FROM DESIGN TO CONSENSUS: EVALUATING A MOBILE LEARNING MODEL USING THE FUZZY DELPHI METHOD

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Abstract

This study aimed to evaluate expert consensus on the constructs and elements of a mobile learning model for secondary school science education in Malaysia. The study formed part of a Type II Design and Development Research (DDR) project, focusing on the model development phase. The proposed model specification was derived from a preceding modified Nominal Group Technique (mNGT) stage involving nine experts. Subsequently, the Fuzzy Delphi Method (FDM) was employed to determine the extent of expert consensus on the proposed model constructs and elements. Thirteen experts assessed 47 units comprising six constructs and 41 elements using a seven-point agreement scale. The analysis involved 611 expert ratings and applied triangular fuzzy numbers, threshold distances, expert consensus percentages, and defuzzification scores. The findings showed that all 47 assessment units satisfied the acceptance criteria applied in the study. All six constructs achieved 100% expert consensus, while consensus for the 41 elements ranged from 92.31% to 100%. Mean threshold distances ranged from 0.046 to 0.064 for constructs and from 0.034 to 0.110 for elements. The model specification encompasses mobile-learning pedagogy, scientific literacy incorporating Habits of Mind, students' digital literacy, technology integration, science learning assessment and monitoring, and implementation support. The findings provide expert-based support for retaining the assessed constructs and elements. However, expert consensus does not establish classroom effectiveness or end-user usability. Further evaluation involving secondary school science teachers is required to examine the model's practical usability.

Keyword(s): *Mobile Learning; Science Education; Design and Development Research; Fuzzy Delphi Method; Expert Consensus.*

INTRODUCTION

Mobile learning offers opportunities to extend science learning beyond conventional classroom settings through access to digital resources, inquiry activities, collaboration, and flexible learning experiences (Garzón & Lampropoulos, 2024; Widowati & Tyas, 2024). However, the availability of mobile devices does not, by itself, establish how technology should support scientific reasoning or classroom instruction. Developing a mobile learning model for secondary school science

education therefore requires attention to pedagogy, disciplinary learning requirements, digital competencies, assessment and implementation conditions.

Garzón and Lampropoulos (2024) examined mobile learning in K–12 science education through a meta-analysis, while Widowati and Tyas (2024) reviewed trends in mobile-based science learning. Together, these studies highlight the importance of pedagogical considerations beyond technological adoption. However, they do not establish the specific components required for a context-sensitive mobile learning model in Malaysian secondary science education.

Noor and Lajium (2026) proposed an integrated conceptual framework for mobile learning in science education encompassing pedagogical design, scientific literacy, digital literacy, and system and implementation support. Although this framework informed the present research, conceptual justification alone could not establish the suitability of the proposed model's specific constructs and elements, requiring further developmental evaluation.

Guided by Design and Development Research (DDR; Richey & Klein, 2007), the broader study began with a needs analysis of teachers' experiences, digital resources, instructional practices, and developmental requirements. A subsequent modified Nominal Group Technique (mNGT) stage involving nine experts produced a proposed specification of six constructs and 41 elements covering pedagogy, scientific literacy and Habits of Mind, digital literacy, technology integration, assessment, and implementation support. These components emerged from the preceding design process rather than being established directly by the literature.

As mNGT did not independently establish expert consensus on each proposed component, the Fuzzy Delphi Method (FDM) was used to assess six constructs and 41 elements as 47 separate units. Thirteen experts evaluated these units using threshold distance, consensus percentage, and defuzzification criteria. Separate assessment prevented agreement on an overarching construct from being assumed to represent agreement on all its elements.

Building on the preceding research stages, this study addresses the following question: To what extent do experts agree on the proposed constructs and elements of a mobile learning model for secondary school science education in Malaysia? The study evaluates these components against predetermined FDM acceptance criteria and examines expert feedback relevant to their clarification. Its contribution lies in providing structured evidence for developmental decisions, rather than establishing instructional effectiveness, independent validation of subsequent refinements, or end-user usability.

LITERATURE REVIEW

Mobile Learning in Secondary School Science Education

Mobile learning extends science education beyond conventional classrooms, but its educational value depends on pedagogical alignment rather than device accessibility alone. Driver et al. (1994) emphasised the individual and social construction of scientific knowledge, while Mishra and Koehler (2006) highlighted the interrelationship of technological, pedagogical, and content knowledge. UNESCO (2023) further emphasised educational purpose, equity, and implementation conditions. Together, these perspectives support treating mobile-learning pedagogy as a distinct construct requiring expert evaluation, without presuming instructional effectiveness.

Scientific Literacy and Habits of Mind

Scientific literacy involves explaining phenomena, evaluating inquiry, and interpreting scientific evidence (OECD, 2023). Habits of Mind encompass dispositions such as persistence, flexible thinking, and reflection when responding to complex situations (Costa & Kallick, 2008). A scoping review by Dauer et al. (2025) identified dispositions and Habits of Mind among the dimensions considered in Vision II scientific literacy assessment for secondary education. Although these domains are conceptually distinct, the proposed model combines them within one construct comprising two internal dimensions. This design decision requires expert evaluation and does not imply a causal relationship between scientific competencies and thinking dispositions.

Digital Literacy and Technology Integration

DigComp 2.2 identifies digital competence areas involving information and data literacy, communication, content creation, safety, and problem-solving (Vuorikari et al., 2022). These competencies concern individuals' responsible engagement with digital information and technologies. Technology integration, by contrast, concerns the pedagogical selection and application of technological resources in relation to instructional objectives and content knowledge (Mishra & Koehler, 2006).

Accordingly, the proposed model treats students' digital literacy and technology integration as separate constructs, distinguishing learner competencies from instructional technology decisions. Emerging applications, including the Internet of Things, may support data-oriented science learning, but their practical use depends on curricular relevance, pedagogical suitability, infrastructure, and implementation feasibility.

Assessment and Implementation Support

Assessment and feedback provide evidence of learners' understanding and progress. Nicol and Macfarlane-Dick (2006) identified formative feedback principles supporting self-regulated learning. Although developed within higher education, these principles offer a conceptual basis for considering assessment and monitoring in secondary science learning.

Implementation support instead concerns the conditions enabling teachers and institutions to apply the model. UNESCO (2023) emphasised equity, educational purpose, and enabling conditions in technology-supported education. The proposed model therefore distinguishes assessment from implementation support, including teacher competencies, institutional arrangements, infrastructure, accessibility, and responsible digital practices. Both constructs require expert evaluation rather than acceptance based solely on conceptual relevance.

Design and Development Research and Expert Consensus

Design and Development Research (DDR) provides a systematic approach to educational model development (Richey & Klein, 2007). Within the broader Type II DDR project, needs analysis and expert-based design preceded the Fuzzy Delphi Method (FDM) evaluation of the proposed model specification. Related studies have applied structured expert judgement to mobile learning environments (Gnanasagaran et al., 2023), STEM teaching models (Zeng et al., 2025), and

educational applications developed through DDR (Yusap et al., 2024). Their methodological relevance does not imply equivalence in research contexts or assessment procedures.

Collectively, the literature supports the conceptual relevance of the proposed domains but does not independently establish the suitability of this study's six constructs and 41 elements. FDM therefore provides structured evidence of expert consensus on the assessed specification. Such agreement supports developmental decisions without demonstrating instructional effectiveness, causal relationships among constructs, or end-user usability.

METHODOLOGY

Research Design and Expert Selection

This study adopted a Type II Design and Development Research (DDR) approach to develop a mobile learning model for secondary school science education in Malaysia. Richey and Klein (2007) described DDR as a systematic approach to investigating the design and development of educational products, tools, and models. The broader study comprised three phases: needs analysis, model design and development, and usability evaluation. Within this framework, the present article focuses specifically on the Fuzzy Delphi Method (FDM) evaluation undertaken during the model development stage, thereby addressing the developmental objective of assessing expert consensus on the proposed model specification.

The preceding model design stage employed the modified Nominal Group Technique (mNGT), involving nine experts who contributed to the generation, refinement, and prioritisation of the proposed model components. McMillan et al. (2016) discussed the structured application of nominal group and Delphi techniques to obtain expert judgements, while related educational development studies have employed NGT and FDM to inform model or application development (Yusap & Nasir, 2024; Yusap et al., 2024). In the present study, these methodological considerations supported the sequential application of mNGT to establish an initial specification comprising six constructs and 41 elements, followed by FDM to evaluate expert consensus on their suitability. The two methods therefore served complementary purposes within the design and development process rather than representing successive rounds of the same expert assessment.

The FDM assessment was conducted in a single round involving 13 experts, comprising the nine experts who participated in the preceding mNGT stage and four additional experts. This procedure was aligned with the study's second research objective and the corresponding research question, which sought to determine the level of expert consensus on the suitability of the proposed model constructs and elements. As the components had already been identified and refined during the mNGT design stage, FDM was employed to assess agreement with the established model specification rather than to generate additional components or examine changes in expert opinions across successive Delphi rounds. All 47 assessment units, comprising six constructs and 41 elements, satisfied the predefined FDM acceptance criteria. Accordingly, the single-round procedure is reported as a methodological feature of the present study rather than a universal requirement of FDM. The panel composition was considered appropriate for the study's consensus-based purpose, with emphasis placed on the relevance and complementarity of expert knowledge rather than numerical size alone.

Purposive sampling was employed to select experts with professional knowledge and experience relevant to the development of a mobile learning model for secondary school science education. Selection emphasised expertise in science education, curriculum, pedagogy,

educational technology, instructional design, and model implementation. Okoli and Pawlowski (2004) highlighted the importance of systematically identifying knowledgeable participants for Delphi-based inquiry. Accordingly, the present study prioritised the relevance and complementarity of professional expertise rather than statistical representativeness, allowing the proposed model to be evaluated from pedagogical, curricular, and technological perspectives. Official letters requesting expert assistance in reviewing research instruments were issued by the Faculty of Education and Sports Studies, Universiti Malaysia Sabah (UMS). Expert participation was voluntary, and relevant professional information was documented while identifying details were excluded from the article to protect confidentiality. The final FDM dataset comprised 13 valid expert responses, which provided expert-based evidence for model development rather than a basis for statistical generalisation to a wider population.

Research Instrument and Data Collection

The FDM instrument was informed by the preceding needs analysis and mNGT stage. It comprised 47 assessment units representing six constructs and 41 elements: mobile-learning pedagogy (K1; six elements), scientific literacy incorporating Habits of Mind (K2; 12 elements), students' digital literacy (K3; seven elements), technology integration (K4; six elements), assessment and monitoring (K5; four elements), and implementation support (K6; six elements). The scientific literacy construct incorporated two subdivisions, scientific literacy competencies and Habits of Mind, within a single construct.

Each construct and element was assessed separately using a seven-point agreement scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Neutral, 5 = Somewhat Agree, 6 = Agree, and 7 = Strongly Agree. The instrument presented the operational description and assessment statement for each component to support experts' judgements regarding its suitability. The construct-level assessments addressed the suitability of the six principal model components, whereas the element-level assessments addressed the 41 specific components identified during the preceding mNGT design stage. Accordingly, the instrument comprised 47 assessment units rather than 47 model elements.

This distinction between construct-level and element-level assessment was important for preserving the structure established during the model design stage. Evaluating the constructs separately from their constituent elements allowed experts to consider the suitability of the broader model domains without assuming that agreement with a construct necessarily implied agreement with every element within it. The resulting assessment structure therefore supported a more differentiated examination of the proposed model specification.

The FDM instrument was administered to the expert panel to evaluate the proposed model specification developed during the preceding mNGT stage. Participation procedures included research information, informed consent, and the use of expert identification codes for response management. Experts assessed the six constructs and 41 elements individually and could provide optional written comments for each construct. The responses were screened to distinguish valid expert submissions from test records. The final dataset comprised 13 valid expert responses, each containing ratings for all 47 assessment units, resulting in 611 quantitative ratings. Written comments were retained separately from the quantitative assessment records to inform subsequent interpretation and refinement of the model specification. Quantitative acceptance decisions applied to the original assessed statements and did not independently validate subsequent explanatory refinements.

Fuzzy Delphi Data Analysis

The quantitative dataset comprised 611 ratings (13 experts × 47 assessment units). Microsoft Excel spreadsheets were used to organise and examine the FDM calculation records. The seven-point ratings were converted into triangular fuzzy numbers (TFNs), comprising lower (l), modal (m), and upper (u) values. The conversion mapping is presented in Table 1 and is consistent with the seven-point TFN scale reported by Abdul Rahman et al. (2022). This mapping was applied consistently across all assessment units to support the subsequent FDM calculations.

Table 1. Conversion of Seven-Point Ratings into Triangular Fuzzy Numbers

Rating	TFN (l, m, u)
1	(0.0, 0.0, 0.1)
2	(0.0, 0.1, 0.3)
3	(0.1, 0.3, 0.5)
4	(0.3, 0.5, 0.7)
5	(0.5, 0.7, 0.9)
6	(0.7, 0.9, 1.0)
7	(0.9, 1.0, 1.0)

Note. TFN = triangular fuzzy number.

For each assessment unit, the aggregated TFN was calculated by averaging the corresponding values across experts:

$$\bar{l} = \frac{\sum_{i=1}^{n} l_i}{n}, \qquad \bar{m} = \frac{\sum_{i=1}^{n} m_i}{n}, \qquad \bar{u} = \frac{\sum_{i=1}^{n} u_i}{n}$$

The distance between each expert's TFN and the aggregated TFN was calculated as:

$$d_i = \sqrt{\frac{(l_i - \bar{l})^2 + (m_i - \bar{m})^2 + (u_i - \bar{u})^2}{3}}$$

The mean threshold distance was obtained as:

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n}$$

Expert consensus was expressed as:

$$\text{Consensus (\%)} = N_c / n \times 100$$

Where N_c is the number of experts whose individual threshold distance satisfies $d_i \leq 0.2$.

The defuzzification score was calculated as:

$$A = \frac{\bar{l} + \bar{m} + \bar{u}}{3}$$

The recorded analysis applied three concurrent acceptance criteria: a mean threshold distance of $\bar{d} \leq 0.2$, expert consensus of at least 75%, and a defuzzification score of $A \geq 0.5$. With 13 experts, at least 10 experts were required to satisfy the individual threshold-distance criterion ($d_i \leq 0.2$) to achieve the minimum consensus percentage. Defuzzification scores were also used for

numerical ordering without implying an instructional sequence or causal hierarchy. In Equations (1)–(5), n represents the number of experts and i denotes an individual expert; l_i, m_i, and u_i denote the individual triangular fuzzy number (TFN) components; and $\bar{l}$, $\bar{m}$, and $\bar{u}$ denote their corresponding aggregated values. The terms d_i and $\bar{d}$ represent the individual and mean threshold distances, respectively; N_c is the number of experts satisfying $d_i \leq 0.2$; and A is the defuzzification score.

Qualitative Feedback and Analytical Rigor

The dataset contained 60 open-ended comments contributed by 10 experts. These comments were reviewed in relation to the six constructs to identify conceptual clarifications, implementation considerations, and potential refinements. Where compound comments were subsequently separated into smaller interpretive units, these units were not counted as additional expert responses.

The consolidated calculation records contained 611 valid ratings across the 47 assessment units. The same TFN conversion scheme, threshold-distance calculation, expert consensus criterion, and defuzzification procedure were applied across all 47 assessment units. Quantitative acceptance decisions remained associated with the original assessed statements, while subsequent explanatory refinements were treated as interpretive outcomes rather than independently reassessed components. The findings were therefore interpreted as expert consensus on proposed model components, not as evidence of classroom effectiveness or teacher usability.

FINDINGS & DISCUSSION

This section presents and discusses the findings of the Fuzzy Delphi Method (FDM) evaluation involving 13 experts. The discussion focuses on expert consensus regarding the six proposed constructs and 41 elements of the mobile learning model, qualitative feedback informing model refinement, and the findings in relation to previous research and theoretical perspectives. The implications, limitations, and directions for future research are also addressed.

Expert Consensus on Model Constructs and Elements

The FDM evaluation involved 13 experts assessing six constructs and 41 elements, yielding 47 assessment units and 611 valid ratings. All units satisfied the recorded acceptance criteria. At the construct level, expert consensus reached 100%, with mean threshold distances ranging from 0.046 to 0.064 and defuzzification scores from 0.91 to 0.94 (Table 2).

Table 2. FDM Results for the Six Model Constructs

Construct	Mean d	Consensus (%)	A
K1	0.061112	100.00	0.928205
K2	0.061112	100.00	0.905128
K3	0.064168	100.00	0.920513
K4	0.064168	100.00	0.912821
K5	0.045834	100.00	0.943590
K6	0.045834	100.00	0.943590

The mean threshold distances were identical for K1 and K2, K3 and K4, and K5 and K6. However, the defuzzification scores differed for K1 and K2 and for K3 and K4, whereas K5 and K6 shared identical values for both measures at the reported precision. Assessment and monitoring (K5) and implementation support (K6) shared the highest construct-level defuzzification score (A = 0.94 when rounded). This numerical tie does not indicate a prescribed instructional sequence or hierarchy among constructs.

All 41 elements independently satisfied the acceptance criteria. Twenty-seven elements achieved 100% consensus (13/13 experts), while 14 achieved 92.31% (12/13 experts). Mean threshold distances ranged from 0.034 to 0.110, and defuzzification scores ranged from 0.86 to 0.95. Across all 47 assessment units, the mean ratings on the seven-point agreement scale ranged from 6.00 to 6.85, indicating some variation in the average expert ratings across the assessed components.

Table 3. Summary of Element-Level FDM Results

Construct	Elements	Decision
K1	6	All accepted
K2 (K2A + K2B)	12 (6 + 6)	All accepted
K3	7	All accepted
K4	6	All accepted
K5	4	All accepted
K6	6	All accepted
Total	**41**	**41 accepted**

Note. Of the 41 elements, 27 achieved 100% consensus and 14 achieved 92.31%. Acceptance decisions were determined for individual elements rather than inferred from their parent constructs.

Illustrative Element-Level FDM Results

Table 4 presents one illustrative element from each construct to demonstrate the statements evaluated by the expert panel. The examples were selected for descriptive purposes rather than according to their rankings. Each element is reported with its mean threshold distance, expert consensus percentage and defuzzification score.

Table 4. Illustrative Element-Level FDM Results Across the Six Constructs

Code	Illustrative element statement	Mean d	Consensus (%)	A
K1E1	Students actively explore, construct, and apply science knowledge and skills, with appropriate autonomy to make choices, monitor, and reflect on their learning.	0.045834	100.00	0.943590
K2A1	Students use scientific knowledge to explain phenomena, cause-and-effect relationships, and related situations based on evidence.	0.055001	100.00	0.935897
K3E1	Students search for, select, and evaluate the accuracy, validity, credibility, relevance, and reliability of scientific information and evidence from digital sources.	0.055001	100.00	0.935897
K4E1	Technology is selected and integrated according to learning objectives, pedagogical approaches, science content, and students' needs.	0.064168	100.00	0.920513

Code	Illustrative element statement	Mean d	Consensus (%)	A
K5E1	Assessment is conducted before, during, and after learning to identify students' prior knowledge, misconceptions, learning progress, and attainment of science competencies using appropriate digital methods.	0.061112	100.00	0.928205
K6E1	Teachers possess and continuously develop knowledge and skills in pedagogy, science content, and digital technologies, including the competence to integrate these areas in implementing the model, through relevant and practice-oriented continuing professional development.	0.045834	100.00	0.943590

Note. The statements are English translations of the original Malay items evaluated by the experts. All six examples met the FDM acceptance criteria. K2A1 represents the scientific literacy dimension of K2, which also incorporates Habits of Mind (K2B). The examples are not intended to represent the complete set of 41 elements.

The illustrative findings complement the overall results in Table 3, which confirm the acceptance of all 41 individually evaluated elements. These findings support the developing model specification but do not establish classroom effectiveness or usability. The six-construct specification is presented in Figure 1. The model comprises mobile-learning pedagogy (K1), scientific literacy and Habits of Mind (K2), digital literacy (K3), technology integration (K4), assessment (K5), and implementation support (K6). The constructs are represented at an equivalent structural level without implying a mandatory instructional sequence or causal relationships.

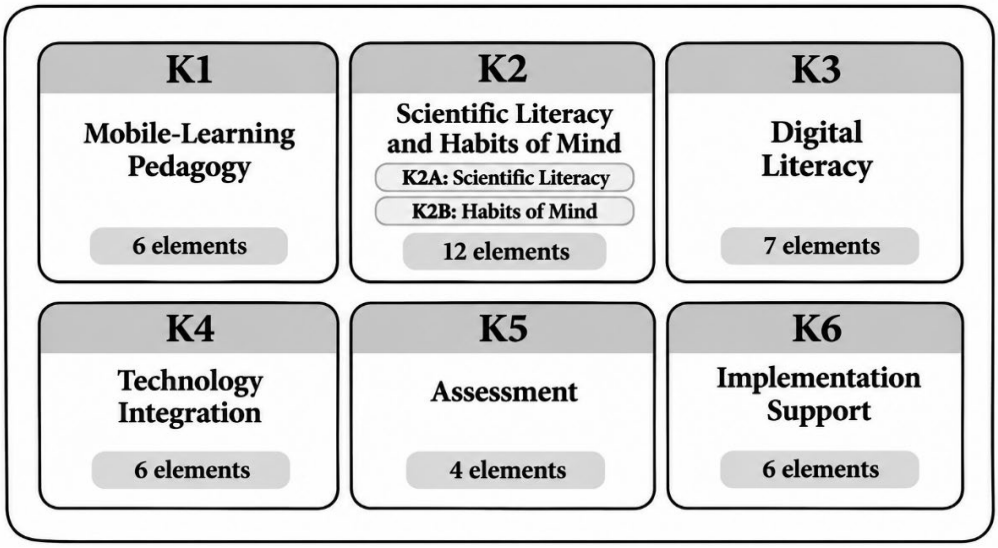

Figure 1: Six-construct specification of the proposed mobile learning model for secondary school science education.

Expert Feedback and Model Refinement Considerations

The evaluation generated 60 open-ended comments from 10 experts. The feedback addressed pedagogical terminology, scientific processes, digital data competencies, computational thinking,

immersive technologies, infrastructure readiness, learning analytics, inclusivity, and responsible technology use.

These comments highlighted considerations extending beyond numerical acceptance, particularly conceptual clarity and implementation conditions. They informed the interpretation of the proposed specification and consideration of possible refinements. Where compound comments were separated into interpretive propositions, these were not counted as additional expert responses.

Thus, qualitative feedback complemented the quantitative findings without changing the original FDM decisions. It provided additional context for interpreting the assessed model specification and identifying areas requiring explanatory refinement. Such refinements were considered in relation to conceptual coherence and implementation feasibility, rather than treated as independently revalidated components.

Discussion in Relation to Previous Research and Theoretical Perspectives

The acceptance of all 47 assessment units is consistent with previous educational development studies in which FDM supported expert evaluation of proposed learning components. Gnanasagaran et al. (2023) identified elements for a mobile learning environment supporting probability problem-solving, while Zeng et al. (2025) reported acceptance of 17 items across three constructs in a STEM teaching model. Similarly, Yusap et al. (2024) applied FDM within a Design and Development Research approach to evaluate the design of an educational application. Although these studies differed in educational context, panel composition, and assessment procedures, they demonstrate the methodological relevance of structured expert judgement in evaluating proposed educational components. In the present study, this approach provided a systematic basis for examining the suitability of both the overarching constructs and their constituent elements rather than relying solely on the outcomes of the preceding model design stage.

The findings also contribute to the developmental application of FDM in science education by examining a model specification that encompasses six complementary constructs. Unlike studies focusing on a particular learning application or instructional domain, the present evaluation considered pedagogical, scientific, digital, assessment, and implementation-related components within a single proposed model. The acceptance of all 47 assessment units therefore provides expert-based justification for retaining the assessed specification as a basis for subsequent model representation and development.

The integration of scientific literacy and Habits of Mind within K2 provides a conceptual basis for considering scientific reasoning alongside dispositions relevant to inquiry and problem-solving. The science framework incorporated in PISA 2022 emphasises scientific competencies associated with explaining phenomena, evaluating inquiry, and interpreting evidence (OECD, 2023). More recent research has also considered dispositions and Habits of Mind in relation to the assessment of scientific literacy in secondary education (Dauer et al., 2025). Taken together, these perspectives support the conceptual relevance of examining scientific competencies and thinking dispositions within the same educational model. However, the decision to integrate these domains under K2 while retaining scientific literacy and Habits of Mind as distinguishable internal dimensions originated from the present model design process. The FDM findings provide expert agreement on this proposed arrangement, rather than demonstrating a causal relationship between the two dimensions or their combined instructional effectiveness.

A further conceptual distinction concerns students' digital literacy (K3) and technology integration (K4). Mishra and Koehler (2006) conceptualised technology integration through the

relationship among technological, pedagogical, and content knowledge, whereas Vuorikari et al. (2022) identified digital competence areas associated with information and data literacy, communication, content creation, safety, and problem-solving. These frameworks address related but different aspects of technology-supported learning. Accordingly, the present model distinguishes learners' digital competencies from pedagogical decisions concerning the selection and application of technological resources. This separation enables the two domains to be evaluated as distinct constructs while recognising their complementary roles in the proposed mobile learning model for secondary school science education.

Overall, the study's contribution lies in bringing these domains together within a structured, expert-assessed model specification. The findings provide a documented basis for retaining six constructs and 41 elements following the application of predetermined FDM acceptance criteria. This developmental contribution is particularly relevant because the proposed specification addresses not only pedagogical and technological considerations but also scientific reasoning, thinking dispositions, assessment, and implementation support. Nevertheless, expert consensus does not establish the relative effectiveness of the constructs, causal relationships among them, or superiority over alternative models. Further evaluation involving secondary school science teachers is therefore required to examine the usability and practical applicability of the proposed model.

Implications, Limitations and Future Research

The accepted constructs and elements provide a structured reference for developing model representations and guidance materials intended for secondary school science teachers. In preparing these materials, attention should be given to implementation considerations identified through expert feedback, including infrastructure readiness, digital competencies, inclusivity, and responsible technology use. These considerations highlight the importance of translating the expert-assessed model specification into guidance that is both contextually relevant and accessible to teachers.

The findings are bounded by the participating expert panel, the statements evaluated, and the predetermined FDM decision criteria. Although the results support the retention of the assessed model specification, expert consensus does not establish improved student learning outcomes or demonstrated usability among end users. Any substantive refinements introduced after the FDM evaluation would require separate justification and verification before being claimed as independently expert-validated.

Future research should examine the usability of the proposed model among secondary school science teachers, particularly the clarity of its constructs and elements, their practical applicability to lesson planning, and the support required for implementation. Such evaluation would provide complementary end-user evidence beyond the expert consensus established in the present study. The resulting evidence could inform further refinement of the model's supporting materials while preserving the distinction between expert consensus and end-user usability.

CONCLUSION

This study evaluated expert consensus on the proposed components of a mobile learning model for secondary school science education in Malaysia using the Fuzzy Delphi Method (FDM). The evaluation involved 13 experts and 47 assessment units comprising six constructs and 41

elements. All assessed units met the recorded FDM acceptance criteria, providing expert-based support for retaining the evaluated model specification.

The findings contribute to the model development process by establishing an expert-assessed specification that integrates mobile-learning pedagogy, scientific literacy incorporating Habits of Mind, students' digital literacy, technology integration, assessment and monitoring, and implementation support. Bringing these complementary domains together provides a structured foundation for subsequent model documentation and usability evaluation with secondary school science teachers. However, the model's instructional effectiveness and practical applicability remain to be established through further research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

Nik Zuraida binti Nik Mohd Noor led the conceptualisation, research design, investigation, data management, formal analysis, project coordination, and preparation of the original manuscript. Denis Andrew D. Lajium provided academic supervision, scholarly guidance, and advice throughout the research process. Chin Kim On contributed academic advice and supervisory support.

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Ethics Statement

This study was conducted within an educational design and development research framework and involved professional experts evaluating the suitability of proposed mobile learning model constructs and elements through the Fuzzy Delphi Method (FDM). Participation was voluntary and based on informed consent. Expert identification codes were used for response management, and the findings were analysed and reported in aggregate form. These procedures were intended to respect participants' autonomy, maintain confidentiality, and support responsible reporting of expert judgements.

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