TPACK-Based Teaching Approaches in Mobile Learning for Biology Education: Insights from NGT & ISM Approaches

Cik Jamaliah Abd Manaf[1], Shakinaz Desa[2]*, Muhammad Ikhwan Mat Saad[3], Muhammad Nidzam Yaakob[4]

[1,2,3]Department of Biology, Faculty of Science & Mathematics, Universiti Pendidikan Sultan Idris, Malaysia

[4]Institute of Teacher Education, Darulaman Campus, Malaysia

***Corresponding Author**

DOI: https://dx.doi.org/10.47772/IJRISS.2025.906000109

Received: 20 May 2025; Accepted: 26 May 2025; Published: 02 July 2025

ABSTRACT

Integrating mobile learning in Biology education necessitates adopting practical teaching approaches that align with technological advancements. However, there remains a lack of structured guidelines for selecting and implementing appropriate teaching methods that maximize the potential of mobile learning in Biology education. Existing studies often focus on digital tools rather than pedagogical strategies that effectively integrate technology, pedagogy, and content knowledge (TPACK). This study addresses this gap by employing the Nominal Group Technique (NGT) and Interpretive Structural Modelling (ISM) to identify and prioritize teaching methods suitable for mobile learning environments. Findings indicate that field-based learning, problem-based learning, and simulation are the most highly ranked approaches, followed by mastery learning, animation, collaborative learning, virtual Reality, flipped classrooms, and inquiry-based learning. Self-directed learning, gamification, and adaptive learning are also recognized as effective strategies. Augmented Reality was not widely accepted, as it did not meet the minimum threshold of voter consensus required for inclusion. By applying the TPACK framework, this study explores how these approaches enhance student engagement, knowledge retention, and active learning in Biology education. The results provide a structured model to guide educators, policymakers, and researchers in optimizing mobile-based instructional strategies for Biology learning.

Keywords: Biology Education, ISM, Mobile Learning, NGT, Teaching Approaches, TPACK

INTRODUCTION

In the digital transformation era, mobile learning has emerged as a powerful modality for enhancing the teaching and learning experience, especially in science education. The flexibility, accessibility, and interactivity of mobile technologies provide unique opportunities to foster deeper engagement, personalized instruction, and student autonomy (Husnita et al., 2023; Jotsov et al., 2023). In Biology education, where abstract concepts, dynamic processes, and visual representations are central to content understanding, mobile learning tools can improve comprehension and retention (Nikou & Economides, 2018; Pedraja-Rejas et al., 2024).

However, integrating mobile technologies into instructional practice requires more than technological familiarity it necessitates a pedagogically sound framework that harmonizes content, pedagogy, and technology. The Technological Pedagogical Content Knowledge (TPACK) model provides such a framework by emphasizing the interconnectedness of what teachers teach (content knowledge), how they teach (pedagogical knowledge), and the tools they use (technological knowledge) (Mishra & Koehler, 2006). Applying the TPACK model in mobile learning contexts enables educators to design both technologically enhanced and pedagogically coherent and content-appropriate instruction (Petko et al., 2025).

Despite its potential, the integration of mobile learning in Biology education remains fragmented, with limited models that systematically identify and prioritize teaching approaches suited for mobile environments (Naveed et al., 2023). Previous research has often focused on isolated strategies or tools without offering a holistic instructional framework grounded in expert consensus (Sangur et al., 2025). Moreover, the dynamic nature of mobile learning demands a structured approach to model development that considers the interrelationships and influence among pedagogical components (Parsons et al., 2024).

The present study aims to identify, validate, and structurally model effective teaching approaches for mobile learning in Biology education using the TPACK framework as the foundation to address this gap. Expert input was collected using the Nominal Group Technique (NGT) to ensure consensus on suitable approaches, followed by Interpretive Structural Modelling (ISM) to develop a hierarchical prototype model that illustrates the interdependencies and influence patterns among the validated components.

LITERATURE REVIEW

Mobile learning (m-learning) has been increasingly recognized as a transformative approach in science education due to its ability to facilitate flexible, student-centered, and personalized learning experiences. In Biology, mobile learning supports interactive visualization, field-based investigations, and real-time feedback—highly valuable features for engaging with dynamic biological processes (Errabo & Ongoco, 2024; Kassa et al., 2024; Situmorang et al., 2024). M-learning applications allow students to access simulations, virtual laboratories, and micro-learning content that enhance conceptual understanding, particularly in topics that are difficult to teach using traditional methods (Chitra et al., 2024; Leong et al., 2021; Rosli & Ishak, 2024; Vijayatheepan, 2023; Wong et al., 2024). Nevertheless, the success of mobile learning depends significantly on the alignment between technology, pedagogy, and content. Studies in Malaysian science classrooms indicate that while mobile device access is growing, many Biology teachers lack structured frameworks to guide effective implementation (Abd Manaf et al., 2024; Farhana et al., 2024). This underscores the need for a pedagogical model that integrates mobile technology meaningfully into Biology instruction.

The Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (2006), offers a comprehensive approach to understanding the knowledge required for effective technology integration in teaching. TPACK highlights the intersection of technological, pedagogical, and content knowledge as the core of digital teaching expertise. In science education, this framework is instrumental in guiding teachers to design lessons that integrate mobile tools with active learning strategies and domain-specific content (Tondeur et al., 2016). Numerous studies confirm that Biology educators with strong TPACK competencies can leverage mobile learning tools for content delivery, visualization, and formative assessment (Criollo-C et al., 2021; Marunevich et al., 2021; Ramírez-Donoso et al., 2023; Zhu et al., 2023). The integration of TPACK has been shown to significantly enhance student engagement and improve understanding of complex Biology concepts such as genetics and photosynthesis (Abdullah & Mahmud, 2024; Angraini et al., 2023). This makes TPACK an essential foundation for developing a scalable and adaptable instructional model for mobile platforms.

Constructivist and inquiry-based pedagogies have long been regarded as effective in Biology education. Approaches such as Inquiry-Based Learning, Problem-Based Learning (PBL), Field-Based Learning, Simulation, and Collaborative Learning are extensively supported by empirical research (Himes et al., 2023; Lai et al., 2022; Ramya et al., 2020)(Zhampeissova et al., 2020). These strategies align with the nature of Biology as an experimental and process-driven discipline. For instance, field-based learning enhances ecological literacy. It connects classroom content with real-world applications (Häggström et al., 2020; Haleem et al., 2022), while simulation tools support the visualization of molecular or cellular processes that are otherwise abstract (Alharbi, 2025; Jenkinson, 2018). Collaborative and PBL strategies, particularly when integrated with mobile platforms, encourage peer interaction and higher-order thinking (Afikah et al., 2022; Nguyen, 2019). Gamification and flipped classroom models are also gaining traction in Malaysian and international contexts for their ability to improve motivation and accommodate diverse learner needs (Diningrat et al., 2023; Z. H. Ismail et al., 2024; Rincon-Flores & Santos-Guevara, 2021).

Expert consensus methods are crucial for validating instructional components in model development research. The Nominal Group Technique (NGT) provides a structured process for collecting expert input, reducing bias, and reaching consensus in educational research (Delbecq et al., 1975). NGT has successfully identified core competencies, prioritized pedagogical strategies, and validated curriculum elements, particularly in STEM education (Anis et al., 2022; Selamat & Adnan, 2024; Vahedian-Shahroodi et al., 2023). Interpretive Structural Modelling (ISM) complements NGT by establishing the components' relationships and hierarchical structure. It supports the visualization of complex systems and helps identify key drivers and dependencies within instructional models (Attri et al., 2013). In the Malaysian context, (Ngu et al., 2024; Siraj et al., 2021) emphasized the relevance of ISM in educational model development to ensure coherence and alignment with national education priorities, particularly in digital transformation efforts. By combining NGT and ISM, researchers can construct instructional models that are empirically validated and structurally robust. This integration is particularly valuable in designing TPACK-based models for mobile learning, where interrelationships between pedagogy, content, and technology must be clearly articulated.

Although numerous studies have explored mobile learning and the application of TPACK in science education, few have systematically identified, validated, and structured specific teaching approaches tailored for Biology education. The lack of hierarchical instructional models prioritizing pedagogical strategies and their technological integration presents a significant gap in research and practice. This study addresses the gap by employing NGT to obtain expert consensus on appropriate teaching approaches for mobile Biology instruction and ISM to develop a prototype model grounded in the TPACK framework. The model aims to guide educators in selecting and sequencing instructional strategies that are effective and optimized for mobile delivery, thus contributing to improved teaching quality and learner outcomes in Biology education.

METHODOLOGY

This research incorporates the Interpretive Structural Modelling (ISM) method alongside the Modified Nominal Group Technique (Modified NGT), grounded in the design and development research framework proposed by Richey & Klein (2014). The NGT involves structured discussions within a small group to reach consensus or agreement on a specific issue (Van De Ven & Delbecq, 1971). The NGT session was held in person with a panel of ten experts in Curriculum and Instruction, Educational Technology, Mobile Learning, and Biology Education. The panel consisted of participants from universities under the Ministry of Higher Education Malaysia, Biology lecturers from matriculation colleges, and lecturers from teacher training institutes, all under the Ministry of Education Malaysia. One participant also represented the Educational Planning and Policy Research Division of Malaysia's Ministry of Education. These experts engaged in structured discussions to identify and refine key practice components. The same panel attended the subsequent Interpretive Structural Modelling (ISM) session. However, one expert could not attend, leaving a group of nine participants. The experts were chosen using purposive sampling, a strategy typically used in research with few participants to guarantee that the sample accurately reflects the required skills and characteristics. The Modified NGT is used to gather and analyze essential elements for model development, while ISM organizes the expert panel's aggregated input into a clear connection map linking various aspects or instrument items (Ngu et al., 2024). The NGT approach, frequently utilized in implementing the ISM method (Siraj et al., 2021), complements ISM effectively, making their combination a suitable approach. The combination of NGT and ISM strengthens the study's methodological validity and reliability (Attri et al., 2013; I. M. Ismail et al., 2023). ISM is a technique for identifying and summarizing the relationships among distinct factors that define a particular issue or situation. It turns unclear and poorly structured mental representations into clear and organised systems (Sushil, 2012; Warfield, 1974b, 1974a).

FINDINGS

NGT Voting Session

To identify and prioritize TPACK-based teaching approach components for mobile learning in Biology education, experts evaluated the proposed elements through structured group discussions using the Nominal Group Technique (NGT). A seven-point Likert scale was employed, and components receiving a consensus

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

level of 70% or higher were considered acceptable (Ahmad et al., 2017; Deslandes et al., 2010; Dobbie et al., 2004). Table 1 presents the detailed findings, including total scores, acceptance percentages, and the ranking of each component based on expert agreement. These results reflect the key instructional strategies deemed suitable for integration into mobile learning environments grounded in the TPACK framework.

Table 1: Ranking and Prioritization of TPACK-Based Teaching Approaches

Teaching Approaches	Total item score	Percentage	Rank Priority	Voter Consensus
1. Inquiry-Based Learning	66	94.3	8	Accept
2. Mastery Learning	67	95.7	4	Accept
3. Problem-Based Learning (PBL)	68	97.1	2	Accept
4. Simulation	68	97.1	2	Accept
5. Animation	67	95.7	4	Accept
6. Self-Directed Learning	65	92.9	10	Accept
7. Collaborative Learning	67	95.7	4	Accept
8. Gamification	63	90	11	Accept
9. *Augmented Reality (AR)	16	22.9	13	Reject
10. Adaptive Learning	59	84.3	12	Accept
11. Flipped Classroom	66	94.3	8	Accept
12. Field-Based Learning	69	98.6	1	Accept
13. Virtual Reality (VR)	67	95.7	4	Accept

Determine Contextual Relationships and Phrasal Relationships

To develop the model, the Interpretive Structural Modelling (ISM) method was applied. During the ISM workshop session, the panel of experts inputted 13 prioritized teaching approach components into the Concept Star software. These components were selected based on the consensus-driven priority list identified earlier through the NGT process (Siraj et al., 2021). Each teaching approach component was then paired with others according to their relative priority, following a consistent hierarchical structure, as shown in Table 1.

To determine the structural importance of these teaching approaches within the model development context, the ISM procedure required the formulation of both contextual and relational phrases. The expert panel collaboratively agreed on the use of these phrases to clarify interdependencies among components.

Contextual phrase example: *To ensure effective TPACK-based teaching in mobile learning for Biology education, it is essential to consider these teaching approaches...*

Relational phrase example: *Prioritizing COMPONENT ... should come before COMPONENT...*

Once these contextual and relational statements were established, the finalized teaching approach components were systematically arranged and presented to the expert panel using the Concept Star software for structural modeling and validation.

Complete the Matrix for Element Interaction and Generate the Model

The Concept Star software was utilized to facilitate the pairing and analysis of teaching approach components within the ISM framework. This software supports expert panel discussions by enabling systematic pairwise comparisons, allowing voting on the relative importance and interrelationships among components. The process was conducted iteratively until all core teaching approaches and related elements were connected and structurally organized. Upon completion of the voting rounds, the expert panel reached a consensus, resulting in the generation of a structured output referred to as a prototype model. Figure 1 illustrates the prototype model of the prioritized teaching approaches, as developed using the Concept Star software.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

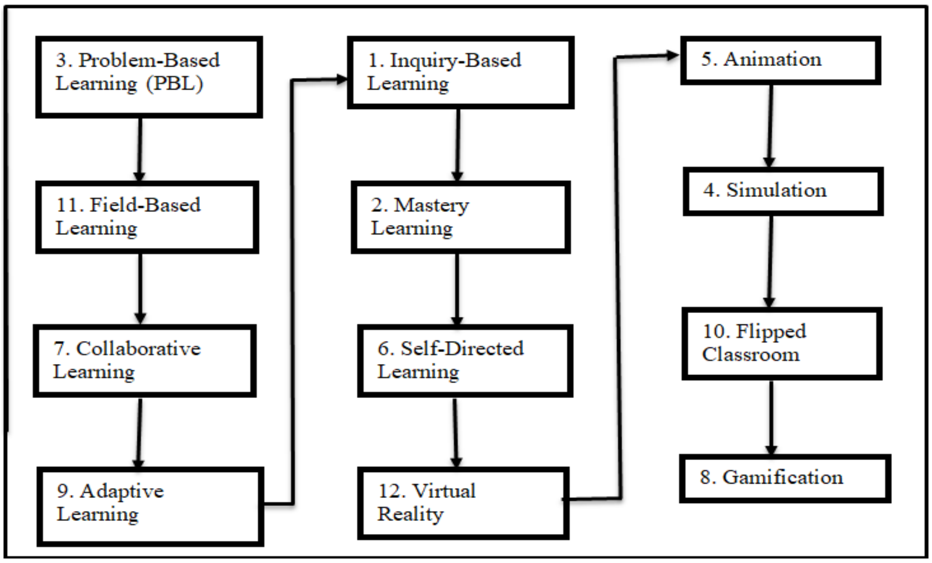

Figure 1: Prototype Model of TPACK-Based Teaching Approaches for Mobile Learning in Biology Education

Display of Models and Simulations

At this stage, the prototype model of TPACK-based teaching approaches, developed using the Concept Star software, was presented to the expert panel for validation and final review. The panel expressed agreement with the visualized structure and confirmed the accuracy of the results. No modifications were suggested during the discussion. The panel unanimously agreed to adopt the prototype model with an emphasis on the core teaching approach components. This selective focus was recommended to ensure a clearer, more streamlined representation, offering better conceptual visibility compared to integrating all model elements simultaneously.

Reachability Matrix

The researcher subsequently performed an analysis using the Cross-Impact Matrix Multiplication method to support the classification of components. This analysis was conducted to determine the driving and dependence power of each variable prior to the classification phase within the developed prototype model, which was customized for the target group. As part of this process, a reachability matrix derived from the prototype model was constructed and presented in Table 2.

Table 2: Reachability Matrix for Teaching Approaches

Reachability Matrix(RM)

Variables	1	2	3	4	5	6	7	8	9	10	11	12	Driving Power
Inquiry Based Learning	1	1	0	1	1	1	0	1	0	1	0	1	8
Mastery Learning	0	1	0	1	1	1	0	1	0	1	0	1	7
Problem-Based Learning (PBL)	1	1	1	1	1	1	1	1	1	1	1	1	12
Simulation	0	0	0	1	0	0	0	1	0	1	0	0	3
Animation	0	0	0	1	1	0	0	1	0	1	0	0	4
Self-Directed Learning	0	0	0	1	1	1	0	1	0	1	0	1	6
Collaborative Learning	1	1	0	1	1	1	1	1	1	1	0	1	10
Gamification	0	0	0	0	0	0	0	1	0	0	0	0	1
Adaptive Learning	1	1	0	1	1	1	0	1	1	1	0	1	9
Flipped Classroom	0	0	0	0	0	0	0	1	0	1	0	0	2
Field-Based Learning	1	1	0	1	1	1	1	1	1	1	1	1	11
Virtual Reality	0	0	0	1	1	0	0	1	0	1	0	1	5
Dependence Power	5	6	1	10	9	7	3	12	4	11	2	8	

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

Following the construction of the reachability matrix, the data were further analyzed by partitioning the matrix based on the degree of influence of each TPACK-based teaching approach component. Each component was examined through its reachability and antecedent sets to identify intersections, enabling the classification of hierarchical levels, as illustrated in Table 3.

Table 3: Partitioning of Reachability Matrix

Idea	Teaching Approaches	Level
3	Problem-Based Learning	12
11	Field-Based Learning	11
7	Collaborative Learning	10
9	Adaptive Learning	9
1	Inquiry-Based Learning	8
2	Mastery Learning	7
6	Self-Directed Learning	6
12	Virtual Reality	5
5	Animation	4
4	Simulation	3
10	Flipped-Classroom	2
8	Gamification	1

Based on the analysis in Table 3, each teaching approach's influence and positional strength were determined through level derivation. A total of five hierarchical levels were identified. Components 7 and 8 were categorized at Level 4, the highest level, while Component 5 was placed at Level 1, indicating the lowest level of influence. These findings correspond with the hierarchical structure generated by the Concept Star software, where Components 7 and 8 appear at the top and Component 5 is positioned at the base.

Consequently, if the level positions are reorganized to reflect the breakdown of the reachability matrix, the resulting hierarchical structure of the Structural Self-Interaction Matrix (SSIM) is presented in Table 4.

Table 4: Component Ranking Level Based on Reachability Matrix

Component	**Teaching Approaches**	**Level**
3	Problem-Based Learning	12
11	Field-Based Learning	11
7	Collaborative Learning	10
9	Adaptive Learning	9
1	Inquiry-Based Learning	8
2	Mastery Learning	7
6	Self-Directed Learning	6
12	Virtual Reality	5
5	Animation	4
4	Simulation	3
10	Flipped-Classroom	2
8	Gamification	1

Classification of Model

The classification of the model represents the final phase in the ISM process, where the teaching approach components are distinguished based on their driving and dependence power. This classification determines whether each component functions primarily as a driving factor or a dependent element. As outlined by Warfield (1974), the prototype model is categorized into four distinct groups: independent, linkage, dependent, and autonomous. This grouping facilitates a clearer understanding of how each teaching approach contributes to the overall structure of the model.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

MICMAC

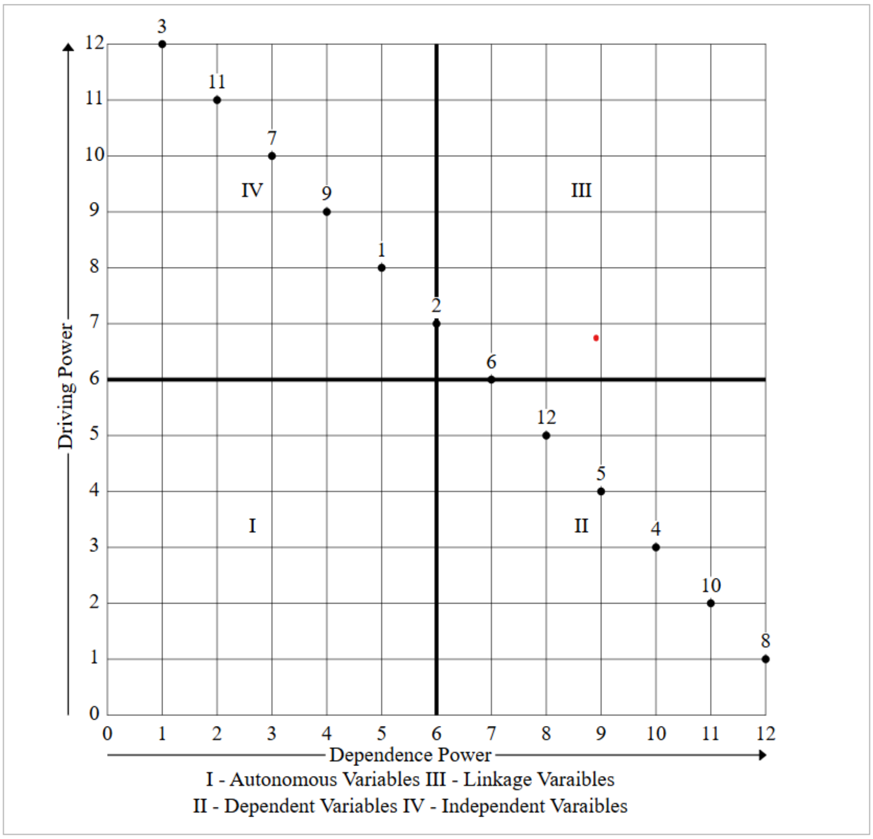

Figure 4: Model Classification Graph

The MICMAC analysis systematically classifies the twelve TPACK-based teaching approach components for mobile learning in Biology education by examining their respective driving and dependence power. The diagram reveals that most components are highly interconnected, with no variables falling into Quadrant I (Autonomous), indicating that all components exert at least moderate influence or dependence within the model. Quadrant II, representing dependent variables, includes Components 4, 5, 10, and 12. These components exhibit high dependence and low driving power, suggesting that other variables influence them and represent outcome-based teaching strategies that rely on foundational elements for implementation.

Quadrant III contains only Component 6, classified as a linkage variable. This component possesses both moderate driving and dependence power, indicating a high degree of interaction and instability. Changes to this component could significantly impact the entire system, highlighting its bridging role in connecting core and outcome-based strategies. In contrast, Quadrant IV, which includes Components 1, 3, 7, 9, and 11, represents the most influential variables in the model. These components demonstrate high driving power with minimal dependence, signifying their role as key drivers of the TPACK-based mobile learning framework. As such, they should be prioritized in instructional design and teacher training initiatives, as they form the strategic foundation for effective mobile learning integration.

Component 2 lies at the intersection of Quadrants III and IV, indicating a transitional component with both influencing and responsive characteristics. Meanwhile, Component 8, positioned at the far end of the dependence axis with very low driving power, represents a highly dependent component within the system. Overall, this MICMAC classification aligns with the ISM-generated prototype model and offers valuable insights into how each teaching approach contributes to the structure and dynamics of TPACK-based mobile learning in Biology education.

DISCUSSION

The prototype model constructed through expert consensus and ISM analysis reflects a systematic organization of teaching approaches prioritized for integration in TPACK-based mobile learning environments for Biology

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

education. This model emphasizes the hierarchical interrelationships among the approaches and aligns with established educational models such as TPACK, SAMR, and Bloom's Digital Taxonomy.

At the foundation of the prototype model are core pedagogical drivers Field-Based Learning, Mastery Learning, and Adaptive Learning, which provide the structural basis for the instructional framework. These approaches reflect a commitment to personalization and contextualization in learning, resonating with the TPACK framework's pedagogical knowledge domain (Mishra & Koehler, 2006). Field-based learning, in particular, has been shown to improve science process skills, observational accuracy, and conceptual understanding by immersing learners in authentic scientific environments (Lanir et al., 2021; Lin et al., 2023; Sidhu, 2014). Mastery learning ensures that foundational knowledge is established before progression, echoing Bloom's Mastery Learning Theory (Bloom, 1968), while adaptive learning integrates technological tools to tailor instruction based on individual learning (Kajonmanee et al., 2018; Matzavela & Alepis, 2021).

The intermediate layer of the model includes Inquiry-Based Learning, Problem-Based Learning (PBL), Collaborative Learning, and Self-Directed Learning. These are linkage strategies foundational approaches inform them and directly influence higher-order instructional strategies. Their placement reflects their dual role as both dependent on and supportive of the core structure. Research consistently shows that inquiry-based learning fosters scientific thinking and deep engagement (Tavares et al., 2021). PBL and collaborative learning support critical thinking, communication, and teamwork essential components in STEM education (Hendarwati et al., 2021; Nguyen, 2019). Self-directed learning, essential in mobile and flexible learning environments, empowers students to manage their learning pathways and aligns well with 21st-century learning frameworks (Evenhouse et al., 2023; Zhang & Pérez-Paredes, 2021).

The top tier of the model consists of Flipped Classroom, Animation, Simulation, Virtual Reality (VR), and Gamification, all of which are technology-enhanced strategies positioned to enhance engagement and support content visualization. These approaches represent transformational practices in line with the SAMR model's augmentation and redefinition levels (Blundell et al., 2022; Romrell et al., 2014). The flipped classroom approach enables students to engage with content asynchronously through mobile platforms, maximizing class time for application and more profound analysis (Diningrat et al., 2023; Pan & He, 2024). Animation and simulation are particularly valuable in Biology for illustrating complex or microscopic processes, such as molecular interactions or physiological mechanisms, which are otherwise abstract (Jiang et al., 2020; Safitri et al., 2021; Schneider et al., 2020). Virtual Reality adds immersive depth, providing learners with spatial understanding and experiential learning in environments such as cellular structures or ecological systems (Chang et al., 2020; Rosli & Ishak, 2024). Gamification enhances motivation through elements of competition, rewards, and progress tracking, which are proven to improve engagement, especially among digital-native learners (Cuervo-Cely et al., 2022; Rincon-Flores & Santos-Guevara, 2021).

The model's structure aligns well with constructivist learning theories, particularly Bruner's Spiral Curriculum and Vygotsky's Zone of Proximal Development (ZPD). Foundational strategies provide scaffolding for learners, while higher-level strategies offer opportunities for cognitive extension through interactive, collaborative, and experiential learning. The sequencing in the ISM-based model reflects an intentional progression from structured, teacher-guided methods to learner-driven, technology-mediated approaches.

Compared to other instructional models in Biology education, such as the 5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate), this prototype offers a broader pedagogical-technological integration. For instance, inquiry-based and field-based approaches correspond to the "Explore" and "Elaborate" phases, while animation, VR, and simulation support the "Explain" phase by making abstract content tangible. This demonstrates how TPACK can be effectively layered with domain-specific models to enhance instructional design.

This prototype model provides a robust, empirically grounded framework for implementing mobile learning in Biology education. It highlights a strategic blend of pedagogical, technological, and content considerations consistent with the TPACK framework while embracing innovation through ISM-based hierarchical structuring. These insights inform effective instructional design and serve as a roadmap for teacher training, curriculum planning, and mobile learning integration across educational levels.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

CONCLUSION

This study successfully identified, validated, and structured a set of practical teaching approaches for mobile learning in Biology education, grounded in the Technological Pedagogical Content Knowledge (TPACK) framework. Through expert consensus via the Nominal Group Technique (NGT) and hierarchical modeling using Interpretive Structural Modelling (ISM), a prototype model was developed to guide the integration of pedagogically sound, technologically supported, and content-relevant strategies in mobile learning contexts.

The findings underscore the prominence of student-centered, inquiry-driven, and experiential learning approaches, such as field-based learning, problem-based learning, and simulations, which are in line with global best practices in science education. The structured configuration of teaching approaches within the prototype model provides valuable insights into the interrelationships and hierarchical importance of each component, offering a robust basis for instructional design in mobile-first learning environments.

This research contributes significantly to the field of mobile learning design by presenting a contextually appropriate, empirically derived model for Biology education. It highlights the need for effective integration of pedagogy, technology, and content to foster active learning, personalization, and real-world application. Additionally, the study reaffirms the importance of continuous professional development for educators in implementing mobile-based strategies effectively.

Limitations of the Study

This study employed a Design and Development Research (DDR) approach, which inherently focuses on iterative design, expert input, and context-specific model development rather than large-scale generalizability. As such, the expert panel involved in the Nominal Group Technique (NGT) and Interpretive Structural Modelling (ISM) sessions was limited in both size and scope. While the selection of experts ensured in-depth insights and high content validity, the relatively small sample size limits the extent to which the findings can be generalized across broader educational contexts.

Furthermore, the study concentrated on the model development phase and did not include empirical classroom implementation or testing. As a result, while the proposed model is theoretically grounded and validated by expert consensus, its practical effectiveness in diverse real-world teaching settings remains to be investigated in future studies.

RECOMMENDATIONS

Based on the findings, the following recommendations are proposed:

1. Future research should implement the prototype model across various educational institutions to assess its effectiveness in real-world Biology classrooms.
2. Gathering student feedback and analyzing learning outcomes associated with each teaching approach will provide empirical support for refining the model.
3. Teacher training programs should incorporate TPACK-aligned mobile learning strategies to ensure educators are equipped to deliver content effectively in mobile environments.
4. The model may be adapted for other science subjects or educational levels, broadening its relevance and impact.

This study lays a solid foundation for transforming Biology education through innovative, technology-enhanced pedagogy and offers a scalable framework for future exploration and application.

Ethics Approval and Consent to Participate

The researchers used the research ethics Educational Research Application System provided by the Research Ethics Committee of Education Planning and Policy Research Division (EPRD), Ministry of Education, Malaysia. All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the Ministry's research committee.

ACKNOWLEDGEMENT

The authors declare that no specific funding was received for this research

REFERENCES

1. Abd Manaf, C. J., Desa, S., & Mat Saad, M. I. (2024). EDUCATOR' S READINESS TOWARDS m-LEARNING IN. Journal of Contemporary Social Science and Education Studies, 4(12), 110–127. https://doi.org/10.5281/zenodo.13370525
2. Abdullah, A., & Mahmud, S. N. D. (2024). Applying TPACK in STEM Education towards 21-st Century: Systematic Literature Review. International Journal of Academic Research in Progressive Education and Development, 13(1), 1014–1032. https://doi.org/10.6007/ijarped/v13-i1/20667
3. Afikah, A., Astuti, S. R. D., Suyanta, S., Jumadi, J., & Rohaeti, E. (2022). Mobile Learning in Science Education to Improve Higher-Order Thinking Skills (HOTS) and Communication Skills: A Systematic Review. International Journal of Advanced Computer Science and Applications, 13(7), 698–704. https://doi.org/10.14569/IJACSA.2022.0130782
4. Ahmad, A. M., Hussin, Z., Yusof, F., & Mohd Jamil, M. R. (2017). NOMINAL GROUP TECHNIQUE (NGT) DAN APLIKASINYA TERHADAP PEMBINAAN ELEMEN ETIKA DAN NILAI (AKHLAK) BERASASKAN AKTIVITI INKUIRI. Journal of Social Sciences and Humanities, 1, 125–145.
5. Alharbi, A. A. (2025). Cognitive learning approach to enhance university students' visualization of molecular geometry in chemical compounds: A case study in Saudi Arabia. Journal of Radiation Research and Applied Sciences, 18(1), 101283. https://doi.org/https://doi.org/10.1016/j.jrras.2024.101283
6. Angraini, E., Zubaidah, S., & Susanto, H. (2023). TPACK-based Active Learning to Promote Digital and Scientific Literacy in Genetics. Journal of Education and Instruction, 13(2), 50–61. https://doi.org/10.47750/pegegog.13.02.07
7. Anis, S. K., Masek, A., Nurtanto, M., & Kholifah, N. (2022). Nominal group technique application towards design of components and elements of non-digital game framework. 11(1). https://doi.org/10.11591/ijere.v11i1.22164
8. Attri, R., Dev, N., & Sharma, V. (2013). Interpretive structural modelling (ISM) approach: an overview. Research Journal of Management Sciences, 2319(2), 1171.
9. Bloom, B. S. (1968). Learning for Mastery. Instruction and Curriculum (Issue 2). https://doi.org/10.1007/978-1-4419-1428-6_4645
10. Blundell, C. N., Mukherjee, M., & Nykvist, S. (2022). A scoping review of the application of the SAMR model in research. Computers and Education Open, 3, 100093. https://doi.org/https://doi.org/10.1016/j.caeo.2022.100093
11. Chang, S.-C., Hsu, T.-C., Chen, Y.-N., & Jong, M. S.-Y. (2020). The effects of spherical video-based virtual reality implementation on students' natural science learning effectiveness. Interactive Learning Environments, 28(7), 915–929. https://doi.org/10.1080/10494820.2018.1548490
12. Chitra, E., Mubin, S. A., Nadarajah, V. D., Se, W. P., Sow, C. F., Er, H. M., Mitra, N. K., Thiruchelvam, V., & Davamani, F. (2024). OPEN A 3 - D interactive microbiology laboratory via virtual reality for enhancing practical skills. Scientific Reports, 1–10. https://doi.org/10.1038/s41598-024-63601-y
13. Criollo-C, S., Guerrero-Arias, A., Jaramillo-Alcázar, A., & Luján-Mora, S. (2021). Mobile learning technologies for education: Benefits and pending issues. Applied Sciences (Switzerland), 11(9). https://doi.org/10.3390/app11094111
14. Cuervo-Cely, K. D., Restrepo-Calle, F., & Ramírez-Echeverry, J. J. (2022). EFFECT OF GAMIFICATION ON THE MOTIVATION OF COMPUTER PROGRAMMING STUDENTS. Journal of Information Technology Education: Research, 21. https://doi.org/10.28945/4917
15. Delbecq, A. L., Van de Ven, A. H., & Gustafson, D. H. (1975). Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes. In Scott, Foresman Glenview.
16. Deslandes, S. F., Mendes, C. H. F., Pires, T. de O., & Campos, D. de S. (2010). Use of the nominal group technique and the delphi method to draw up evaluation indicators for strategies to deal with

violence against children and adolescents in Brazil. Revista Brasileira de Saude Materno Infantil, 10(SUPPL. 1), 29–37. https://doi.org/10.1590/s1519-38292010000500003

17. Diningrat, S. W. M., Setyosari, P., Ulfa, S., & Widiati, U. (2023). The Effect of an Extended Flipped Classroom Model for Fully Online Learning and its interaction with Working Memory Capacity on Students' Reading Comprehension. Journal of New Approaches in Educational Research, 12(1), 77–99. https://doi.org/10.7821/naer.2023.1.1073
18. Dobbie, A., Rhodes, M., Tysinger, J. W., & Freeman, J. (2004). Using a modified nominal group technique as a curriculum evaluation tool. Family Medicine, 36(6), 402–406.
19. Errabo, D. D., & Ongoco, A. A. (2024). Effects of interactive-mobile learning modules in students' engagement and understanding in genetics. Journal of Research in Innovative Teaching and Learning, 17(2), 327–351. https://doi.org/10.1108/JRIT-01-2024-0023
20. Evenhouse, D., Lee, Y., Berger, E., Rhoads, J. F., & DeBoer, J. (2023). Engineering student experience and self-direction in implementations of blended learning: a cross-institutional analysis. International Journal of STEM Education, 10(1). https://doi.org/10.1186/s40594-023-00406-x
21. Farhana, Z., Khan, A. S., & Chowdhury, S. A. (2024). ICT in biology education: teachers' readiness and implementation challenges in the context of Bangladesh. Discover Education, 3(1). https://doi.org/10.1007/s44217-024-00273-w
22. Häggström, M., Schmidt, C., & Margaretha, H. (2020). Enhancing children ' s literacy and ecological literacy through critical place-based pedagogy. Environmental Education Research, 26(12), 1729–1745. https://doi.org/10.1080/13504622.2020.1812537
23. Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. Sustainable Operations and Computers, 3, 275–285. https://doi.org/10.1016/j.susoc.2022.05.004
24. Hendarwati, E., Nurlaela, L., & Bachri, B. S. (2021). The collaborative problem based learning model innovation. Journal of Educational and Social Research, 11(4), 97–106. https://doi.org/10.36941/jesr-2021-0080
25. Himes, M. P., Spires, H. A., Krupa, E. E., Borden, M. L., & Eagle, J. L. (2023). Project-Based Inquiry (PBI) Global during a Pandemic: A New Learning Ecology Perspective. Education Sciences, 13(11). https://doi.org/10.3390/educsci13111099
26. Ismail, I. M., Sanmugam, M., Hassan, H., Nadzeri, M. B., Rahim, A. A. A., & Khamis, N. Y. (2023). Redesigning of Mobile Content to Enhance Learning Activities Preparation by Preschool Experts. International Journal of Interactive Mobile Technologies, 17(15), 53–67. https://doi.org/10.3991/ijim.v17i15.39325
27. Ismail, Z. H., Shahabuddin, M. Z., & Muhamad, F. N. (2024). GAMIFICATION ADAPTATION IN TEACHING AND LEARNING AMONG THE SECONDARY SCHOOL TEACHERS IN. International Journal of Modern Education, 6(23), 613–629.
28. Jenkinson, J. (2018). Molecular Biology Meets the Learning Sciences: Visualizations in Education and Outreach. Journal of Molecular Biology, 430. https://doi.org/10.1016/j.jmb.2018.08.020
29. Jiang, F., Lin, D., Tang, L., & Zhou, X. (2020). Interactive Simulation of DNA Structure for Mobile-Learning. In N. N.J., M. L., W. M., C. N., & P. Z. (Eds.), Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 12523 LNCS (pp. 176–187). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-030-65736-9_16
30. Kajonmanee, T., Srisawasdi, N., & Chaipah, K. (2018). A personalized mobile learning system for solving STEM teachers' TPACK problems. ICCE 2018 - 26th International Conference on Computers in Education, Workshop Proceedings. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85060010719&partnerID=40&md5=49015633a974628f5b0accc355782ce6
31. Kassa, M. M., Azene, M. K., Mengstie, S. M., & Ferede, M. W. (2024). Effect of using multimedia and dynamic classroom integrated instruction on grade 11 students' biology academic achievement. Heliyon, 10(18), e37315. https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e37315
32. Lai, D., Lew, S., & Ooi, S. (2022). Mobile Interactive System in Virtual Classroom based on TPACK: A Study from Students' Perspectives. Journal of Logistics, Informatics and Service Science. https://doi.org/10.33168/LISS.2022.0312
33. Lanir, J., Yosfan, M., Wecker, A., & Eilam, B. (2021). Student Informal Learning at Museum Field

Trips using Tablet Computers. 22nd International Conference on Human-Computer Interaction with Mobile Devices and Services. https://doi.org/10.1145/3406324.3410542

34. Leong, K., Sung, A., Au, D., & Blanchard, C. (2021). A review of the trend of microlearning. Journal of Work-Applied Management, 13(1), 88–102. https://doi.org/10.1108/JWAM-10-2020-0044
35. Lin, C.-J., Tang, K.-Y., & Tu, Y.-F. (2023). Advancements and research topics of museum-based mobile learning: a review of journal publications from 2008 to 2019. Interactive Learning Environments, 31(8), 4729–4752. https://doi.org/10.1080/10494820.2021.1981394
36. Marunevich, O., Kolmakova, V., Odaruyk, I., & Shalkov, D. (2021). E-learning and m-learning as tools for enhancing teaching and learning in higher education : a case study of Russia. 03007.
37. Matzavela, V., & Alepis, E. (2021). Decision tree learning through a Predictive Model for Student Academic Performance in Intelligent M-Learning environments. Computers and Education: Artificial Intelligence, 2. https://doi.org/10.1016/j.caeai.2021.100035
38. Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. Teachers College Record: The Voice of Scholarship in Education, 108(6), 1017–1054. https://doi.org/10.1177/016146810610800610
39. Ngu, K. S., Siraj2, S., & Alias, N. (2024). Aplikasi Kaedah Interpretive Structural Modelling untuk Pembinaan Model Intergenerasi. Jurnal Kurikulum & Pengajaran Asia Pasifik, 12(2), 1–8.
40. Nguyen, T. (2019). USING PROBLEM-BASED LEARNING TO PROMOTE STUDENTS ' USE OF HIGHER-ORDER THINKING SKILLS AND FACILITATE THEIR LEARNING USING PROBLEM-BASED LEARNING TO PROMOTE STUDENTS ' USE OF HIGHER-ORDER THINKING SKILLS AND FACILITATE THEIR LEARNING. April 2018. https://doi.org/10.25073/2525-2445/vnufs.4249
41. Pan, Y., & He, W. (2024). Research on the influencing factors of promoting flipped classroom teaching based on the integrated UTAUT model and learning engagement theory. Scientific Reports, 14(1). https://doi.org/10.1038/s41598-024-66214-7
42. Ramírez-Donoso, L., Pérez-Sanagustín, M., Neyem, A., Alario-Hoyos, C., Hilliger, I., & Rojos, F. (2023). Fostering the use of online learning resources: results of using a mobile collaboration tool based on gamification in a blended course. Interactive Learning Environments, 31(3), 1564–1578. https://doi.org/10.1080/10494820.2020.1855202
43. Ramya, M. V, Purushothama, G. K., & Prakash, K. R. (2020). M-Learning Based Remote Laboratory for Electronics Experiments. International Journal of Online and Biomedical Engineering, 16(11), 4–15. https://doi.org/10.3991/iioe.vl6il1.16177
44. Richey, R., & Klein, J. D. (2014). Design and development research. In Handbook of Research on Educational Communications and Technology: Fourth Edition (pp. 141–150). https://doi.org/10.1007/978-1-4614-3185-5_12
45. Rincon-Flores, E. G., & Santos-Guevara, B. N. (2021). Gamification during Covid-19: Promoting active learning and motivation in higher education. Australasian Journal of Educational Technology, 37(5), 43–60. https://doi.org/10.14742/ajet.7157
46. Romrell, D., Kidder, L. C., & Wood, E. (2014). The SAMR Model as a Framework for Evaluating mLearning. Journal of Asynchronous Learning Networks, 18(2), 1–15.
47. Rosli, R., & Ishak, N. A. (2024). Integration of Virtual Labs in Science Education: A Systematic Literature Review. Jurnal Pendidikan Sains Dan Matematik Malaysia, 14(1), 81–103. https://doi.org/10.37134/jpsmm.vol14.1.8.2024
48. Safitri, D., Lestari, I., Maksum, A., Ibrahim, N., Marini, A., Zahari, M., & Iskandar, R. (2021). Web-Based Animation Video for Student Environmental Education at Elementary Schools. International Journal of Interactive Mobile Technologies, 15(11), 66–80. https://doi.org/10.3991/ijim.v15i11.22023
49. Schneider, J., Schaal, S., & Schlieder, C. (2020). Integrating simulation tasks into an outdoor location-based game flow. Multimedia Tools and Applications, 79(5–6), 3359–3385. https://doi.org/10.1007/s11042-019-07931-4
50. Selamat, S. S. M., & Adnan, N. H. (2024). Nominal Group Technique for Identifying Challenges in Data Measurement Within Fundamental of Computer Science Curriculum. International Journal of Research and Innovation in Social Science, VIII(2454), 2676–2685. https://doi.org/10.47772/IJRISS
51. Sidhu, R. K. (2014). Field Based Learning : New Approach To Learn Field Based Learning : New Approach To Learn. International Multidisciplinary E-Journal, III(June 2014), 153–158.

52. Siraj, S., Abdullah, M. R. T. L. A., & Muhamad Rozkee, R. (2021). Pendekatan Kajian Rekabentuk dan Pembangunan: Aplikasi kepada kajian pendidikan. Penerbit Univerditi Pendidikan Sultan Idris.
53. Situmorang, R. P., Suwono, H., Susanto, H., Chang, C.-Y., & Liu, S.-Y. (2024). Learn biology using digital game-based learning: A systematic literature review. Eurasia Journal of Mathematics, Science and Technology Education, 20(6). https://doi.org/10.29333/EJMSTE/14658
54. Sushil. (2012). Interpreting the interpretive structural model. Global Journal of Flexible Systems Management, 13(2), 87–106. https://doi.org/10.1007/S40171-012-0008-3
55. Tavares, R., Vieira, R. M., & Pedro, L. (2021). Mobile app for science education: Designing the learning approach. Education Sciences, 11(2), 1–23. https://doi.org/10.3390/educsci11020079
56. Tondeur, J., Braak, J., Ertmer, P. A., & Ottenbreit-leftwich, A. (2016). Understanding the relationship between teachers ' pedagogical beliefs and technology use in education : A systematic review of qualitative evidence. Educational Technology Research and Development, October 2017. https://doi.org/10.1007/s11423-016-9481-2
57. Vahedian-Shahroodi, M., Mansourzadeh, A., Moghani, S. S., & Saeidi, S. (2023). Using the Nominal Group Technique in Group Decision-Making: A Review. Med Edu Bull, 4(14), 837–882. https://doi.org/10.22034/MEB.2024.434656.1090
58. Van De Ven, A., & Delbecq, A. L. (1971). Nominal versus interacting group processes for committee decision-making effectiveness. Academy of Management Journal, 14(2), 203–212. https://doi.org/10.2307/255307
59. Vijayatheepan, R. (2023). Virtual Lab for Interactive Learning in Science Education Virtual Lab for Interactive Learning in Science Education. December.
60. Warfield, J. N. (1974a). Developing Subsystem Matrices in Structural Modeling. IEEE Transactions on Systems, Man, and Cybernetics, SMC-4(1), 74–80. https://doi.org/10.1109/TSMC.1974.5408523
61. Warfield, J. N. (1974b). Toward Interpretation of Complex Structural Models. IEEE Trans. Syst. Man Cybern., 4, 405–417. https://api.semanticscholar.org/CorpusID:26862218
62. Wong, K. L., Cheng, W. F., Sze, M. T., Choy, S. H., Jim, K. L., Tsang, Y. H., Leung, C. W., & Mak, C. L. (2024). Borderless Lab 365: a real-time web-based remote laboratory platform for Hong Kong high school students in response to the pandemic. International Journal of Mobile Learning and Organisation, 18(2), 194–214. https://doi.org/10.1504/IJMLO.2024.137628
63. Zhampeissova, K., Kosareva, I., & Borisova, U. (2020). Collaborative Mobile Learning with Smartphones in Higher Education. International Journal of Interactive Mobile Technologies, 14(21), 4–18. https://doi.org/10.3991/ijim.v14i21.18461
64. Zhang, D., & Pérez-Paredes, P. (2021). Chinese postgraduate EFL learners' self-directed use of mobile English learning resources. Computer Assisted Language Learning, 34(8), 1128–1153. https://doi.org/10.1080/09588221.2019.1662455
65. Zhu, C., Leung, C. O. Y., Lagoudaki, E., Velho, M., Segura-Caballero, N., Jolles, D., Duffy, G., Maresch, G., Pagkratidou, M., & Klapwijk, R. (2023). Fostering spatial ability development in and for authentic STEM learning. Frontiers in Education, 8(April), 1–17. https://doi.org/10.3389/feduc.2023.1138607