. Lastly, the spirit of cooperation with friends during activities makes pupil learning a valuable experience. However, there are also uninteresting comments provided by the pupils, and the theme that emerged due to the coding of uninteresting experiences comments is shown in Table 6.

Table 5. Themes of STEM-EDP Kombucha based on experience

Theme	Comments
Skilled	<p>“I think that I’m becoming more skilled in performing the tasks given.” (Respondents 3 and 14)</p> <p>“I can do it myself.” (Respondent 11)</p> <p>“I’m good at handling lab equipment.” (Respondent 12)</p>
Interest	<p>“I enjoy watching the SCOBY moves in the water.” (Respondent 1)</p> <p>“SCOBY is soft like jelly.” (Respondent 15)</p> <p>“I enjoy making kombucha.” (Respondents 6 and 9)</p> <p>“I like to make kombucha. I want to make it at home too.” (Respondents 2 and 16)</p> <p>Respondent 8 drew a picture of a smiling person and a jar of kombucha.</p>
Satisfaction	<p>“I’m able to hold a SCOBY.” (Respondent 10)</p> <p>“My kombucha was successfully produced. I want to take it home.” (Respondent 5)</p> <p>“I made strawberry kombucha. So delicious. Can I sell it?” (Respondent 7)</p>
Cooperation	<p>“I’m able to do activities with my friends.” (Respondent 4)</p> <p>Respondent 13 drew a picture of making kombucha with friends.</p>

Table 6. Uninteresting experiences during STEM-EDP kombucha

Theme	Comment
Fermentation time	<p>“The time taken for the fermentation process is quite long. I can’t wait to taste the kombucha.” (Respondent 1)</p> <p>“I waited a long time for the fermented kombucha to be ready.” (Respondent 14)</p>
Fermentation condition	<p>“I don’t like the smell of this kombucha. It smells sour and has an unpleasant smell.” (Respondents 9, 3, and 5)</p>
Group	<p>“I don’t really like being in this group. At first the group members were OK, but after a while I felt left out.” (Respondent 11)</p>

The three themes coded were (i) fermentation time, (ii) fermentation condition, and (iii) group assigned. There were pupils who showed impatience because they had to wait a long time to see and taste the mature kombucha. Some pupils also could not stand the sour smell of kombucha during the first fermentation process, but all pupils were interested in the flavour of kombucha that goes through the second fermentation process. In addition, there were pupils who were less comfortable learning with group members that they were not interested in. This needs to be taken seriously because it is one of the factors that interfere with the full engagement of pupils in the classroom.

For the reflective journal, it provided deeper insights into the teaching and learning process during the STEM-EDP Kombucha. As the teacher facilitated the activity, several key observations emerged. First, pupils showed high engagement, particularly during hands-on tasks such as measuring pH, handling the SCOBY, and observing the fermentation process. The teacher noted that pupils who were initially hesitant became more confident as they interacted with the materials, aligning with the “skilled” and “interest” themes identified in the survey results, as stated also in the journal entry:

Pupils were interested in making kombucha from the beginning. They were wondering about the fermentation process and how it relates to microorganisms. The fact that it was a hands-on activity engaged them right away, they were excitedly involved, asking questions, providing their own insight. Anal, who used to find the lessons boring, exclaimed, “This is so cool! Do you even know that we can brew tea with microorganisms.” Rooney, who a moment before had seemed disengaged, was now fully in the moment, saying “I can’t wait to see how it turns out. This is much more interesting and fun than the balloon yeast activity.”

The journal also highlighted effective collaborative learning. Pupils naturally divided tasks among themselves, demonstrating teamwork and problem-solving skills. The teacher observed that groups with clear communication and active participation were more successful in completing tasks efficiently. However, a few pupils needed guidance to stay engaged, especially those who were initially less interested in the activity. This aligns with the “group” theme from the uninteresting experiences, where some pupils felt disconnected from their assigned teams. As highlighted in the journal:

I saw my pupils work together as a team. They began to divide themselves into groups, each taking on a role to help facilitate the success of the activity. One group took charge of preparing the tea, carefully measuring the ingredients and making sure they had the right ratios. A separate group focused on sterilising the equipment, knowing that a clean environment is helpful in preventing contamination. A third group did the adding of the SCOBY and watching of the fermentation process. What was remarkable

to me about that was the way they communicate and coordinated seamlessly with each other. But not everything went smoothly. Several pupils found themselves estranged from their assigned teams. They strained while looking for a role in the group and had little idea of what to do that would make them effective. I stepped in and led some conversations encouraging these pupils to share their grievances and be more involved with their peers.

Another key reflection was the importance of patience in the fermentation process. The teacher noted that while pupils were excited to see results, waiting for kombucha to ferment tested their perseverance. Some pupils frequently checked on their samples, asking when they would be ready. As noted in the journal entry:

As interesting as it is, the fermentation process takes time. From their lives of instant satisfaction in the digital world, the pupils were impatient for the kombucha to ferment. They gathered every day around the fermentation jars, peering intently at the bubbling liquid, asking, “Is it ready yet?” Dude, I could feel their impatience, with a blend of curiosity and eagerness. So, I used this opportunity to teach them about how important it is to be patient, and to consider letting nature take its course. We talked about how fermentation is an important time and how rushing it could impact the finished product. I urged them to watch the changes every day, to take note of the subtle differences in scent and appearance, and to consider the science happening before them.

This observation supports the “fermentation time” theme from Table 6. To manage this, the teacher introduced discussions about real-world fermentation applications, helping pupils appreciate the process rather than just the final product.

Additionally, sensory experiences played a crucial role in pupils’ perceptions. While many were fascinated by the appearance and texture of the SCOBY, a few expressed discomforts due to its slimy texture and strong smell. The teacher noted that pre-explaining the fermentation process and normalising the sensory aspects helped pupils adapt more quickly. As recorded in the journal:

The SCOBY immediately caught the interest of the pupils. It’s strange. The pupils felt squeamish looking at it, but they bravely reached out to touch and inspect it, awed by its jellylike feel and translucent sheets. Getting to handle and see how it worked certainly generated interest and excitement, allowing for unique experience for everyone. But the reaction was not all positive. Some pupils were put off by the SCOBY’s has a slimy texture and strong, vinegary smell. To help with this, I prompted the open dialogue about how they felt and responded. We chatted about how some people

are more sensitive than others, and how we all have textures or smells we don't prefer and that's perfectly acceptable. I also offered alternative ways for those who were not comfortable to participate. For example, they might watch and write down what they see rather than touch the SCOBY.

In conclusion, the reflective journal reinforced the survey findings by providing an in-depth look at classroom dynamics, engagement levels, and teaching strategies. The teacher's observations highlighted the strengths of the STEM-EDP Kombucha while also identifying areas for improvement, particularly in managing group dynamics and setting expectations for fermentation time. These insights are valuable for refining future STEM-based investigations to enhance pupil engagement and learning outcomes.

DISCUSSION

The study aimed to evaluate how integrating STEM-EDP into kombucha production impacted the engagement of Jahai *Orang Asli* pupils. Drawing from prior studies that highlight the significance of pupils' engagement in STEM for skill development and academic success (Reeve, 2012; Skinner et al., 2017; Subramaniam et al., 2022), this investigation delved into the advantages of introducing STEM concepts through EDP to elementary school pupils, as proposed by Capobianco et al. (2018).

The analysis of outcomes, backed by teachers' reflective journals and pupils' work evidence, demonstrates a significant enhancement in pupils' engagement through the STEM-EDP Kombucha. This platform offered an experiential learning experience that not only deepened behavioural and emotional engagement in science learning but also nurtured a sense of responsibility among the pupils. The hands-on and collaborative nature of the project encouraged proactive scientific inquiry and knowledge acquisition.

Additionally, incorporating a video that encouraged critical thinking and opinion-sharing on enhancing the immune system through healthy eating sparked discussions centred on problem-solving and scientific concepts. STEM-EDP Kombucha not only expanded pupils' knowledge of microorganisms but also reinforced textbook content. The pupils' effort, attention, and perseverance culminated in successful kombucha production, reflecting their enjoyment, interest, and satisfaction with STEM learning, essential emotional attributes according to Reeve et al. (2004). Not only did the STEM-EDP Kombucha project offer a distinctive hands-on learning opportunity for pupils, but it also nurtured a sense of curiosity and exploration. Blending science, technology, engineering, maths, and the art of brewing kombucha produced a genuinely unique educational opportunity. Pupils were able to see the direct results of their efforts in the successful production of kombucha, sparking a sense of achievement and pride in their work. This innovative approach to STEM education not only engaged pupils in a fun and interactive way but also deepened their understanding of complex scientific

concepts in a tangible and memorable way. The hands-on nature of the project allowed pupils to apply theoretical knowledge to real-world situations, enhancing their problem-solving skills and critical thinking abilities. Through the incorporation of creativity and experimentation, pupils were motivated to think innovatively and tackle challenges with a fresh perspective. Overall, the kombucha brewing project not only enriched the pupils' educational experience but also instilled a passion for learning and a desire to explore the endless possibilities of STEM fields.

The kombucha brewing project stands out from traditional classroom activities by immersing pupils in scientific concepts through hands-on experimentation. Unlike textbook learning, this project allowed pupils to see the practical applications of their theoretical knowledge in a tangible way. By encouraging creativity and innovation, it sparked a new level of engagement and enthusiasm for STEM subjects among the participants. Overall, the kombucha brewing project distinguished itself by not only educating pupils but also inspiring them to think critically and problem-solve with a fresh perspective.

Finally, the findings suggest pupil-centred approach stands in harmony with a body of research that has consistently demonstrated the effectiveness of pupil-centred pedagogies in enhancing pupil participation and engagement within STEM disciplines. Specifically, the works of Ahmad et al. (2023), Kartini et al. (2023), and Shukri et al. (2019; 2020), provide empirical evidence that when pupils are given more control over their learning process, they tend to become more actively involved in their education, leading to improved outcomes in STEM subjects. In the context of this study, the kombucha product made by pupils indicated their engagement, which helped the teachers understand the steps in the intervention.

While the findings align with previous studies, it is important to critically consider alternative explanations that may have influenced these outcomes. One such factor is the novelty effect, which refers to the temporary boost in engagement and performance that can occur when learners are exposed to a new or unfamiliar activity. Research by Marek and Wu (2021) and Iannone and Vondrova (2024) suggest that educational interventions often benefit from initial excitement and curiosity, which may not be sustained over time. In this study, the uniqueness of brewing kombucha – a culturally relevant and hands-on activity may have contributed to heightened engagement due to its novelty. However, the sustained interest observed throughout the fermentation period, as documented in the reflective journal and pupil interaction, suggests that the impact extended beyond initial excitement. This aligns with findings by Rodrigues et al. (2022), who argue that novelty can evolve into deeper learning when paired with meaningful tasks and contextual relevance.

Another consideration is teacher facilitation bias, where the teacher's enthusiasm, guidance, or expectations may inadvertently influence pupil engagement and outcomes.

While teacher involvement was essential in scaffolding the kombucha making process, steps were taken to mitigate bias. Observational data were recorded systematically, and pupil reflections were analysed independently to ensure that engagement was authentically expressed. Moreover, the use of pupil-centred strategies such as allowing pupils to divide tasks, make decisions, and reflect on their own learning support the argument that engagement stemmed from intrinsic motivation rather than external influence. This is consistent with Ahmad et al. (2023) and Kartini et al. (2023), who found that autonomy and ownership in STEM tasks foster genuine participation and reduce dependency on teacher direction.

By acknowledging these counterpoints, the study strengthens its interpretation of findings. While novelty and facilitation may have played a role, the convergence of survey data, reflective journal, and tangible pupil outputs, e.g., kombucha product, provides a triangulated basis for concluding that the STEM-EDP intervention had a meaningful impact on pupil engagement and learning.

Several context-specific challenges faced by the Jahai *Orang Asli* pupils may have influenced their engagement in the STEM-EDP Kombucha. One key issue is linguistic barriers, as many *Orang Asli* pupils speak indigenous languages at home and may have limited proficiency in bahasa Melayu – the primary language of instruction. This can affect their ability to comprehend scientific terminology and express their understanding during STEM activities. To address this, the teacher employed simplified language, visual aids, and hands-on demonstration to bridge communication gaps and ensure inclusivity.

Another challenge is irregular school attendance, which is common among *Orang Asli* pupils due to factors such as remote living conditions, family responsibilities, and limited transportation access. In this study, attendance fluctuations were observed, and the intervention was adapted to accommodate pupils who missed sessions by providing catch-up activities and peer support. These adjustments were crucial in maintaining continuity and ensuring that all pupils could participate meaningfully.

Furthermore, socio-cultural dynamics played a role in shaping pupils' responses to the STEM-EDP Kombucha. The integration of kombucha making process involving fermentation and natural ingredients resonated with the pupils' lived experiences and traditional knowledge, fostering a sense of relevance and ownership. However, some pupils initially hesitated to engage due to unfamiliarity with scientific tools or fear of making mistakes. Culturally responsive teaching strategies, such as affirming pupils' contributions and encouraging collaborative learning, helped build confidence and reduce anxiety (Idrus et al., 2023).

By acknowledging and addressing these contextual challenges, the study reinforces the importance of designing STEM interventions that are not only engaging but

also culturally and linguistically responsive. This ensures that indigenous pupils are supported holistically, allowing them to thrive in STEM learning environment.

CONCLUSION

This study focused on the integration of STEM education with the EDP through kombucha-making as a contextualised learning activity for *Orang Asli* students from the Jahai tribe. The results indicate that this experiential approach may improve students' engagement with STEM disciplines and promote both behavioural and emotional involvement. The kombucha products created by the pupils provided visible evidence of their participation and served as preliminary indicators of the potential effectiveness of this approach.

The results are intriguing, but they should be viewed with caution because of the study's limitations. The lack of a control group, the small sample size, the use of only a few tools, and cultural and linguistic differences all make it hard to apply the results to other situations. Future research must rectify these limitations by utilising more stringent methodologies, including comparative or control groups, implementing mixed-methods approaches to obtain both qualitative and quantitative data, and executing multi-site or larger-scale trials to evaluate scalability and robustness.

Despite its limitations, this study offers preliminary evidence that weaving culturally relevant practices such as kombucha-making into STEM education can meaningfully enhance pupil engagement, especially within Indigenous learning contexts. The findings resonate with key educational theories, including Experiential Learning Theory, Self-Determination Theory, and Culturally Relevant Pedagogy, all of which highlight the value of active, hands-on, and culturally grounded learning experiences. Such approaches can make STEM concepts not only more accessible but also more personally meaningful to learners. Looking ahead, future research could build on this work by incorporating structured feedback mechanisms, providing tailored support for learners with varying needs, and embedding interdisciplinary elements to enrich both the process and outcomes of learning.

In conclusion, the STEM-EDP Kombucha initiative points to a promising pathway for making STEM education more engaging and culturally meaningful. With continued refinement and stronger validation through future research, this approach holds potential to foster more inclusive, motivating, and contextually relevant learning experiences—not only for indigenous pupils but also for diverse learners in wider educational settings.

CONFLICT OF INTEREST

The authors declare that they have no known financial, professional, contractual, or personal conflicts of interest that could have appeared to influence the work reported in this manuscript.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analysed during the current study are not publicly available due to participant confidentiality but are available from the corresponding author on reasonable request.

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CONTRIBUTIONS OF AUTHORS

Ahmad Adnan Ahmad Shukri: Conceptualisation, methodology, data collection, and original draft preparation.

Nur Jahan Ahmad: Conceptualisation, review and editing.

Siti Nor Fazila Ramly: Writing and resources.

H. Husamah: Resources.

STATEMENT OF ARTIFICIAL INTELLIGENCE (AI) USE

Artificial intelligence tools were used only to improve language clarity, sentence structure, and overall readability. The conceptualisation, data analysis, interpretation, and synthesis were entirely human-authored.

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