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Primary Teachers' Perceptions of Augmented Reality for Teaching Balanced Nutrition with Ethnoscience

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Abstract: Nutritional challenges among Indonesian school-aged children persist due to limited nutrition literacy and the absence of structured, curriculum-integrated instruction. While food provision remains important, meaningful progress requires effective pedagogical strategies within primary education. However, teachers often lack access to government-endorsed, culturally relevant resources and targeted professional development. This qualitative study investigates the perceptions of six purposively selected primary teachers (three males, three females), trained in STEM and gamification, regarding the use of traditional Indonesian foods and Augmented Reality (AR) to support nutrition education. A descriptive research design was employed, with data collected through semi-structured interviews and non-participant classroom observations of science lessons incorporating game-based learning. Thematic coding and triangulation techniques enhanced analytical rigour and credibility. Findings suggest that teachers demonstrated a sound grasp of nutrient content in traditional foods—such as cassava and fish—and integrated these examples into science topics like digestion and body systems. While realia proved more effective with younger pupils, AR enabled older learners to visualise microscopic processes, including nutrient breakdown during cooking. Teachers perceived AR as fostering inquiry-based learning, promoting cultural authenticity, and aligning with Green-STEM values. They also acknowledged the influence of Generation Alpha's digital habits and stressed the importance of age-appropriate, visually engaging approaches. This study concludes that culturally grounded AR resources, when combined with sustained teacher training, offer significant potential to enhance nutrition education in primary schools. Practical implications include the phased integration of AR-based ethnoscientific content into curricula, the use of gamified strategies to promote sustainable dietary behaviours, and further longitudinal research into the pedagogical impact of educational technology in nutrition learning.

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INTRODUCTION

The need to address nutrition-related challenges among school-aged children has become increasingly urgent due to the rising prevalence of unhealthy eating behaviours, persistent undernutrition, and the early onset of non-communicable diseases such as diabetes, obesity, and cardiovascular conditions (Sarjito, 2024; Dwijayanti, 2024). This situation is compounded by evidence showing that many children lack foundational nutrition literacy, which may hinder their ability to make informed food choices later in life. In Indonesia, these challenges are further complicated by a significant detachment of young learners from their rich local food cultures. This phenomenon is driven largely by the growing influence of globalised consumption patterns and modern fast-food culture, which often overshadow the traditional knowledge and practices embedded in Indonesian cuisine (Hidaayatullaah et al., 2021; Silla et al., 2023). Traditional Indonesian foods, which are deeply interwoven with cultural values and hold substantial

nutritional benefits, offer an invaluable opportunity as educational entry points for introducing scientific concepts related to balanced diets and healthy living (Sujana et al., 2014; Silla et al., 2023).

Despite this potential, recent studies have highlighted that there remains limited scholarly attention regarding how primary school teachers conceptualise, understand, and deliver nutrition education, particularly through integrating ethnoscientific dimensions that connect local food heritage with scientific principles (Hidaayatullaah et al., 2021; Silla et al., 2023). This lack of integration reflects a broader issue: the disconnection between culturally relevant content and science pedagogy in Indonesian classrooms. Given that teachers are the primary agents responsible for implementing curricula, their conceptual frameworks and pedagogical choices critically influence whether nutrition content is taught in a manner that is both meaningful and contextually relevant to students' lived experiences (Beach, 2023; Anam et al., 2023).

A further concern relates to the vertical coherence and integration of nutrition education across different stages and levels of schooling in Indonesia. Nutrition-related content is often presented in a fragmented and isolated manner within the curriculum, resulting in limited continuity across subjects and grade levels. Many science educators face constraints such as lack of time, insufficient teaching resources, and inadequate pedagogical tools, which may limit their ability to scaffold nutrition literacy effectively (Sujana et al., 2014; Beach, 2023). Consequently, they may fail to appreciate the importance of structuring nutrition education progressively, ensuring that knowledge and skills build upon one another in a developmentally appropriate yet scientifically rigorous way. Without such structured integration, students are at risk of forming misconceptions or disengaging from food-related science topics altogether. Understanding how teachers perceive the importance of integrating nutrition content across the science education continuum is therefore essential to informing reforms that promote sustained healthy behaviours and scientific literacy throughout students' educational trajectories (Sopandi & Sukardi, 2020; Beach, 2023). Since primary education represents the foundational stage for cultivating scientific reasoning and health awareness, neglecting to contextualise and embed essential nutrition concepts early on risks widening conceptual gaps and misconceptions as learners advance to higher education levels (Anam et al., 2023).

An equally pressing issue pertains to the representation of abstract scientific content—especially chemical concepts related to food and nutrition—in primary classrooms. Such chemical representations require learners to perform complex cognitive transformations, which can be particularly challenging for younger students, especially in environments where visualisation and interactive learning tools are scarce (Dabrowski & McManamy, 2020; Cheng et al., 2020). How teachers choose to simplify, visualise, and relate abstract processes—such as digestion, nutrient absorption, metabolic transformations during cooking, and food component interactions—significantly impacts students' conceptual understanding and engagement (Anam et al., 2023; Sujana et al., 2014). However, there is a paucity of research exploring how Indonesian primary school teachers navigate these representational challenges, especially within the culturally rich and diverse contexts of traditional Indonesian foods (Hidaayatullaah et al., 2021; Silla et al., 2023). Existing instructional practices rarely utilise tools that can bridge students' concrete experiences with the abstract nature of scientific knowledge, thus limiting students' ability to meaningfully connect traditional food experiences with scientific explanations. Investigating their instructional strategies, perceived constraints, and resource needs is crucial for developing tailored teaching aids, professional development, and curricular resources that enhance effective food-related science education (Beach, 2023).

In light of these pedagogical challenges, Augmented Reality (AR) has emerged as an innovative and promising tool to support science learning by enabling learners to visualise complex and often invisible scientific phenomena in an interactive, immersive, and culturally meaningful way (Boel et al., 2024; Ferro et al., 2021). AR technology can situate scientific content—such as chemical transformations during cooking, nutrient degradation in processing, or identification of food groups—within familiar cultural narratives and ethnoscientific knowledge frameworks (Gui et al., 2023; Harnal et al., 2024). Despite widespread global advances in AR for STEM education, the use of AR in primary nutrition education remains under-explored, particularly in low- and middle-income countries like Indonesia (Boel et al., 2024; Saputra et al., 2025). Furthermore, there is limited understanding of the pedagogical readiness and

attitudes of primary teachers towards AR integration, including factors such as digital literacy, perceived ease of use, and perceived relevance (Barua & Bharali, 2023; Ferro et al., 2021). Therefore, critical investigation into how primary school teachers perceive and are willing to implement AR in science instruction is warranted. This is especially true when considering pedagogical frameworks such as critical pedagogy, developmental psychology, and Green-STEM education, which together advocate for contextualised, inquiry-based, and sustainability-oriented approaches to science teaching (Beach, 2023; Holt & Sprott, 2025).

Despite increasing global recognition of the vital role of nutrition education in early childhood development, existing research in Indonesia has not sufficiently addressed how primary teachers conceptualise and implement balanced nutrition education, especially in relation to local food cultures (Hidaayatullaah et al., 2021; Silla et al., 2023). Current studies predominantly focus on health outcomes, dietary behaviours, or curriculum content analysis, with limited exploration of teachers' pedagogical perspectives—particularly on the integration of ethnoscientific knowledge and chemical representations within primary science classrooms (Sujana et al., 2014; Anam et al., 2023). Moreover, there is scant research on the potential of technology-enhanced learning tools, such as Augmented Reality (AR), to facilitate meaningful, culturally embedded, and scientifically accurate nutrition instruction for young learners (Boel et al., 2024; Harnal et al., 2024). These research gaps underscore the urgent need for studies that examine how teachers can bridge traditional knowledge and science education using innovative tools in real classroom contexts.

The novelty of this study lies in its interdisciplinary and integrative approach, combining insights from ethnoscience, nutrition education, chemical representation, AR technology, and Green-STEM pedagogy to holistically examine teachers' perceptions and practices within their cultural and educational contexts (Beach, 2023; Anam et al., 2023). By focusing on traditional Indonesian foods as culturally significant vehicles for teaching balanced nutrition, the study introduces an innovative instructional framework that bridges indigenous knowledge with contemporary scientific understanding (Silla et al., 2023; Hidaayatullaah et al., 2021). Furthermore, this research pioneers the examination of AR as a pedagogical tool for visualising complex food-related scientific processes in the primary education context (Boel et al., 2024; Harnal et al., 2024). This approach not only fills theoretical and empirical gaps but also aims to develop practical, context-responsive recommendations for integrating nutrition education and technology in science classrooms. Consequently, this work fills both theoretical and empirical gaps while offering practical recommendations for developing technology-based learning interventions that are developmentally appropriate, culturally relevant, and aligned with sustainability principles (Saputra et al., 2025; Holt & Sprott, 2025).

This study specifically aims to explore five interrelated research questions: (1) How do primary teachers conceptualise balanced nutrition concepts within the context of traditional Indonesian foods? (2) What is their perceived importance of integrating nutrition content across different levels of science education? (3) How do teachers perceive and represent chemical concepts related to traditional Indonesian food education? (4) What are their attitudes towards the use of technology in teaching and learning processes? and (5) How do they perceive the implementation and pedagogical value of Augmented Reality (AR) in primary science education for teaching balanced nutrition effectively? The findings are expected to contribute to curriculum development, teacher training programmes, and the design of AR-based instructional media that support contextualised, engaging, and scientifically grounded nutrition education at the primary level.

METHOD

Research Design

This study adopts a qualitative case study design aimed at exploring in depth the perceptions of primary school teachers regarding the teaching of balanced nutrition and the integration of technology, with a particular emphasis on the use of Augmented Reality (AR), in delivering such content to pupils. The case study approach is well-suited for capturing the complexity and contextual nuances of classroom practices, as it allows for a thorough investigation into how individual educators interpret, plan, and enact

nutrition education within their specific teaching environments. By focusing on the lived experiences and professional judgements of teachers, the study seeks to understand not only what is taught, but how and why particular methods and technological tools are chosen. Moreover, the research critically examines the extent to which AR-based interventions are aligned with curricular goals and pupils' developmental needs, ensuring that such innovations are both relevant and pedagogically effective. The research was conducted through a series of stages beginning with the formulation of research questions, followed by the development and validation of data collection instruments, the recruitment of participants, and the implementation of data collection. These stages were then followed by data analysis, interpretation, and synthesis of findings into thematic insights.

Research Participants

The sample comprised six primary school teachers, consisting of three males and three females, selected through purposive sampling. Participants were chosen based on specific criteria to ensure their relevance to the research aims. Each teacher had a minimum of two years of teaching experience, thereby providing a sufficient foundation for reflective and practice-based insights.

Besides to their teaching background, all participants had previously undertaken coursework related to 21st-century learning paradigms during their undergraduate studies. They had completed modules such as STEM Education in Primary Schools and Gamification in Primary School Teaching, particularly in relation to science learning. These academic experiences were deemed essential, as they provided participants with both theoretical knowledge and pedagogical familiarity with integrative and technology-enhanced instructional approaches. Such qualifications ensured that the participants were well-positioned to reflect critically on the use of educational technologies, including AR, in primary-level nutrition education.

Research Instruments

The instruments employed in this study consist of semi-structured interview questions and classroom observations, specifically conducted during instances where teachers utilised educational games to teach science concepts. The interview component was designed to elicit in-depth responses that reflect both the cognitive and pedagogical orientations of the participating teachers. The interview protocol comprises five core questions, each aligned with the study's thematic focus.

First, teachers were asked to articulate their understanding of balanced nutrition concepts as represented in traditional Indonesian foods. This question aimed to uncover the extent of content knowledge and cultural contextualisation embedded in their instructional approach. Second, the interview explored teachers' views on the urgency and pedagogical relevance of integrating such content into science education across all educational levels, with particular attention to foundational stages. The third question probed their perceptions of how chemical representations can or should be incorporated into lessons about traditional foods, thereby examining the interface between everyday cultural knowledge and abstract scientific concepts. The fourth question examined teachers' broader perceptions regarding the use of technology in educational contexts, allowing insights into both opportunities and reservations surrounding its integration. Lastly, the fifth item focused specifically on teachers' perceptions of AR as a tool for enhancing science instruction in primary schools. This included reflections on its feasibility, pedagogical affordances, and alignment with curriculum objectives.

Observational data were used to triangulate interview findings and to capture authentic teacher–pupil interactions during game-based science learning activities. Both instruments underwent a validation process involving expert review to ensure content relevance, clarity, and alignment with the research objectives. The interview guide was assessed by specialists in science education and educational technology, while the observation rubric was piloted and revised based on expert feedback to improve its reliability.

Data Analysis

The interview data were subjected to a thematic coding process to identify recurring patterns, categories, and emerging constructs relevant to the research focus. This analytical procedure enabled the organisation of qualitative responses into meaningful themes that reflected the teachers' perceptions and instructional orientations. To enhance the credibility and trustworthiness of the findings, methodological

triangulation was employed by cross-referencing interview data with observational evidence gathered during classroom activities. This cross-validation ensured that the themes identified were not only grounded in stated beliefs but also reflected in actual teaching practices. Data analysis was supported using qualitative analysis software to manage and code the data efficiently. Two researchers independently coded the transcripts, and discrepancies were resolved through discussion to ensure consistency and strengthen inter-coder reliability. Thematic saturation was considered achieved when no new themes emerged across the remaining data sets.

RESULT

Triangulated data from interviews and observations indicate that teachers possess a sound understanding of the chemical composition of traditional Indonesian foods and support their integration into science education to promote both health and cultural awareness. They highlight simple food chemistry concepts—such as preservation with sugar or salt and the risks of synthetic additives and carcinogens from poor food processing—to develop pupils' nutritional literacy. While advocating for technology like Augmented Reality to visualise sub-microscopic changes in food preparation, teachers stress that realia remains essential for younger learners. Overall, the findings underscore the importance of culturally grounded, developmentally appropriate, and scientifically accurate representations of food chemistry in primary education. The detailed discussion is shown below.

Teachers' Understanding of Balanced Nutrition Concepts in Traditional Indonesian Foods

The triangulated analysis of interview and observational data revealed a coherent understanding among teachers regarding the chemical composition and nutritional value of traditional Indonesian foods as sources of balanced nutrition. Through systematic coding, teachers consistently identified macronutrients in terms of their chemical nature: carbohydrates primarily derived from cassava (rich in starch polymers), proteins sourced from animal-based foods such as fish (notably high in essential amino acids), and plant-based proteins from soybeans, which contain notable levels of globulin and other storage proteins. Additionally, lipids were acknowledged as being predominantly obtained from fish oils, rich in omega-3 fatty acids, thus providing essential fatty acids crucial for human health (Sukardi et al., 2022a; Sumarni et al., 2022). Importantly, participants questioned the necessity of dairy products, such as milk, in the diet when macronutrient needs are met through traditional foods. This position reflects an awareness of the biochemical implications of overconsumption of certain nutrients, with a particular concern for preventing obesity—a condition linked to excess lipid and carbohydrate intake and metabolic imbalances (Sukardi et al., 2022b).

Teachers also highlighted challenges in teaching these concepts to primary pupils, especially those belonging to Generation Alpha, who show a marked preference for processed and convenience foods. This generational shift presents a significant pedagogical obstacle in promoting the chemical understanding and health benefits of traditional foods (Yean & Rahim, 2021). Furthermore, teachers emphasised the chemical integrity of traditional foods, noting their freedom from artificial additives—such as synthetic dyes, sweeteners, and preservatives—whose chemical structures and metabolic effects remain a concern in nutritional science. This aligns with the broader scientific consensus advocating for minimal exposure to such compounds due to potential adverse health effects (Sukardi et al., 2021). Thus, the integrated findings underscore a critical intersection between chemistry education and nutrition pedagogy: while teachers possess a sound chemical understanding of food composition and its health implications, effective translation of this knowledge into engaging and meaningful learning experiences remains constrained by pupils' contemporary dietary preferences. This highlights the imperative for chemistry education to incorporate culturally relevant and scientifically accurate representations of food chemistry to foster both cognitive and affective learning outcomes in nutrition (Sukardi et al., 2022a; Macbeth et al., 2021).

The Perceived Importance of Integrating Nutrition Content Across Science Education Levels

The data analysis, derived from rigorous coding and triangulation of interviews and classroom observations, indicated unanimous agreement among teachers regarding the inclusion of traditional food

content within the primary science curriculum. Educators articulated a dual rationale: firstly, to enhance pupils' awareness of the superior health benefits associated with local, traditional foods, and secondly, to foster cultural preservation through curricular integration (Sumarni et al., 2016). Teachers expressed confidence that such content offers valuable opportunities to introduce fundamental scientific principles to young learners. For example, they identified simple chemical processes such as food preservation by osmotic effects using sugar or salt, which do not rely on synthetic preservatives that could potentially compromise health or immune function. This exemplifies a practical intersection between everyday cultural practices and basic food chemistry, which can be leveraged pedagogically to elucidate concepts of molecular interactions and food safety (Sukardi et al., 2017).

The modes of integrating this content were described as contextually relevant and developmentally appropriate. For instance, lower primary science topics such as "My Body" can be used to engage pupils in discussions about making healthy food choices, while units on healthy eating or the digestive system provide natural contexts for exploring food composition and nutritional science. This approach underscores an educational strategy that combines culturally meaningful content with foundational scientific concepts, thereby facilitating both cognitive engagement and cultural literacy (Nguyen et al., 2020). Overall, the findings highlight the potential for embedding simple yet scientifically robust food chemistry concepts within primary education, enabling pupils to develop an informed understanding of nutrition that is grounded in both science and local cultural heritage (Gui et al., 2023).

Teachers' Perceptions of Chemical Representation in the Context of Indonesian Food Education

The coding and triangulation of interview and observational data reveal that teachers aspire to present a multifaceted representation of food chemistry in their pedagogy. Beyond merely illustrating the molecular structures of macronutrients and micronutrients, educators emphasised the importance of conveying critical health-related chemical facts to their pupils. This includes highlighting the prevalence and risks associated with synthetic food colourants, which, despite their visually appealing qualities, pose greater health hazards compared to natural colourants derived from plant-based sources (Sukardi et al., 2022a).

Teachers also sought to incorporate awareness of carcinogenic compounds that may form during improper food processing methods, such as frying or inadequate cooking, which fail to meet established health standards. By exposing pupils to such chemical hazards, educators aim to foster critical consciousness regarding food safety and health implications, encouraging more informed dietary choices (Sukardi et al., 2022b; Willcox-Pidgeon et al., 2020).

Teachers expressed interest in employing microscopic imagery of foods subjected to different cooking methods—specifically frying and boiling—to visually demonstrate chemical and physical transformations at the cellular level. This strategy is intended to deepen students' understanding of how food preparation alters nutritional value and safety, thereby cultivating an informed awareness of food chemistry grounded in both scientific fact and everyday experience. This integrative pedagogical approach aligns with contemporary science education goals, which advocate for contextualised learning that bridges molecular chemistry, health science, and cultural relevance, ultimately promoting scientifically literate and health-conscious pupils (Ye et al., 2024).

Attitudes Towards the Use of Technology in Teaching and Learning Processes

The analysed data, derived from meticulous coding and triangulation of interviews and observations, indicate a unanimous consensus among teachers regarding the essential role of technology in enhancing student engagement within science education. Educators emphasised that the integration of technological tools serves as a catalyst for stimulating pupils' interest and motivation, thereby potentially improving learning outcomes (Ferro et al., 2021). However, for lower primary school pupils, teachers advocated for a more tactile and sensory-rich approach through the use of realia—concrete, physical learning materials—in science instruction. This preference reflects an understanding of developmental psychology and pedagogical theory, which suggest that younger learners benefit most from direct sensory experiences that engage multiple senses simultaneously. Employing realia in teaching fundamental scientific concepts optimises sensory perception and aids cognitive assimilation by grounding abstract ideas in tangible contexts (Sukardi et al., 2021). Therefore, while technology holds

promise for enriching science education across all levels, these findings highlight the necessity for age-appropriate media selection. For early learners, realia remain indispensable to facilitate experiential learning, ensuring that foundational scientific principles are both accessible and meaningful (Harnal et al., 2024).

Perceptions of AR Implementation in Primary Science Education

The analysis of coded and triangulated interview and observational data reveals a strong endorsement by teachers for the utilisation of AR in primary science education, particularly as a tool for representing sub-microscopic phenomena. Educators highlighted the capacity of AR to render otherwise abstract chemical and biological processes in a simplified, accessible format that aligns with the cognitive abilities of young learners (Sukardi et al., 2017).

Moreover, teachers advocated for the incorporation of interactive modelling within AR applications to visually demonstrate comparative scientific concepts. For example, contrasting the effects of frying versus boiling on food allows pupils to discern differences in nutrient retention and degradation. Such dynamic visualisation facilitates an experiential understanding of food chemistry, reinforcing theoretical knowledge through engaging, concrete representations (Dabrowski & Manson McManamy, 2020). This approach aligns with contemporary pedagogical frameworks that prioritise multi-modal learning and visualisation of invisible scientific processes, thereby enhancing conceptual clarity and retention. Overall, the strategic use of AR, complemented by modelling, presents a promising avenue for enriching the primary science curriculum with meaningful, interactive content (Ye et al., 2024).

DISCUSSION

Positioning AR as a Transformative Tool for Teaching Food Chemistry in Primary Science Education

The present study reveals that primary school teachers demonstrate a scientifically coherent and culturally rooted understanding of balanced nutrition, particularly as it is embedded in traditional Indonesian cuisine. This finding indicates not only an appreciation of indigenous knowledge but also a conscious effort among educators to bridge traditional practices with contemporary scientific principles. Their insights reflect accurate conceptual understanding of the chemical composition of local food items, such as staple sources of carbohydrates, proteins, and micronutrients, while also illustrating a strong pedagogical commitment to translating such scientific knowledge into meaningful, contextually grounded classroom practices. By leveraging familiar food items and culturally embedded eating habits, teachers are able to foster scientific literacy that resonates with pupils' everyday experiences, thus enhancing both comprehension and retention.

Notably, teachers displayed awareness of the biochemical implications of dietary choices and the health risks associated with poor food processing methods, including the use of synthetic additives, excessive heating, and the overconsumption of ultra-processed foods. Their responses reveal a critical stance towards industrial food practices that often prioritise shelf-life and appearance over nutritional integrity. This critical awareness is indicative of an emerging pedagogical consciousness — one that views science not as a neutral body of knowledge but as a transformative tool to interrogate and improve societal health norms. This approach aligns with the argument that connecting food-based chemistry to students' lived realities promotes both deeper engagement and a more socially responsive understanding of science (Howell et al., 2021; Macbeth et al., 2021). In this sense, food becomes not only a subject of scientific inquiry but also a site for cultural reflection and ethical discussion.

Teachers strongly supported embedding nutrition education across the primary science curriculum, particularly through themes such as body systems, growth, digestion, and environmental sustainability. These themes offer accessible entry points for pupils to engage with complex scientific content without abstracting it from their everyday lives. The cross-disciplinary nature of food — touching on biology, chemistry, environmental science, and health education — allows for a more holistic pedagogical approach. This integration not only deepens conceptual understanding of food chemistry but also fosters cultural literacy, environmental sensitivity, and critical consumer behaviour (Nguyen et al., 2020; Rivera Zea, 2024). It is through this interdisciplinary lens that science education can contribute to the cultivation of sustainable food habits and a more reflective public discourse on nutrition and well-being.

A key finding of the study concerns the representational strategies adopted by teachers to convey food-related chemical phenomena. Teachers demonstrated considerable pedagogical sensitivity in selecting visual and experiential representations that were developmentally appropriate and culturally resonant. For instance, rather than employing abstract molecular models, they preferred representations that illustrated how carcinogenic compounds might form through everyday cooking methods such as grilling or frying, or how nutrient content could be preserved through steaming or fermentation. These visuals were chosen not only for their instructional clarity but also for their capacity to stimulate reflective and critical thinking among pupils. Such representational practices reveal an intention to not merely transfer knowledge, but to foster health-conscious attitudes and ethical reflection.

In this regard, the pedagogical shift from traditional textbook diagrams to more interactive and meaningful visuals reflects a broader evolution in science education — one that prioritises learner engagement, contextual relevance, and moral development. This approach draws upon the theoretical foundations of constructivist and socio-cultural learning theories, which posit that learners construct knowledge more effectively when new information is meaningfully connected to prior experiences and cultural contexts. Importantly, these representational strategies honour pupils' lived experiences and seek to empower them as informed and critical participants in their food environments (Rosyidah et al., 2013; Rikizaputra et al., 2022; Silla et al., 2023). Such practices further reflect a commitment to science education that is both inclusive and socially just.

Technology also emerged as a pivotal theme in teachers' vision for future-oriented science instruction, particularly in addressing the challenges of visualising complex and often invisible food-related phenomena. While there was widespread endorsement for the use of digital tools to enhance engagement and understanding, teachers made important developmental distinctions. For younger primary pupils — typically in lower grades — hands-on, realia-based learning experiences were considered more suitable due to their sensory and motor development stages. In contrast, upper primary pupils, having developed more advanced cognitive and psychomotor skills, were seen as ready to engage with immersive technologies such as Augmented Reality (AR) and Artificial Intelligence (AI). These technologies were valued for their potential to visualise sub-microscopic processes, such as nutrient breakdown, chemical transformations during cooking, and the impact of preservatives or acidity levels on food stability (Koumpouros, 2024; Pawitan et al., 2023).

The use of AI in particular was viewed as especially promising, though teachers also warned against its uncritical or purely aesthetic application. AI, when strategically deployed, can support the development of investigable questions, hypothesis formulation, data interpretation, and argumentation based on evidence — all key components of scientific literacy. Teachers envisioned AI as a means to make abstract scientific processes more accessible and investigable, while also enabling personalised learning paths that accommodate diverse learner needs and preferences. Importantly, this digital approach must be embedded in a thoughtful pedagogical framework, one that ensures learners are not passive recipients of content but active constructors of meaning (Liu, 2022; Sukardi et al., 2022).

From a STEM education standpoint, the study found that AI-based platforms are uniquely positioned to support interdisciplinary and inquiry-based learning. Pupils can engage in activities such as modelling food systems, analysing nutritional data, simulating cooking processes, and even designing culturally appropriate food innovations that reflect both health goals and environmental consciousness. These capabilities support the cultivation of core STEM competencies, including systems thinking, technological fluency, and ethical decision-making — competencies that are increasingly essential in the 21st-century knowledge society (Ortiz-Rojas et al., 2025; Sukardi et al., 2021). Moreover, AI tools can serve as catalysts for fostering creativity and critical innovation, enabling pupils to not only consume knowledge but also to generate novel solutions to local and global food challenges.

When situated within a critical science education framework, the potential of AI becomes even more significant. Teachers imagined upper primary pupils — whose cognitive and moral capacities are more developed — using AI not just for content acquisition, but for interrogating deeper socio-environmental issues. For instance, they might explore themes such as food justice, inequality in food access, or the environmental impacts of various food production systems. Such inquiries encourage pupils to view science as a human endeavour shaped by values, power structures, and ecological realities (Lestari et al.,

2021; Kuswanto et al., 2023). This approach advances a more emancipatory vision of science education, one that nurtures critical consciousness and empowers learners to become agents of change in their communities.

In conclusion, the findings of this study illuminate a promising and future-oriented pathway for science pedagogy rooted in food-based learning. The strategic integration of Artificial Intelligence — particularly in upper primary contexts — must be developmentally calibrated, pedagogically grounded, and ethically framed. When designed with clarity and purpose, immersive technologies such as AR and AI have the potential to transform abstract scientific content into dynamic, relatable, and thought-provoking learning experiences. They can support conceptual understanding while also cultivating cultural pride, environmental responsibility, and critical engagement with pressing societal issues. Evidence from recent studies further supports the use of well-designed AR games and AI-driven learning tools in promoting higher-order thinking, metacognitive skills, and sustained engagement with science (Kharbouch et al., 2024; Saputra et al., 2025). Ultimately, science education that leverages the cultural richness of food, the cognitive power of immersive technologies, and the ethical aspirations of critical pedagogy holds immense potential to prepare learners for a future that demands both scientific competence and social awareness.

Culturally Rooted Pedagogies in Food Chemistry

This study demonstrates that primary educators possess a sound understanding of nutrition science contextualised within traditional Indonesian food systems. This knowledge goes beyond basic nutritional literacy, offering a pedagogical bridge between science education and indigenous knowledge systems. Teachers' engagement with food chemistry reflects both cognitive competence and cultural consciousness.

Crucially, this study illustrates how teachers apply chemical knowledge to critique modern food practices, including the overuse of additives and industrial processing techniques. Their critical stance affirms that science education can be transformative, fostering reflective health practices among learners (Howell et al., 2021; Macbeth et al., 2021).

Interdisciplinary Integration and Holistic Science Education

By integrating food content across biology, chemistry, and health science, teachers support a holistic curriculum. This cross-disciplinary approach promotes conceptual clarity while embedding values of sustainability, cultural literacy, and ethical consumption (Nguyen et al., 2020; Rivera Zea, 2024). The representational strategies employed—such as using visual depictions of food transformation—reflect teachers' intent to stimulate higher-order thinking and critical awareness. Rather than abstract representations, teachers favour culturally situated, process-based visuals to encourage ethical and informed decision-making.

Research Advantages and Limitations

This research offers a detailed, empirically grounded insight into how primary school teachers integrate chemical and nutritional concepts within culturally relevant contexts. Its strengths lie in its use of triangulated data and thematic analysis, which provide depth and rigour. However, several limitations must be acknowledged. First, the research was geographically confined to specific regions in Indonesia, limiting the generalisability of findings to other cultural contexts. Second, while the qualitative approach captured deep insights, it lacked quantitative validation that could have measured the extent of knowledge retention among pupils.

Future studies should adopt mixed-methods approaches, incorporate student learning outcomes, and explore cross-cultural comparisons to examine how similar pedagogical strategies function in diverse educational systems. Furthermore, longitudinal studies could better assess the lasting impacts of integrating culturally rooted food chemistry into science curricula.

CONCLUSION

This study addresses the research questions by revealing that primary school teachers in Indonesia demonstrate a critical awareness of balanced nutrition, particularly within the context of traditional Indonesian foods. The findings provide a deeper understanding of how teachers perceive the integration of nutrition education into science instruction and how they relate chemical concepts to culturally relevant food contexts. These insights affirm that nutrition education, when grounded in students' cultural backgrounds, can be meaningfully embedded in primary science teaching.

The study also finds that teachers hold generally positive attitudes toward the use of digital technologies, especially Augmented Reality (AR), which they view as a promising tool to visualise abstract and sub-microscopic scientific phenomena, such as chemical changes in food. This reflects a strong alignment between the pedagogical potential of AR and the developmental readiness of upper primary students. Furthermore, teachers recognise that integrating AR within Green-STEM education can support inquiry-based learning and promote scientific reasoning rooted in local culture and sustainability values.

Practically, these findings highlight the need to incorporate culturally relevant nutrition content progressively into the primary science curriculum. This should be supported by targeted teacher training in both nutrition science and AR-based pedagogy. AR applications—such as interactive games or simulations—offer a concrete pathway to link ethnoscience, Green-STEM, and digital learning, thereby fostering students' creativity, critical thinking, and awareness of sustainable food practices.

Future research should focus on the design, implementation, and evaluation of AR-based educational resources that integrate balanced nutrition and local food heritage. Longitudinal studies are also recommended to assess the impact of such technology-enhanced learning on students' conceptual understanding, dietary behaviours, and sustainability attitudes. These findings can inform curriculum development and educational policy aimed at strengthening culturally relevant and sustainability-oriented science education in Indonesian primary schools.

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