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Teacher's Practice in Digital Inquiry-based Science Learning in a Primary School

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Abstract

This study aimed to explore the implementation of digital inquiry-based science learning in a rural primary school classroom in Melaka, Malaysia. The participants were eight Year 4 pupils (10–11 years old). Using a classroom action research approach, the study utilized two action research cycles using the BSCS 5E Instructional Model to create lesson plans. The study's findings reveal that effective digital inquiry-based science learning development in primary schools requires activities that align with and harness pupils' prior knowledge, cross-curricular applications, differentiated learning, inquiry scaffolding, technological scaffolding, pupils' technological skills, independent learning, learning by doing, and the opportunity to make connections, express ideas and report discoveries. The study illustrates that digital inquiry-based science learning is well-suited for practice in primary schools, enhancing both teachers' pedagogical approaches and pupils' conceptual understanding.

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1 Introduction

Science education aims to broaden pupils' scientific knowledge, foster enjoyable learning experiences, and deepen their interest in science through real-world experiences closely tied to the learning objectives (Feille, 2021; Gilbert, 2016). The science education field has undergone numerous reforms since its inception. A comprehensive examination of previous studies reveals the shift from a more cognitive, teacher-centric model to a more holistic, student-centered approach (Akuma & Callaghan, 2019; Gomez-Arizaga et al., 2016; McLaughlin & MacFadden, 2014), and the increasingly important role of new technologies (Díaz et al., 2019; Harlen & Qualter, 2018; Kumar Basak et al., 2018). Thus, these studies highlight the impact of the evolution of science education on pupils as learners.

Traditionally, pupils' cognition has been a primary focus of research in science education, with instructional and conceptual approaches potentially shaping pupils' attitudes, motivations, and perspectives on science (Gomez-Arizaga et al., 2016; Mupira & Ramnarain, 2018). However, in recent decades, inquiry-based learning has been at the forefront of reforms in science education and remains a crucial element in progressing the field of science teaching and learning, proving more effective than traditional instructional approaches (Akuma & Callaghan, 2019; McLaughlin & MacFadden, 2014). In inquiry-based learning, pupils are encouraged to engage in a high level of questioning and exploration to investigate real-world issues (Muhamad Dah et al., 2023). Gillies (2020) contended that when pupils engage in inquiry-based science, they grasp the processes employed by communities of scientists in examining phenomena. Consequently, inquiry-based learning activities should emulate the work of scientists by allowing students to design their research based on their own interests, involving the formulation of research questions, sourcing information, planning and conducting investigations and drawing conclusions (Muhamad Dah et al., 2024; Rönnebeck et al., 2016). This process stems from the idea that pupils should genuinely understand the studies they undertake rather than merely memorize facts. Inquiry-based learning is a highly effective approach for enabling students to utilize their existing knowledge and investigative skills to understand the world to apply their existing knowledge and investigative skills to comprehend the world, fostering a stronger sense of ownership over their education and guiding them toward enhanced understanding, active motivation, and positive attitudes toward science (Bevins & Price, 2016). It is now widely acknowledged that assuming the role of scientists in inquiry-based learning empowers pupils to engage in meaningful and active learning experiences.

In the 21st century, technology is pivotal in reshaping education, prompting professionals, educators, and pupils to re-evaluate traditional concepts. Kumar Basak et al. (2018) emphasized the need to harness technology to reconfigure education, anticipating more significant benefits. Emerging technologies are expected to continually advance teaching and learning, offering opportunities for transformative educational experiences (Díaz et al., 2019). Terms like electronic and mobile learning are interchangeably used, reflecting the ongoing discourse on evolving technologies in educational settings. Digital learning is a broad concept encompassing various tools and methodologies that leverage technology to enhance student learning experiences. Fundamental digital learning involves immersing users in an environment that integrates multiple technologies for functions such as learning, engagement, assessment, and navigation (Sarkar et al., 2017).

Digital technology has revolutionized education, reshaping it to align with the dynamic nature of the scientific inquiry process. Harlen and Qualter (2018) stressed the advantages of digital technologies in scientific inquiry lessons, citing benefits like data collection, model utilization, and collaborative learning. Simultaneously, this development underscores the significant and positive influence of digital technology tools in technology-supported inquiry settings, which play a pivotal role in fostering an interactive educational environment that promotes deeper engagement and understanding among pupils (Rocha Fernandes et al., 2019; Zydney & Warner, 2016). The expanding and profound applications of digital learning in education, especially in science education, call for educators to integrate these technologies into their instructional practices to keep pace with the rapid evolution of information and communication technology (ICT) (Harlen & Qualter, 2018).

2 Problem Statement

This study utilized The Science Standards-Based Curriculum for Primary Schools (KSSR), which is designed to stimulate pupils' interest in science and cultivate their creativity through hands-on experiences and investigations (Ministry of Education Malaysia [MOE], 2018). To achieve these objectives, the inquiry approach was chosen as the primary pedagogy for teaching and learning in science education. The rationale for this choice was the fact that despite the substantial emphasis on the significance of inquiry in science education, its application in classroom contexts is infrequent (Gillies, 2020). Choi et al. (2021) noted that primary science teachers recognize the importance of the inquiry approach and generally comprehend its implementation in their teaching and learning processes. Nevertheless, many science teachers still favor the traditional teacher-centered method, as the inquiry approach is perceived as a complex process demanding specific classroom conditions and instructional materials (Baroudi & Rodjan Helder, 2021). Consequently, the convenience of planning a science lesson often takes precedence over ensuring pupils benefit from the advantages offered by the inquiry approach.

Recognizing the challenges associated with implementing an inquiry-based approach, primary science teachers have opted for a more traditional lecturing approach, delivering content without actively engaging pupils, thereby reducing interactions in the classroom (Tay & Saleh, 2019). Consequently, pupils are solely exposed to teacher explanations, missing out on the development of scientific skills and the opportunity to enhance their scientific thinking through hands-on inquiry activities (Baharom et al., 2020). Additionally, Baroudi and Rodjan Helder's (2021) study identified several factors contributing to science teachers' reluctance to adopt the inquiry-based approach. The primary obstacles include limited access to ICT and teaching resources, a lack of proficiency in integrating ICT into inquiry-based classroom settings, and insufficient training or professional development. This is echoed by Mahmud et al. (2018), who emphasized the need to enhance science teachers' ICT expertise, given the prevailing deficiency in incorporating ICT into lessons due to inadequate training.

Teachers' ability to integrate technology into diverse teaching approaches has become paramount due to rapid technological advancement, which is reshaping the dynamics of teaching and learning in classrooms. Nicol (2021) asserted that the evident connection between new inquiry-based instructional methods and both hard and soft technology underscores the transformative impact of technology on teaching practices. With the advent of 5G technology, the rise of artificial intelligence, and the ongoing exploration of technology's role in education, it is becoming apparent that inquiry instruction methods will continue to evolve in tandem with technological advancements (Nicol, 2021). Recent research has emphasized that science instructors must possess a solid understanding of how technology can be effectively integrated with pedagogy and content knowledge to optimize the science teaching and learning experience (Kapici & Akcay, 2020; Tanak, 2020).

The imperative to develop digital inquiry-based science learning is evident in the challenges surrounding the implementation of the current primary science curriculum. Despite the intent to foster interest and creativity through hands-on experiences and investigations, the predominant use of traditional, teacher-centered methods hampers the practical application of the inquiry approach in classrooms (Halim et al., 2018). In recognizing the importance of inquiry, primary science teachers often opt for convenience in lesson planning, leading to a missed opportunity for pupils to actively engage in scientific thinking and skills development. Barriers such as limited access to ICT resources, a lack of proficiency in integrating technology into inquiry-based settings, and inadequate professional development further contribute to teachers' reluctance to adopt digital inquiry methods (Baroudi & Rodjan Helder, 2021). In light of rapid technological advancements and the transformative impact of technology on teaching practices, there is a critical need to bridge the gap between inquiry-based science education and evolving technological landscapes (Bidarra & Rusman, 2017). Emphasizing the integration of technology into teaching approaches is essential to enhance science teachers' proficiency, ensuring they can effectively leverage digital tools to optimize the inquiry-based learning experience for primary school pupils. This alignment between inquiry-based education and technological innovation is paramount for preparing pupils to navigate the complexities of the modern world and develop the essential scientific skills needed for their future endeavors.

3 Research Background

In preparation for conducting the present study, five prior studies on integrating digital learning into inquiry-based science lessons were identified for discussion. Falloon (2017) explored how mobile devices and software could aid primary school pupils in science classes. The Okiwibook scientific app, designed for children aged 7 to 12, was utilized because it was easy to use and incorporated quizzes and science activities focused on energy-related topics. The study involved 65 fifth- and sixth-grade pupils (aged 10 to 11 years old), revealing three notable effects. Firstly, pupils employed more procedural scaffolds during investigations based on the task's urgency. Secondly, the study indicated that pupils spent less time on conceptual scaffolds within the app, prioritizing activity over conceptual understanding. Lastly, the study suggested that utilizing the technological gadget as a learning scaffold, especially when combined with other devices or apps, was advantageous for a more organized teaching and learning process.

Lin et al. (2019) investigated mobile technology's influence on primary school pupils' learning and self-competence. The study, involving 312 sixth-grade pupils aged 12 to 13, did not focus on a specific app but instead utilized a variety of programs and services on a mobile device. The research included structured actions such as conventional classroom learning for information acquisition and self-directed learning at home, where pupils watched movies and animations in a location convenient to them. Two outlined activities were online peer conversations to provide feedback on friends' contributions and the enhancement of scientific knowledge while transferring problem-solving knowledge to new settings. The study concluded that technology-assisted self-study positively impacted pupils' academic abilities in science, highlighting the potential for increased creativity and problem-solving skills through favorable perceptions of technology-based self-learning.

So et al. (2019) explored how primary school pupils formed attitudes toward online science learning using various electronic media. The study involved 330 pupils in grades 3 through 6 (ages 8 to 12) and centered on the use of mobile devices with multiple applications and functions, including tablets. The intervention was structured into three stages: deliberation, presentation, and self-evaluation. During the discussion phase, pupils used multimedia to demonstrate their understanding of the issue. In the presentation phase, pupils immersed themselves in multimedia to acquire scientific knowledge, and the self-review phase concluded with assessment and reflection. The study demonstrated that incorporating various electronic media facilitated pupils' self-learning by inspiring and motivating them to study science topics, ultimately enhancing their conceptual comprehension.

Song and Wen (2018) conducted a study employing a Bring Your Own Device (BYOD) approach, combining multiple learning apps to influence the inquiry-based approach of primary school pupils. The researchers selected 28 sixth-grade pupils aged 10 to 11. This study utilized five apps – Skitch, Evernote, Edmodo, Camera, and Recording – and structured the inquiry process into six phases: engage, explore, observe, explain, reflect, and share procedures for learning at home, school, and online. By integrating these apps, pupils could establish connections between ideas and scientific concepts, leading to increased knowledge gains. Most pupils were able to critically reflect on their lessons, applying the topics in the laboratory. Furthermore, the seamless integration of the apps allowed young pupils to advance their understanding, suggesting that BYOD offers limitless opportunities.

Wu et al. (2021) explored the development of primary pupils' problem-solving skills using spherical video-based virtual reality. The study involved 54 Grade 5 pupils aged 10 to 11, focusing on the science topic of pinhole imaging. Pupils viewed a 360-degree aperture image, guiding them through the scientific process in panoramic virtual reality films. Group discussions followed, where they applied this knowledge to create a Sun and Moon Lamp. The study revealed two main findings. Firstly, spherical video-based virtual reality enhanced pupils' problem-solving skills by exposing them to more precise knowledge principles than conventional videos. Additionally, utilizing specific phenomena in virtual reality engaged pupils in learning environments rich in interactive features.

One significant research gap in the integration of digital tools into inquiry-based science education for primary school pupils pertains to the teachers' practices and their pedagogical strategies. While existing studies have primarily focused on evaluating the impact of digital tools on pupils' learning outcomes, there's been limited exploration into how teachers effectively incorporate these tools into their instructional practices. Investigating the strategies teachers employ, their instructional decision-making processes, and the challenges they encounter in facilitating digital inquiry is essential for shaping effective implementation frameworks. Moreover, while limited attention has been given to examining issues of equity and access related to digital inquiry, understanding how teachers address disparities in technology resources and digital literacy skills among pupils' populations in the rural area settings. By delving deeper into teachers' practices, this study can provide valuable insights into optimizing the integration of digital tools to enhance inquiry-based science education, fostering more inclusive and equitable learning environments.

4 Conceptual Framework

The conceptual framework for this study follows Kamarudin et al. (2024) and is based on the BSCS 5E Instructional Model (Bybee et al., 2006). The model comprises five stages: engagement, exploration, explanation, elaboration, and evaluation. Each stage has a distinct role, aiding teachers in delivering comprehensive instruction and fostering a deeper understanding of students' scientific and technological knowledge, attitudes, and abilities. Bybee (2015) outlined the significance of each phase within the 5E Instructional Model. In the engagement phase, pupils' interest was captured through demonstrations or scenarios, sparking their curiosity and questions. Exploration follows, providing opportunities to address any imbalances generated during engagement, while the explanation phase focuses on understanding scientific phenomena. Elaboration involves transferring knowledge to new contexts, building upon previous learning, and evaluation allows for self-assessment and tracking progress towards learning objectives in the final phase. Figure 1 below shows the conceptual framework of this study.

5 Methodology

The study was conducted at a national primary school designated as a Sekolah Luar Bandar (Rural School). In this context, "Sekolah Luar Bandar" denotes schools situated in rural areas, as opposed to urban locales, which usually have a lower pupil enrolment rate compared to their urban counterparts. The choice of a rural school aligns with the assumption that such schools generally lack exposure to digital learning environments and materials related to digital technologies. The participants involved in this study were fourth-grade pupils aged between 10 and 11 years old. They belonged to a single classroom comprising a total of eight pupils, with an equal distribution of four boys and four girls.

The first author of this study served as a primary science teacher and expressed a keen interest in utilizing action research to enhance his teaching

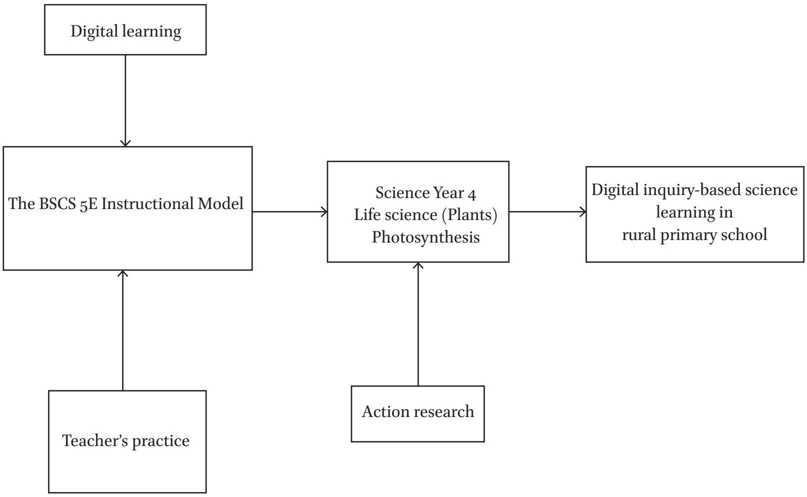

FIGURE 1 Framework for digital inquiry-based science learning in rural primary school.

methods. In embracing the dual role of both teacher and researcher, he engaged in simultaneous research and classroom instruction. This unique approach leveraged his expertise, leading him to scrutinize and refine his own teaching practices. However, it is crucial to acknowledge the potential for bias in self-reflection and evaluation. To mitigate this bias, the primary author emphasized his multiple positionalities throughout the study, as outlined by Herr and Anderson (2015). These positionalities ranged from being an insider studying his own practices to acting as an insider collaborating with an outsider. The second author played a crucial role as a critical friend (see Mat Noor & Shafee, 2021). In this capacity, he served as a valuable collaborator, actively contributing by sharing ideas and providing constructive feedback that proved instrumental in enhancing the implementation process for digital inquiry-based science learning.

Additionally, we adhered to the principles of outcome, process, and democratic validity. Achieving outcome validity involves meeting three essential criteria: addressing research questions, providing solutions to problems, and developing new research questions (Leuverink & Aarts, 2019). Herr and Anderson (2015) highlighted the importance of process validity in addressing the contentious issue of defining what constitutes evidence to support an argument. Democratic validity assesses the degree to which research is collaboratively conducted with all stakeholders to address the investigated problem (Herr & Anderson, 2015). To achieve all the validity criteria, we comprehensively explored our instructional methodologies, pupils' learning processes, and the repercussions of our actions (Kamarudin & Mat Noor, 2023). Through these measures, we aimed to generate a teacher action research study characterized by validity and high quality. Such a study is anticipated to play a pivotal role in nurturing teachers' professional growth and development (Mat Noor et al., 2023).

This study comprised two cycles of action research. The initial cycle adhered to the primary sequence of the BSCS 5E Instructional Model (Bybee et al., 2006). According to Feldman et al. (2018), the traditional distinction between action research cycles is ambiguous, and can be more aptly viewed as an ongoing, continuous process that incorporates both main and mini cycles. Ideally, the choice of these cycles is left to the researcher, allowing for the customization and adaptation of the practical timeframe to enhance its effectiveness. In this study, the decision to conduct a mini-cycle as the second phase emerged from our dissatisfaction with the evaluation process in digital inquiry-based science learning following thoughtful discussions. Figure 2 illustrates the extension of the action research cycles in this study.

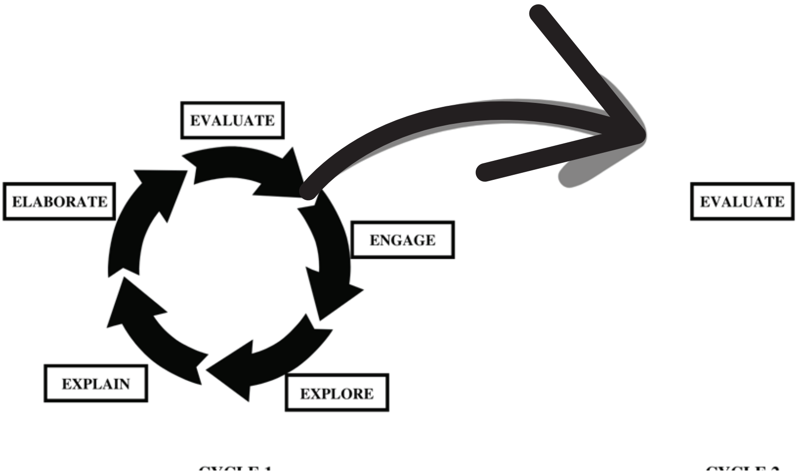

FIGURE 2 The two cycles of action research.

This classroom action research study applied a qualitative data collection method, aligning with the chosen empirical action research design. The qualitative approach was selected to offer in-depth insights and descriptions of individual participants' perspectives. To ensure comprehensive coverage of all research questions and enhance reliability, we utilized multiple data sources simultaneously, a strategy known as triangulation. Data were collected via interviews and observations. Before gathering data for this study, we developed an interview protocol. The interview followed a semi-structured format, incorporating a blend of highly and less structured questions. The interviews revolved around a set of questions or topics designed for exploration (Merriam & Tisdell, 2016), which focused on the process of implementing digital inquiry-based science learning in the classroom. Eleven themes were subsequently developed utilizing reflexive thematic analysis (Braun & Clarke, 2019).

Reflexive thematic analysis emphasizes the active role of the researcher in coding and analyzing data while highlighting the importance of reflecting on theme development and acknowledging the inevitable subjectivity of data analysis shaped by the researcher's assumptions and practices (Braun & Clarke, 2021).Through collaborative efforts, we identified, developed and deliberated on codes and categories to enhance the depth of data interpretation. Leveraging our shared theoretical assumptions, analytical proficiency, and the interpreted insights from the data (Braun & Clarke, 2021), we formulated emerging themes associated with developing digital inquiry-based science learning in a primary school context.

Meanwhile, the observation process included gathering data from reflection logs, teaching transcripts and pupils' work. Video recordings were employed to capture explicit teaching transcripts due to the rapid pace of the teaching and learning process and to aid them to reflect back on their practice (Tripp & Rich, 2012). This facilitated our observation of pupils' discourse throughout the digital inquiry-based science learning process. In addition, as an extra qualitative data collection approach, we maintained a reflection log at the end of each lesson. These logs documented our assessment of the alignment between fundamental teaching and learning principles and the actual implementation of the digital inquiry-based learning action plan. The final method of data collection involved pupils' work, encompassing both digitally uploaded work through the Cloud and handwritten assignments completed during the lesson.

6 Discussions

Eleven themes related to the development of digital inquiry-based science learning in a primary school setting were generated by employing reflexive thematic analysis (Braun & Clarke, 2019). These themes encompassed various aspects of pupils' learning, as well as curricular and teaching approaches.

6.1 *Pupils' Prior Knowledge*

Prior knowledge encompasses the preconceived notions or misunderstandings that pupils may have regarding scientific phenomena (Cook, 2006). Through participation in inquiry-based activities, primary school pupils can confront and challenge their misconceptions, allowing them to reconcile any disparities between their existing knowledge and scientific evidence (Bybee et al., 2006). In this study, we gauged pupils' prior knowledge before the lesson was conducted, which stood as a prerequisite in constructing the lesson plans. Furthermore, pupils were asked to provide as many answers as possible related to preliminary questions in the Engage phase to obtain their initial conceptions associated with scientific knowledge, as illustrated in the teaching transcript below:

P: What will happen when you plant the seeds?
T: Plant the seeds, what will happen?
P: (It will) live.
T: Write that.
P: How many (should we) write?

T: As many as you can. Okay, all the answers will appear here. Just write. Imagine when you plant it. What will happen?

TT1/50–55

Chang et al. (2020) emphasised the significance of probing pupils' existing knowledge during digital inquiry-based science lessons. They argued that context-specific epistemic beliefs and prior knowledge play a positive role in enhancing pupils' engagement and reasoning, contributing to their active involvement in science lessons. This assertion is further supported by van Riesen et al. (2018), who noted that pupils with low-intermediate prior knowledge tend to gain more conceptual understanding than those with low prior knowledge. The hypothesis is that pupils need some level of previous knowledge to benefit fully from the provided support. Therefore, the present study demonstrates that eliciting pupils' initial understandings assisted the teacher in developing tailored digital inquiry science lessons.

6.2 *Cross-Curricular Applications*

We planned activities that could be integrated with Music and Arts within the five-stage digital inquiry-based science learning sequence (Figure 3), thus

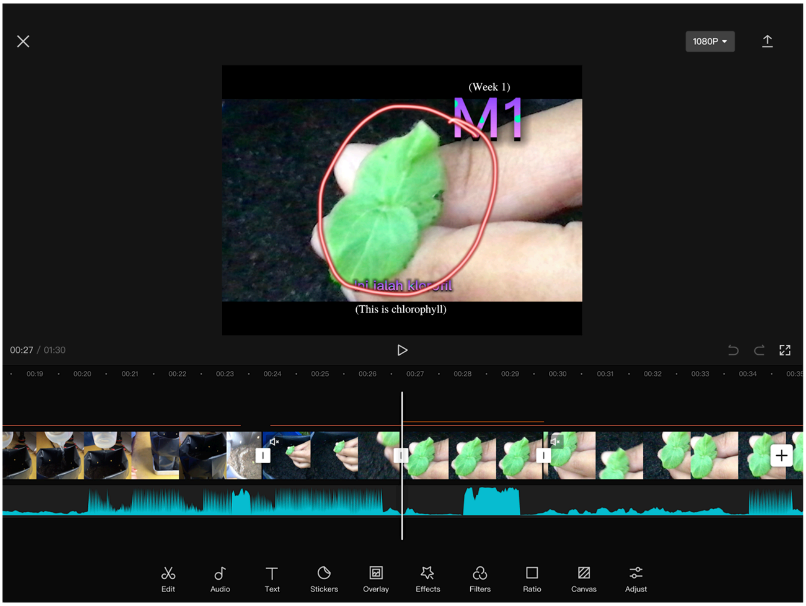

FIGURE 3 Pupils practice the arts of visual graphics and music in producing their video presentations.

fostering connections across different subjects and enhancing cross-curricular applications. Digital arts empower pupils to convey their understanding of scientific concepts using various modes of visuals, audio, and interactive elements to craft vibrant and captivating presentations or projects (Aguilar & Turmo, 2019). This diverse mode of expression enables pupils to demonstrate their creativity and tailor their learning encounters, as seen in the pupils' work below.

The incorporation of scientific knowledge across various disciplines can be highly beneficial for achieving scientific literacy. This approach facilitates the integration of elements of scientific literacy into non-scientific subjects, contributing to a more comprehensive understanding of scientific concepts and issues among pupils (Karampelas, 2019). Adopting a cross-curricular approach allows teachers to create a platform where pupils can apply skills and concepts acquired from different subjects. Additionally, this method enables children to recognize how to utilize, develop, and expand their skills, instilling a sense of purpose and value (Harish et al., 2012).

6.3 *Differentiated Learning*

Primary schools encompass heterogeneous pupil populations with differing abilities, interests, and learning preferences. The application of differentiated learning in digital inquiry-based science affords teachers the flexibility to customize instruction to align with the unique needs of each pupil. In integrating digital inquiry-based science learning, we provided pupils with diverse mediums to assess their understanding, accommodating various learning styles. This is exemplified in Figure 4, where instructions for activities within the Seesaw app were delivered through written text, audio narration, and step-by-step video.

This study demonstrated the implementation of differentiated learning, where pupils were granted the autonomy to select their learning resources and determine how to present their findings, notably enhancing their grasp of the science topic. Özdeniz et al. (2023) emphasized that incorporating differentiated learning into primary science education led to improved conceptual understanding among pupils, as it immersed them more deeply in integrated science contents. Differentiated learning has the potential to be highly beneficial as it offers flexibility and tailored instruction based on each learner's personality and preferred learning style. It strongly emphasizes individual pupils' needs, adjusting the learning experience accordingly (Krishan & Al-Rsa'I, 2023).

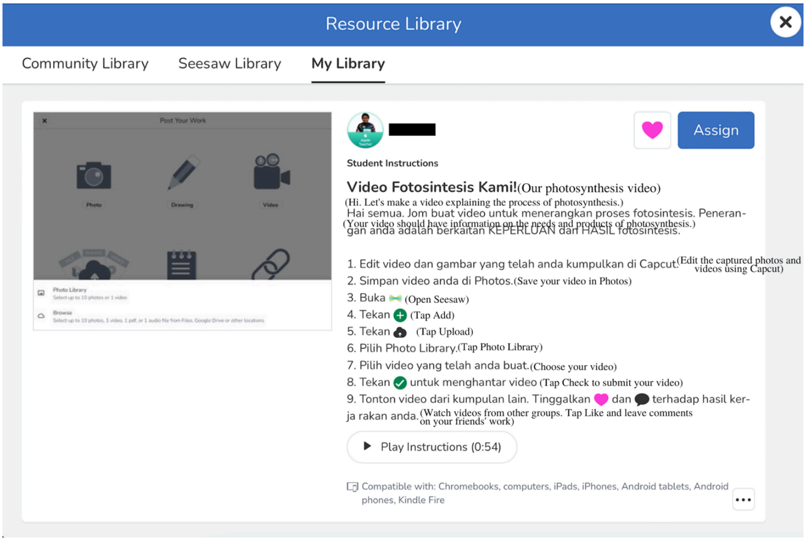

FIGURE 4 Instructions in the Seesaw app were given via text, voice and video.

6.4 *Inquiry Scaffolding*

In the digital learning environment, inquiry scaffolding adheres to the concept of a step-by-step transfer of responsibility. Initially, we gave pupils explicit guidance and support, and these scaffolds diminished gradually as their proficiency in scientific inquiry increased. This progressive transition allows pupils to assume learning control, cultivate independence, and apply inquiry skills autonomously. In the reflection log below, we emphasized the significance of inquiry scaffolding, mainly as pupils were not accustomed to having opportunities to plan their scientific investigations independently.

> In the past, I have noticed that some pupils tend to depend solely on my instructions, limiting their exploration and understanding of the topic. I believe this may be due to their familiarity with traditional classroom settings, where they rely heavily on lectures and demonstrations. Thus, pupils need to be facilitated to independently conduct scientific investigations.
>
> RL1/10

During the inquiry-based science lesson, scaffolding plays a crucial role, empowering science teachers to foster the self-directed learning of their pupils (van Uum et al., 2017). Inquiry scaffolds held particular significance in this study, where we emphasized the importance of evidence and argumentation.

Throughout the lessons, we assisted pupils in selecting data that best represented their understanding of the topic. Regarding argumentation, the teacher encouraged diverse forms of discourse involving verbal dialogue and feedback on pupils' work. This aligns with Jin and Kim's (2021) study, which underscores the purpose of inquiry scaffolding in enhancing pupils' comprehension of scientific argumentation in the classroom, aiding them in substantiating statements with robust evidence.

6.5 *Technological Scaffolding*

Primary school pupils not only benefit from inquiry scaffolding but also require additional technological assistance in digital inquiry-based science education. Technological scaffolding was crucial in enabling primary school pupils to participate in independent learning. When we provided them with access to technology and appropriate guidance, pupils could explore scientific concepts and initiate their own investigations. Technology facilitated self-paced learning, allowing pupils to revisit information, review concepts, and engage in self-directed inquiry. The interview transcript below illustrates the implementation of technological scaffolding in digital inquiry-based science learning, where pupils received assistance from peers and teachers to become acquainted with a relatively new app.

R: So, if you didn't know something (about the app), what did you do?
P2: I asked my friends.
R: You asked your friends. What else did you do?
P1: I asked the teacher.
R: You asked the teacher. When you asked him, what did he do?
P6: The teacher explained.
R: Okay, how did the teacher explain?
P6: He explained how to (use the app) if we didn't understand.

IV1/107–111

In this study, some primary school pupils were not accustomed to using several of the provided digital tools, necessitating guidance and time, particularly in the initial stages of the lesson, with a gradual reduction as the lesson unfolded. Technological scaffolding serves as a bridge to familiarize pupils with digital tools and ensure they derive maximum benefit from them. Providing as-needed specialized scaffolds in digital learning environments, with minimal teacher supervision, is crucial for empowering pupils to become self-regulated learners and actively engage in their learning processes and collaborative activities. Without sufficient scaffolding, pupils may encounter difficulties comprehending the technology employed (Blake, 2016; So et al., 2019).

6.6 *Pupils' Technological Skills*

Technological skills empower pupils to participate actively in digital inquiry-based science learning. Proficiency in utilizing digital devices, mobile applications, and online resources equips pupils with the skills to navigate digital platforms, retrieve pertinent scientific information, and engage in virtual experiments or simulations. A robust command of technological skills enables pupils to maximize the utility of digital tools and resources, thereby deepening their conceptual understanding. The below reflection log excerpt indicates that by the lesson's end, our workload had diminished as pupils had surpassed expectations related to their technological skills, evolving into independent learners in the context of digital inquiry-based science learning.

> The pupils' performance exceeded expectations as they quickly became familiar with the applications introduced to them. They even progressed beyond expectations as they started exploring the apps independently without requiring additional guidance.
>
> RL5/8

As pupils advanced in their learning, their technological proficiency improved, prompting the teacher to consider and adapt their approach to managing digital inquiry-based science learning. This adjustment is essential because incorporating digital elements, especially in primary education, enhances pupils' technological skills and eliminates barriers and boundaries. It promotes a sustained enthusiasm for knowledge acquisition by utilizing digital resources in the teaching and learning process (Hasin & M Nasir, 2021). The school curriculum incorporates technological tools and strategies to instill the crucial skills and knowledge required for 21st-century learning. Effective teaching and learning strategies empower pupils by enabling them to develop learning skills, media literacy, and life skills (Tohara et al., 2021).

6.7 *Becoming Independent Learners*

Within digital inquiry-based science learning, primary pupils acquire the capacity to autonomously navigate digital tools, carry out investigations, and delve into scientific knowledge. They cultivate the skill of identifying their learning objectives, outlining the necessary steps to attain them, and actively seeking pertinent information and experiences. This self-directed approach fosters independence and instils a sense of ownership in the learning journey. In the following interview transcript, pupils were prompted to assume responsibility for the activities, unleashing their creativity in crafting video presentations to articulate their comprehension of the subject.

R: You can do what your heart desires … That means …
P3: (The) teacher said we could do (the work) according to our creativity.
R: Using your own creativity. That means you're free to follow your own creativity. What else are you free to do besides being creative when making the video? Can you explain?
P2: (We) can do what we want.

IT1/432–435

Independent learning is a crucial component supporting active engagement in digital inquiry-based science education in primary schools. Wiemer (2019) emphasized that inquiry-based learning is a teaching approach that melds independence with teacher guidance, empowering pupils to take control of their learning. It grants them significant autonomy to organize, plan, and execute their learning processes while teachers offer appropriate guidance and encouragement. During the lesson, pupils conduct independent investigations with the aid of digital teaching materials, all while under the teacher's supervision. This is particularly important because pupils often encounter challenges in effectively navigating technological platforms to access relevant information, underscoring a deficiency in their digital literacy skills (Tohara et al., 2021).

6.8 *Learning by Doing*

Engaging in hands-on learning within digital inquiry-based science encourages active involvement from pupils in the educational process. Rather than being passive recipients of information, pupils in primary schools become dynamic contributors to their own learning. They actively delve into scientific concepts, conduct investigations, analyze data, and formulate conclusions. This is evident in the below teaching transcript, where the teacher emphasized to pupils that elucidating their actions during investigations is more important than creating elaborate presentations.
P: My drawing is not good, Mr.
T: It's okay. It doesn't need to be good.
P: You can read this right, Mr.?
T: Ha, yes. Yes.
P: She is doing the design.
T: Yeah, draw pictures. Explain what you have drawn.

TT4/148–153

Chen et al. (2020) discussed learning by doing in digital learning, emphasizing that incorporating digital resources during practical activities enhances pupils' grasp of abstract scientific concepts and improves their practical skills. This equips them with a more profound understanding of the practical aspects of “doing science” in the developmental process. Additionally, learning by doing motivates pupils to actively participate in designing, creating, and honing their spatial awareness, thus fostering their creativity and sense of responsibility. This approach nurtures a peer learning environment where pupils construct their own understanding and retain knowledge through hands-on experiences (Niiranen, 2021).

6.9 *Making Connections*

As a theme, making connections highlights the importance of nurturing conceptual understanding in the context of digital inquiry-based science learning. When pupils associate novel concepts with familiar ideas, they cultivate a more cohesive and interconnected grasp of scientific principles. They can discern patterns, similarities, and differences between concepts and apply this knowledge to novel situations. The capacity to establish connections and transfer knowledge contributes to an enriched overall understanding of scientific phenomena. This aspect of making connections is exemplified in Figure 5, where pupils applied their prior knowledge to plan the necessary steps for their investigations in the worksheet.

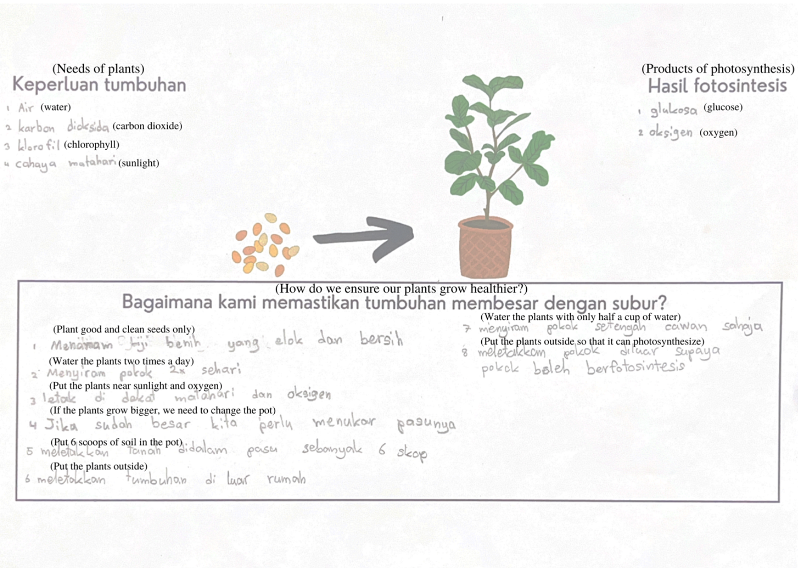

FIGURE 5 Pupils making connections between their prior and current knowledge.

Pupils' ability to make connections between their prior and current learning is essential to digital inquiry-based science learning. Dabholkar et al. (2020) described how facilitating the establishment of epistemic connections among pupils involves building knowledge through science inquiry practices and redesigning learning environments using learning management systems. Additionally, it consists of implementing inquiry activities that align with these objectives and providing appropriate inquiry scaffolding. Primary science teachers aim to involve pupils in practical inquiry activities while also assisting them in establishing meaningful connections between the construction of substantial scientific knowledge and these activities. This is accomplished by encouraging pupils to make connections by synthesizing and summarizing their work, thereby promoting the development of their scientific communication skills (Ramnarain, 2015).

6.10 *Expressing Ideas*

Offering pupils chances to articulate their thoughts gives them a sense of empowerment and validates their voices, fostering a feeling of ownership and control over their educational path. This affirmation establishes a classroom atmosphere where pupils experience value, respect, motivation, and engagement, thus cultivating a deep sense of belonging. The teaching data reveal that pupils were granted autonomy to devise their investigations independently, outlining procedures in the provided worksheet. In the interview transcript, pupils were encouraged to showcase their creativity and decide on the presentation format for data related to scientific knowledge.

R: No, what are the things you're free to do in the videos?
P1: Emojis.
R: Inserting emojis. What else?
P2: Can insert words.
R: What?
P2: Words.
R: Inserting words. So, you're free to do what you want. Does the teacher say you must follow specific rules?
P1: No.

IT1/449–456

Primary pupils should be given opportunities to articulate their thoughts, enabling them to actively engage in digital inquiry-based science lessons. One way pupils gained these opportunities was by sharing ideas with their classmates. The exchange of ideas among peers enhanced the pupils' ability to explain concepts effectively during the inquiry process. This, in turn, offered valuable insights into effectively facilitating pupils' engagement, emphasizing the importance of actively encouraging pupils to express their ideas (Matuk et al., 2019). The expression of ideas and the interpretation of scientific representations are crucial for nurturing pupils' scientific literacy. It actively prepares them to participate in discussions on scientific concepts and issues, aligning with fostering a deeper understanding of science (Gillies & Rafter, 2020).

6.11 *Reporting Discoveries*

Reporting discoveries enables pupils to commemorate their successes and express their enthusiasm for learning science. It provides a stage for them to exhibit their commitment, creativity, and problem-solving skills, fostering a feeling of pride and fulfilment. An illustration of pupils reporting their discoveries is illustrated in Figure 6. In this instance, pupils communicate the significance of scientific phenomena through a combination of graphic representations and verbal explanations, drawing on insights from prior investigations.

In the context of active learning, primary pupils share their findings based on the investigations conducted in inquiry-based learning. Pupils' past experiences, the knowledge they bring to the table, the availability of digital teaching resources in the school, and their individual abilities collectively shape

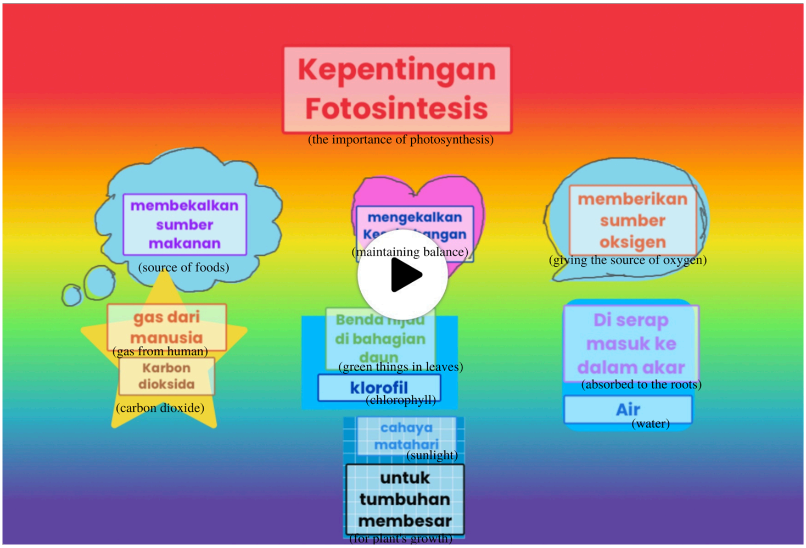

FIGURE 6 Pupils report their discoveries and understandings via mind maps and voice recordings.

how they perceive and communicate their discoveries within the framework of inquiry-based science learning in educational settings (Williams & Otrel-Cass, 2017). Dewi et al. (2021) demonstrated that the facilitating role of digital inquiry-based learning encourages the extensive sharing of discoveries and ideas. This is made possible through visual representations, analysis, and the integration of knowledge. Incorporating digital technology empowers pupils to explore, interpret, and communicate information more effectively, enhancing their overall comprehension and engagement with scientific subjects.

7 Conclusions and Implications

Digital inquiry-based science learning is gaining prominence in primary school education, with a growing focus on its effectiveness and implementation. Expanding the scope of this topic, the present study delved into the process of implementing digital inquiry-based science learning in a rural primary school in Melaka, Malaysia, presenting findings from a classroom action research study.

The study underscores the importance of effective lesson development as a fundamental element to ensure the seamless implementation of instructional plans. Primary science teachers were encouraged to navigate classroom strategies that enhanced their lesson-planning skills, particularly when incorporating inquiry-based instruction. This necessitated a robust pedagogical foundation and demanded a commitment to time management and proficiency in technology usage (Qablan & DeBaz, 2015).

The study also underscores the necessity for systematic guidance in implementing digital inquiry-based science teaching. Primary science teachers require support to align their lessons with science content and utilize technology effectively (Kamarudin et al., 2022). The absence of clear guidelines for science teachers indicates a gap that educational institutions and policymakers must address by providing comprehensive support and resources (Halim et al., 2018). Additionally, the collaborative relationship between science teachers and primary pupils is recognized as pivotal, with digital technology facilitating this partnership. Pupils transition between roles as learners and experts, leveraging technology to enhance their agency and develop scientific knowledge and digital skills (Johnston, 2019).

This study emphasizes the imperative of a holistic approach, encompassing the adept use of technology and continuous professional development. Teachers must be equipped with the skills to navigate digital tools effectively, fostering an environment where technological advancements amplify rather than replace traditional pedagogical methods. Resource development assumes a pivotal role, necessitating the creation of interactive and curriculum-aligned digital content that caters to diverse learning styles. Furthermore, the study advocates for a paradigm shift towards student-centric learning, where pupils actively explore scientific concepts, fostering curiosity and independent inquiry. This multifaceted strategy, intertwining teacher proficiency, resource richness, and student engagement, is fundamental for the seamless implementation of digital inquiry-based science education in primary schools, ensuring a transformative and empowering learning experience for young minds.

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