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GoSET2025Malacca
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e-IPH
e-International Publishing House Ltd., United Kingdom

Global Conference on Social Science, Education and Technology 2025
Mudzaffar Hotel, Melaka, Malaysia, 1-2 Feb 2025
Organised by: Maths Proofread and Iman Excellence Center, Malaysia

Designing a TPACK-Based Mobile Learning Model for Biology Education using the Nominal Group Techniques

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Abstract
Mobile learning (m-learning) enhances STEM education, particularly in biology, by supporting visualization and interaction. However, a structured framework integrating technological, pedagogical, and content knowledge (TPACK) is essential. This study designs a TPACK-based mobile learning model for biology using the Nominal Group Technique (NGT). A workshop with 10 experts identified seven key components and 67 elements, with nine elements rejected due to low consensus. The validated framework will guide model development using Interpretive Structural Modelling (ISM) to enhance critical thinking, collaboration, and digital citizenship, ultimately fostering effective mobile learning environments for biology education.

Keywords: Biology, Mobile Learning. Nominal Group Technique, TPACK

1.0 Introduction

The Fourth Industrial Revolution (4IR) has profoundly transformed multiple sectors, including education, through emerging technologies such as artificial intelligence (AI), robotics, and the Internet of Things (IoT). These advancements demand the development of 21st-century skills such as critical thinking, collaboration, creativity, and adaptability (Sujarwo et al., 2022). In response, Education 4.0 promotes the integration of human capabilities with technological innovations to prepare students for future challenges. Among the transformative strategies aligned with this paradigm is mobile learning (m-learning), which leverages portability, accessibility, and interactivity to support flexible, student-centered learning (Dahri et al., 2023).

In science education, particularly biology, m-learning enhances conceptual understanding through interactive and dynamic tools. Mobile applications and digital platforms allow students to engage in immersive and experiential learning, such as simulating real-world biological processes (Chitra et al., 2024). Multimedia-based learning enhances conceptual understanding by providing interactive experiences suited to students' cognitive abilities (Ceken & Taskin, 2022). However, integrating m-learning effectively into the curriculum requires educators to master the intersection of content, pedagogy, and technology, as described by the Technological Pedagogical Content Knowledge (TPACK) framework. Moreover, sustainability in teacher education is essential to ensure long-term, effective pedagogical practices that address contemporary teaching challenges (Desa et al., 2021). The TPACK framework provides a theoretical

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DOI: https://doi.org/10.21834/e-bpj.v10iSI32.7050

foundation for designing technology-enhanced instruction aligned with subject-specific objectives. Recent studies also emphasize the value of TPACK-driven mobile learning models in enhancing Biology instruction (Abd Manaf et al., 2025).

Despite its theoretical value, applying TPACK in biology-based m-learning remains underexplored. Educators frequently encounter challenges such as limited professional training, inadequate resources, and a lack of structured models tailored to the needs of biology instruction (Schmid et al., 2021). In addition, key elements like digital citizenship, which promote ethical and responsible technology use, are often overlooked in current research (Velasco et al., 2024). To address these gaps, this study aims to design an innovative instructional model for Biology education that integrates mobile learning based on the TPACK framework. The development process employs the Nominal Group Technique (NGT), a structured consensus-building method that ensures the model's contextual relevance and practical applicability.

The specific objectives of this study are to:

1. Identify the essential components of a TPACK-based mobile learning framework for Biology education through expert input using the Nominal Group Technique (NGT);
2. Prioritize the identified components based on expert consensus to guide the design of a relevant and practical mobile learning framework.The specific objectives of this study are to:

By focusing on components such as learner analysis, instructional strategies, and responsible technology use, this study contributes to the development of an expert-informed, future-ready mobile learning model tailored to the evolving needs of Biology education.

2.0 Literature Review

Mobile learning (m-learning) is transformative in STEM education, especially in Biology, where visual and interactive elements enhance conceptual understanding (Stojšić et al., 2022). Generation Z learners favor real-time feedback, multimedia resources, and social learning, which makes m-learning particularly suitable for addressing their preferences. To meet these expectations, educators must design m-learning frameworks that support personalized and adaptive learning (Mandau & Lakulu, 2022). Although m-learning promotes flexibility and engagement, its impact depends on how effectively educators align it with structured pedagogical strategies (Pedraja-Rejas et al., 2024).

Despite the widespread adoption of mobile technologies, educators have developed few structured TPACK-based m-learning models tailored to Biology. The TPACK framework, which combines content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK), provides a comprehensive foundation for integrating technology into instruction (Mishra & Koehler, 2006). However, many teachers struggle to apply TPACK effectively due to digital literacy gaps, curriculum misalignment, and resource limitations (Crompton et al., 2024). Even with the availability of advanced mobile applications, educators risk underutilizing these tools without clear instructional designs (Lukianets & Lukianets, 2023). In Biology education, this issue becomes more critical as educators require models that support the visualization of complex cell processes and ecological interactions (Schmid et al., 2021).

Researchers have called for integrating discipline-specific instructional frameworks to improve the relevance and effectiveness of mobile learning. Rosli and Ishak (2024) showed that virtual laboratories in science classes enhance both accessibility and concept mastery. Similarly, Abdullah et al. (2022) and Shambare and Simuja (2024) highlighted the value of augmented reality and simulations for helping students understand abstract biological phenomena. However, educators in many developing regions still face disparities in access to technology and professional training. Ofosu-Asare (2024) emphasized that infrastructural constraints and policy gaps continue to hinder the implementation of effective m-learning systems. To ensure inclusivity and equity, developers of TPACK-based m-learning models must address these issues, particularly in underserved and rural settings.

Educators must also align mobile technologies with active pedagogical strategies. Approaches such as gamification, inquiry-based learning, and collaborative activities help learners develop motivation, creativity, and problem-solving skills (Rincon-Flores & Santos-Guevara, 2021). However, without a structured instructional framework, these strategies often remain fragmented. Although studies confirm the benefits of mobile-assisted learning, researchers still lack expert-validated models that meet the specific instructional needs of Biology while promoting responsible digital behavior. Bibliometric studies further emphasize the rising global focus on mobile learning, yet highlight a gap in models specific to biology education (Abd Manaf et al., 2024). Incorporating digital citizenship into instructional design has become more urgent with the rise of AI, online misinformation, and ethical issues surrounding digital collaboration (Velasco et al., 2024; Ahmad Pua'at & Mohamad Yunus, 2023).

To address these challenges, this study adopts the Nominal Group Technique (NGT) as a structured methodology to identify and validate instructional elements for a mobile learning model. NGT enables experts to reach consensus on essential components, which ensures the framework remains relevant, scalable, and pedagogically sound (Vahedian-Shahroodi et al., 2023). Building on recent research and addressing critical gaps, this study designs a TPACK-driven mobile learning model for Biology education that integrates digital citizenship, instructional design theory, and technological pedagogy. This expert-informed model bridges the gap between theory and classroom practice and responds to the evolving demands of 21st-century learning.

3.0 Methodology

This study employed the Design and Development Research (DDR) approach (Richey & Klein, 2014), which consists of three phases: needs analysis, design and development, and evaluation. The study focused on the second phase, where components of a TPACK-driven mobile learning framework for biology were designed. The needs analysis findings emphasized the need for a structured framework to support educators in integrating mobile learning. To address this, a Modified Nominal Group Technique (NGT) was used for component identification and validation, complemented by Interpretive Structural Modeling (ISM) to refine the framework.

The Nominal Group Technique is a consensus-building method that combines qualitative idea generation with semi-quantitative prioritization, making it useful for educational framework development (Mullen et al., 2021). This study adopted a modified NGT by distributing a pre-session questionnaire, allowing participants to reflect on components beforehand (Søndergaard et al., 2018). A purposive sample of ten experts in Educational Technology, Biology Education, and Curriculum Design was selected based on at least five years' experience in digital learning. Expert discussions were guided by a structured questionnaire incorporating elements from TPACK, FRAME, and ASSURE models.

Panel members included university academics, matriculation biology lecturers, and teacher training educators under Malaysia's Ministry of Education, along with one representative from the Educational Planning and Policy Research Division (EPRD). The NGT session used a 7-point Likert scale with a ≥70% agreement threshold for consensus (Harvey & Holmes, 2012). Microsoft Excel was used to calculate agreement percentages. ISM structured relationships among validated elements (Warfield, 1974). Ethical approval was obtained from the institutional review board, and informed consent was secured from all participants. Anonymizing data maintained confidentiality, and participants were informed of their right to withdraw at any stage.

4.0 Findings

The findings from the Modified Nominal Group Technique (NGT) were used to identify and prioritize the essential elements to be incorporated into the TPACK-based mobile learning framework for biology education. Toward the finish of the modified nominal group technique session, the experts proposed and consensually concurred on the final list of components and elements for the framework. Table 1 highlights the score values, percentages, and prioritization of elements for analyzing learners within the TPACK-based mobile learning framework for biology education through analysis of the NGT method. All elements achieved an acceptance percentage above 70% and were thus accepted by expert consensus.

Table 1: Ranking and Prioritization of Analyzing Learners

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Student profile	69	98.6%	1	Accepted
2.	Learning style	68	97.1%	3	Accepted
3.	Level of prior knowledge	63	90.0	7	Accepted
4.	Cognitive ability	66	94.3	6	Accepted
5.	Motivation	69	98.6	1	Accepted
6.	Access to technology	67	95.7	5	Accepted
7.	Digital literacy skills	68	97.1	3	Accepted

Acceptance percentage ≥70%

Table 2 presents the findings from the modified NGT process, outlining the ranking and prioritization of learning objectives for the TPACK-based mobile learning framework in biology education. All elements achieved an acceptance percentage above 70% and were thus accepted by expert consensus.

Table 2: Ranking and Prioritization of Learning Objectives

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Listing basic Biology concepts	69	98.6	1	Accepted
2.	Explaining basic Biology concepts	69	98.6	1	Accepted
3.	Identifying Biology lab equipment	67	95.7	4	Accepted
4.	Readiness to use Biology lab equipment	67	95.7	4	Accepted
5.	Conducting Biology lab experiments	*68*	97.1	3	Accepted
6.	Critical thinking skills	66	94.3	7	Accepted
7.	Problem-solving skills	67	95.7	4	Accepted

Acceptance percentage ≥70%

Table 3 presents the findings from the modified NGT process, outlining the ranking and prioritization of teaching approaches and methods for the TPACK-based mobile learning framework in biology education. All elements, except augmented reality, achieved an acceptance percentage above 70% and were thus accepted by expert consensus. Notably, augmented reality (score: 16, 22.9%) was rejected due to its low acceptance percentage, reflecting concerns about feasibility and accessibility.

Table 3: Ranking and Prioritization of Teaching Approaches and Methods

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Inquiry-based learning	66	94.3	8	Accepted
2.	Mastery learning	67	95.7	4	Accepted
3.	Problem-based learning	68	97.1	2	Accepted
4.	Simulation	68	97.1	2	Accepted
5.	Animation	67	95.7	4	Accepted
6.	Self-directed learning	65	92.9	10	Accepted
7.	Collaborative learning	67	95.7	4	Accepted
8.	Gamification	63	90.0	11	Accepted
9.	*Augmented Reality	16	22.9	13	Rejected

10.	Adaptive learning	59	84.3	12	Accepted
11.	Flipped Classroom	66	94.3	8	Accepted
12.	Field-based learning	69	98.6	1	Accepted
13.	Virtual Reality	67	95.7	4	Accepted

Acceptance percentage ≥70%
*Element rejected (Acceptance percentage for this element is ≤70%)

Table 4 presents the findings from the modified NGT process, outlining the ranking and prioritization of technology, media, and materials utilization for the TPACK-based mobile learning framework in biology education. All elements, except for the development of interactive media, searching for current biology information, and explanation of biology content, achieved an acceptance percentage above 70% and were thus accepted by expert consensus. Rejected elements include the development of interactive media (15.7%), searching for current biology information (17.1%), and explanation of biology content (18.6%).

Table 4: Ranking and Prioritization of Utilization of Technology, Media, and Materials

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Learning Planning	66	94.3	7	Accepted
2.	Development of Teaching Materials	69	98.6	1	Accepted
3.	Digital References	66	94.3	7	Accepted
4.	Use of Videos and Multimedia	67	95.7	3	Accepted
5.	Digital Assessment and Question Construction	67	95.7	3	Accepted
6.	*Development of Interactive Media	11	15.7	12	Rejected
7.	Utilization of Virtual Media	67	95.7	3	Accepted
8.	*Searching for Current Biology Information	12	17.1	11	Rejected
9.	*Explanation of Biology Content	13	18.6	10	Rejected
10.	Group Formation and Projects	66	94.3	7	Accepted
11.	Summary of Biology Content	69	98.6	1	Accepted
12.	Digital-Based Assessment	67	95.7	3	Accepted

Acceptance percentage ≥70%
**Element rejected (Acceptance percentage for this element is ≤70%)*

The findings for the ranking and prioritization of learning activities, as outlined in Table 5, highlight the critical components for designing engaging and effective TPACK-based mobile learning in biology education. These components serve as a foundation for fostering interactive and meaningful learning experiences tailored to the unique requirements of biology education in a mobile learning context. All elements achieved an acceptance percentage above 70% and were thus accepted by expert consensus.

Table 5: Ranking and Prioritization of Learning Activities

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Biology Blog Project	68	97.1	6	Accepted
2.	Virtual Experiment	69	98.6	3	Accepted
3.	Online Sharing	70	1000	1	Accepted
4.	Interactive Quiz	70	100	1	Accepted
5.	Online Q&A Sessions	67	95.7	7	Accepted
6.	Multimedia Project	69	98.6	3	Accepted
7.	Field Experiment	69	98.6	3	Accepted
8.	Gamification	66	94.3	9	Accepted
9.	Artificial Intelligence	67	95.7	7	Accepted

Acceptance percentage ≥70%

Table 6 presents the findings from the modified NGT process, outlining the ranking and prioritization of assessment methods for the TPACK-based mobile learning framework in biology education. All elements, except for the use of rubrics, multimedia presentation, virtual poster, and mind map, achieved an acceptance percentage above 70% and were thus accepted by expert consensus.

Table 6: Ranking and Prioritization of Assessment

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Formative Assessment	70	100	1	Accepted
2.	Summative Assessment	70	100	1	Accepted
3.	Peer Assessment	68	97.1	6	Accepted
4.	Self-Assessment	69	98.6	4	Accepted
5.	Project-Based Assessment	70	100	1	Accepted
6.	*Use of Rubrics	11	15.7	9	Rejected
7.	*Multimedia Presentation	11	15.7	9	Rejected
8.	*Virtual Poster	10	14.3	11	Rejected
9.	Performance-Based Assessment	69	98.6	4	Accepted
10.	*Mind Map	12	17.1	8	Rejected
11.	e-Portfolio	68	97.1	6	Accepted

Acceptance percentage ≥70%
**Element rejected (Acceptance percentage for this element is ≤70%)*

Table 7 presents the findings from the modified NGT process, outlining the ranking and prioritization of digital citizenship practices for the TPACK-based mobile learning framework in biology education. All elements, except for media and information literacy, achieved an acceptance percentage above 70% and were thus accepted by expert consensus. Conversely, media and information literacy (18.6%) were rejected due to low acceptance, indicating perceived challenges in its applicability or alignment with the framework's current objectives. Notably, copyright awareness was suggested by the panel of experts and received strong support, highlighting its growing relevance in digital education.

Table 7: Ranking and Prioritization of Digital Citizenship Practices

No.	Elements	Score	Percentage	Rank Priority	Voter Consensus
1.	Digital Ethics	70	100	1	Accepted
2.	Critical Evaluation of Content Usage	67	95.7	4	Accepted
3.	Cybersecurity	68	97.1	2	Accepted
4.	Sustainable Digital Practices	59	84.3	7	Accepted
5.	Ethical Use of Digital Resources	67	95.7	4	Accepted
6.	**Copyright Awareness	67	95.7	4	Accepted
7.	*Media and Information Literacy	13	18.6	8	Rejected
8	Self-Reflection and Regulation	68	97.1	2	Accepted

Acceptance percentage ≥70%
**Element rejected (Acceptance percentage for this element is ≤70%)*
***Element suggested by a panel of experts*

5.0 Discussion

Designing a TPACK-based mobile learning framework for biology requires a holistic understanding of technology, pedagogy, and content. This study validates seven essential components: Analyzing Learners, Learning Objectives, Teaching Approaches, Utilization of Technology, Learning Activities, Assessment, and Digital Citizenship Practices. Each component shapes a structured, effective mobile learning environment that aligns with 21st-century educational needs. Learner analysis is fundamental for designing personalized and inclusive mobile learning experiences. Motivation, digital literacy, and cognitive ability influence engagement, aligning with Self-Determination Theory (Ryan & Deci, 2014) and Sociocultural Theory (Vygotsky, 1978). While digital literacy is crucial for effective interaction with STEM-based m-learning tools, disparities in technological access remain challenging. Institutions must prioritize equitable access and educator training to bridge these gaps.

Learning objectives must align with curriculum standards and 21st-century skills. Grounded in Bloom's Taxonomy (Anderson et al., 2001), mobile learning should foster higher-order thinking, while Kolb's Experiential Learning Theory (1984) supports hands-on tasks like virtual labs. Although critical thinking ranked lower, it remains essential in biology's evidence-driven learning approach (Jamil, 2024). Adaptive learning tools, including simulations and gamification, can enhance engagement and cater to diverse learning needs. Teaching approaches emphasize active and experiential learning through Problem-Based Learning (PBL) and simulations, supported by Constructivist Learning Theory (Vygotsky, 1978) and Kolb's learning cycle (1984). Virtual reality (VR) improves engagement by creating immersive learning environments (Perinpasingam et al., 2023), while digital game-based learning fosters 21st-century skills (Tay et al., 2022). However, despite its potential, the adoption of emerging technologies such as augmented reality (AR) is hindered by high costs and limited teacher readiness (Akçayır & Akçayır, 2017). While AR has been recognized for enhancing interactive learning, concerns remain regarding its feasibility in diverse educational settings. Some studies suggest that technical difficulties, lack of institutional support, and the need for extensive teacher training limit its widespread use. In contrast, Abdullah et al. (2022) demonstrated that AR significantly enhances students' academic achievement, satisfaction, and interest in science learning

Technology, media, and materials significantly enhance biology instruction when properly aligned with pedagogical objectives. High-quality multimedia tools, collaborative projects, and structured learning plans foster engagement and critical thinking (Kassa et al., 2024). However, resource constraints and technological readiness gaps pose barriers to implementation (Shwedeh et al., 2024). A gradual integration of innovative tools alongside teacher training programs is essential for scalable adoption. Learning activities should incorporate collaborative, interactive, and experiential strategies to foster higher-order thinking skills. Virtual experiments, AI-driven feedback, and gamification have been shown to enhance engagement and personalized learning experiences (Syarifuddin et al., 2024). Reflective tasks, such as blog writing and self-assessment projects, further encourage critical thinking (Mohamad et al., 2023). Institutions must ensure that these technologies are accessible and aligned with curriculum objectives.

Assessment practices should integrate formative, summative, and project-based evaluations to support continuous learning and skill development (Nikou & Economides, 2021). Digital tools like rubrics and multimedia presentations enhance assessment transparency but require adequate teacher training (Olson & Krysiak, 2021). Investing in digital infrastructure is crucial to overcoming technology-related assessment challenges. Digital citizenship practices are essential for fostering ethical and responsible online behavior (Capuno et al., 2021). Aligned with Ribble's Digital Citizenship Framework (2015), this component emphasizes cybersecurity, digital ethics, and copyright awareness. However, media literacy remains underdeveloped due to curriculum misalignment and limited teacher preparedness (Prasetiyo et al., 2021). Embedding media literacy within digital citizenship education can enhance critical thinking and prepare students for ethical engagement in digital spaces. This study underscores the importance of expert-driven validation in designing a robust TPACK-based mobile learning model. Institutions can foster inclusive, engaging, and future-ready learning environments for biology education by effectively integrating technology, pedagogy, and content.

6.0 Conclusions and Recommendations

This study illustrates the effectiveness of the Nominal Group Technique (NGT) in designing a structured mobile learning framework for Biology education grounded in the TPACK model. By integrating insights from the FRAME, TPACK, and ASSURE models, the proposed framework aligns content, pedagogy, and technology through expert validation. It emphasizes core components such as learner analysis, learning objectives, instructional strategies, technology integration, assessment, and digital citizenship practices. These elements support 21st-century learning by enhancing student engagement, critical thinking, and problem-solving skills.

However, this study acknowledges several limitations. First, the expert panel size was limited to ten participants, which may affect the generalizability of the findings. Second, the study focused only on the design and validation phases and did not evaluate the model's implementation in real classroom settings. Third, excluding certain emerging technologies, such as augmented reality and media literacy, reflects feasibility, cost, and teacher readiness challenges.

To strengthen the model's impact and usability, future studies should:

- Pilot the validated framework in actual Biology classrooms to examine its effectiveness in improving student learning outcomes;
- Conduct longitudinal research to assess the sustainability and scalability of the model across diverse educational contexts;
- Integrate emerging tools such as AI-driven adaptive learning and virtual laboratories while addressing accessibility gaps;
- Develop targeted professional development programs to enhance teachers' TPACK and digital citizenship competencies.

Future research can further support the development of inclusive, technology-enhanced learning environments in Biology education by addressing these limitations and continuing to refine the model through empirical implementation.

Acknowledgements

The authors express their sincere gratitude to Universiti Pendidikan Sultan Idris (UPSI) for their support and to the Educational Policy Planning and Research Division (EPRD), Ministry of Education Malaysia, and Matriculation Division, Ministry of Education Malaysia for granting permission to conduct this research. Special thanks also go to Dr Muhammad Nidzam Yaakob, who provided valuable suggestions and encouragement for this publication.

Paper Contribution to Related Field of Study

This study develops a TPACK-based mobile learning framework for biology education, integrating technology, pedagogy, and content to enhance student engagement. The Nominal Group Technique (NGT) ensures a practical and adaptable model, incorporating digital citizenship and 21st-century teaching strategies like problem-based learning and gamification. The findings guide educators, policymakers, and researchers in integrating AI, AR, and virtual simulations for effective and accessible mobile learning in STEM education.

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