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## International Social Sciences and Education Conference 2025

*"Empowering Knowledge: Driving Change Through Social Science and Educational Research"*

## Virtual Conference

### 24-25 May 2025

Organised by: CLM PUBLISHING RESOURCES

# Designing TPACK-Driven Mobile Learning with Digital Citizenship for Biology Education: Insights from NGT and ISM Approaches

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**Abstract**
The rapid digitization of education and the complexity of scientific content demand the integration of digital citizenship in TPACK-based mobile learning for Biology. This study aimed to identify and prioritize relevant digital citizenship practices using a Design and Development Research approach. In Phase One, the Nominal Group Technique with 10 experts evaluated eight proposed practices. Phase Two employed Interpretive Structural Modeling with nine experts to structure hierarchical relationships. Seven practices were retained, with Ethical Use of Digital Resources as the top-level driver. The resulting framework supports ethical and discipline-specific mobile learning models, promoting responsible digital engagement in Biology education.

Keywords: Biology, Digital Citizenship, Mobile Learning, TPACK



## 1.0 Introduction

The rapid advancement of mobile technology has significantly transformed the educational landscape, offering greater flexibility and personalized learning opportunities (Qazi & Mtenzi, 2023). In the context of Biology education, which often deals with abstract, multistep processes such as cellular respiration, gene expression, and ecological interactions, effective pedagogy requires tools that support visualization, interactivity, and contextual understanding. Traditional teaching methods may fall short in addressing these demands, making mobile learning (m-learning) a promising strategy to enhance comprehension, engagement, and application of biological knowledge.

However, the integration of mobile devices alone does not guarantee improved learning outcomes or responsible digital behavior. Biology, as a science subject, also raises critical ethical considerations, such as issues in genetic engineering, environmental sustainability, and bioethics. These underscore the need to cultivate digital citizenship, which includes online safety, ethical conduct, critical digital literacy, and responsible technology use (Greene & Crompton, 2024). Despite the growing relevance, digital citizenship is rarely addressed in subject-specific m-learning, especially in Biology.

The Technological Pedagogical Content Knowledge (TPACK) framework has been widely used to guide technology integration by combining technological, pedagogical, and content expertise (Ning et al., 2024). Yet, TPACK applications often omit the ethical dimension of technology use, which is crucial in scientific fields like Biology. Although mobile learning and digital citizenship have been studied independently, there remains a notable gap in merging these areas into a unified, discipline-specific model.

To address this gap, the present study aims to develop a framework that integrates digital citizenship practices into TPACK-driven mobile learning tailored for Biology education. The primary objective is to identify the core digital citizenship practices relevant to Biology instruction through expert consensus. A secondary objective is to examine the interrelationships and prioritization of these practices using Interpretive Structural Modeling (ISM). Grounded in a Design and Development Research (DDR) approach, this study utilizes the Modified Nominal Group Technique (NGT) to elicit expert input, followed by ISM to structure the relationships among the practices. The outcome is a pedagogically sound and ethically responsive instructional model that supports the cultivation of responsible digital behavior within Biology education.

## 2.0 Literature Review

Mobile learning (m-learning) has gained considerable traction in recent years, particularly for its ability to support interactive, flexible, and personalized instruction in science education. Numerous studies have demonstrated that m-learning is effective in facilitating the understanding of complex biological processes such as photosynthesis, genetics, and ecosystems (Toh & Tasir, 2024). However, despite the pedagogical benefits of mobile technology, its integration alone does not ensure the development of responsible or ethical digital behaviors among students (Chigona et al., 2024). This shortcoming highlights the importance of incorporating digital citizenship principles into m-learning environments.

Digital citizenship refers to the responsible and ethical use of digital technologies and has been framed extensively in general education contexts, most notably by Ribble (2015), who introduced nine foundational elements such as digital literacy, cybersecurity, and ethical use. While valuable, these frameworks often lack contextual adaptation to specific disciplines. Existing research, such as that by Capuno et al. (2022) shows that students may possess general digital awareness but lack the ability to apply these principles in subject-specific learning, particularly in Biology. Biology education often involves ethically sensitive content, such as cloning, genetic engineering, biodiversity, and environmental sustainability, necessitating a more specialized and ethically grounded approach to digital engagement (Altınsoy & Boyraz, 2024).

To address this gap, the current study is grounded in three key models: the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which integrates pedagogy, content, and technology but underrepresents digital ethics; Ribble's (2015) digital citizenship model, which offers ethical dimensions to digital use but is seldom contextualized for science education; and the Design and Development Research (DDR) methodology (Richey & Klein, 2014), which allows for systematic model design, refinement, and validation. Drawing from these foundations, a conceptual framework was constructed that embeds digital citizenship within TPACK-aligned mobile learning for Biology. Key elements such as ethical use of digital resources, digital ethics literacy, self-regulation, content evaluation, cybersecurity, copyright awareness, and sustainable digital practices were identified and critically reviewed based on pedagogical needs. This integrated model not only fills a conceptual gap in the literature but also aligns with current educational shifts toward values-driven, responsible digital learning environments.

## 3.0 Methodology

This study adopted a Design and Development Research (DDR) methodology as outlined by Richey and Klein (2014), which is appropriate for systematically constructing and validating educational models. DDR emphasizes iterative development grounded in expert input, making it particularly suitable for this study's aim of developing a framework for integrating digital citizenship into TPACK-based mobile learning for Biology education. Two structured qualitative techniques were employed in this study: the Modified Nominal Group Technique (NGT) and Interpretive Structural Modeling (ISM). These methods were selected due to their complementary strengths in model design and expert consensus building. NGT is well-established for identifying and prioritizing key elements based on expert judgment in a structured manner (Delbecq et al., 1975), while ISM is effective for systematically analyzing the relationships among those elements to produce a hierarchically structured model (Sushil, 2012). This combined approach is widely used in DDR-based educational research to enhance model validity and theoretical grounding (Siraj et al., 2021).

In Phase 1, the Modified NGT was conducted with a panel of ten purposively selected experts in Biology education, curriculum and instruction, and educational technology. The experts included university lecturers under the Ministry of Higher Education Malaysia, matriculation college lecturers, teacher educators, and a representative from the Educational Planning and Policy Research Division (EPRD) of the Ministry of Education. The in-person NGT session involved brainstorming, silent idea generation, round-robin sharing, clarification, and individual ranking using a seven-point Likert scale to evaluate eight proposed digital citizenship practices in Biology mobile learning. Practices scoring 70% or above were accepted for inclusion. Data collected from this session included individual ratings and group consensus notes, which were tabulated and analyzed to determine the final list of practices. In Phase 2, ISM was employed with nine of the original ten panelists (one was unable to participate) to identify and structure the interrelationships among the accepted practices. Using the ISM process, participants conducted pairwise comparisons to determine how each practice influenced or depended on the others. These judgments were compiled into a Structural Self-Interaction Matrix (SSIM), which was then converted into a binary

Reachability Matrix. The data were further processed using MICMAC (Cross-Impact Matrix Multiplication Applied to Classification) analysis to classify the practices into independent, dependent, linkage, or autonomous categories based on their driving and dependence power (Ahmad et al., 2021).

The use of NGT ensured that key elements were grounded in expert consensus, while ISM enabled the construction of a logically structured hierarchy of these elements. The integration of both methods within the DDR framework ensured the internal coherence, conceptual soundness, and empirical validity of the resulting model. This methodology provides a robust foundation for developing a discipline-specific digital citizenship framework that is pedagogically sound, ethically relevant, and contextually appropriate for TPACK-based mobile learning in Biology education.

## 4.0 Findings

The findings of this study are organized according to the research objectives, which focus on identifying key digital citizenship practices relevant to Biology education and exploring how these practices are interrelated and prioritized through the use of Interpretive Structural Modeling (ISM). To identify and rank digital citizenship practices, experts evaluated eight proposed practices through structured small-group discussions using a seven-point Likert scale, with practices scoring 70% or higher being acceptable (Deslandes et al., 2010). Initially, eight recommended practices were reviewed, but only seven were approved for inclusion. This selection excludes Media and Information, underscoring the need for discipline-specific tailoring of digital citizenship. The data show that the lowest rating for any approved practice was 1, indicating *strongly disagree*, and the highest rating was 7, indicating *strongly agree*. These approved practices were then organized into a hierarchical structure based on their priority values, as graphically in Table 1.

Table 1: Ranking and Prioritization of Digital Citizenship Practices

| | Experts | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Digital Citizenship Practices | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total item score | Percentage | Rank Priority | Voter Consensus |
| 1. Digital Ethics Literacy | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 70 | 100 | 1 | Suitable |
| 2. Critical Evaluation of Content Usage | 7 | 7 | 7 | 6 | 6 | 7 | 7 | 7 | 6 | 7 | 67 | 95.7 | 4 | Suitable |
| 3. Cybersecurity | 7 | 7 | 7 | 6 | 7 | 6 | 7 | 7 | 7 | 7 | 68 | 97.1 | 2 | Suitable |
| 4. Sustainable Digital Practices | 7 | 6 | 7 | 6 | 7 | 6 | 7 | 7 | 5 | 1 | 59 | 84.3 | 7 | Suitable |
| 5. Ethical Use of Digital Resources | 7 | 7 | 6 | 7 | 7 | 7 | 7 | 7 | 6 | 6 | 67 | 95.7 | 4 | Suitable |
| 6. Copyright Awareness | 7 | 7 | 7 | 6 | 6 | 7 | 7 | 7 | 7 | 6 | 67 | 95.7 | 4 | Suitable |
| 7. Media and Information | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 13 | 18.6 | 8 | Not Suitable |
| 8. Self-Reflection and Regulation | 7 | 7 | 7 | 7 | 7 | 6 | 7 | 7 | 7 | 6 | 68 | 97.1 | 2 | Suitable |

The approved practices were analyzed using Interpretive Structural Modeling (ISM) with the same group of experts (n=9). Concept Star software was used to automate the generation of the relationship model, capturing the directional influence between elements. Figure 1 illustrates the influence hierarchy, demonstrating how foundational elements drive dependent ones.

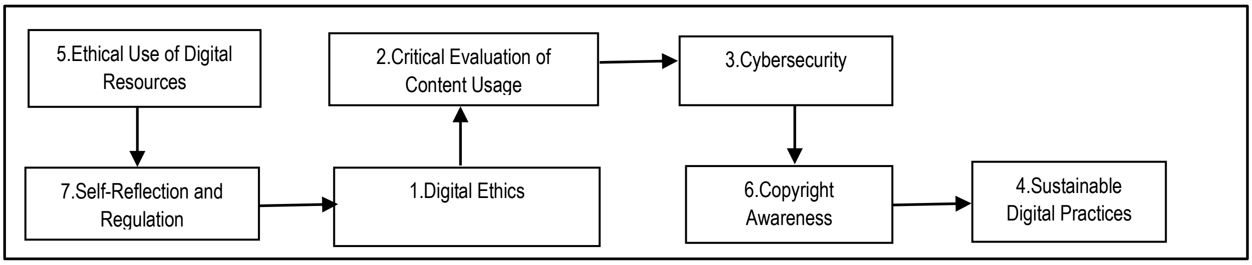


Fig.1: Digital Citizenship Practices According to their Importance

The Concept Star software generates a detailed relationship model, illustrated in Figure 1, to provide a clear understanding of the connections between various digital citizenship practices. In the model, directional arrows denote driving components, with the logic that if element A drives element B and element B drives element C, element A must also drive element C, but not vice versa. Figure 1 demonstrates that *ethical use of digital resources* drives *self-reflection and regulation,* which in turn influences *digital ethics literacy*. *Digital ethics literacy* fosters *critical evaluation of content usage*, which impacts *cybersecurity*. *Cybersecurity* drives *copyright awareness*, which subsequently supports *sustainable digital practices*. Thus, the *ethical use of digital resources* ultimately drives *sustainable digital practice*. The concepts of *driving power* and *dependent power*, central to this model, are applied in constructing the Reachability Matrix, shown in Table 2, which visually maps these intricate linkages.

Table 2: Reachability Matrix for Digital Citizenship Practices

| Elements | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Driving Power |
|---|---|---|---|---|---|---|---|---|
| 1. Digital Ethics Literacy | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2. | Critical Evaluation of Content Usage | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 4 |
| 3. | Cybersecurity | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 3 |
| 4. | Sustainable Digital Practices | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 5. | Ethical Use of Digital Resources | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 |
| 6. | Copyright | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 |
| 7. | Self-Reflection and Regulation | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 6 |
| Dependence Power | | 3 | 4 | 5 | 7 | 1 | 6 | 2 | |

The values "0" and "1" are determined from Figure 1 based on the following criteria: "i" and "j" are the strategies. Input (i, i) is marked as "1" because i drives i
Input (i,j) is denoted as "1", because i drives
Input (j, i) is denoted as "0" because i is not driven by j.

As explained in the MICMAC Diagram section, practices are categorised according to their driving and dependent powers. The findings are displayed in Table 3, where the seven practices are ranked from least to most important. Level 7 is the most influential practice, while Level 1 is the least effective. The significance of each practice and how it affects other practices determines its place. All practices are arranged in decreasing order of relevance, with Practice Idea 5 at Level 7 (most significant) and Practice Idea 4 at Level 1 (least significant).

Table 3: Partitioning of Reachability Matrix

| Idea | Practice Statement | Level |
|---|---|---|
| 5 | Ethical Use of Digital Resources | 7 |
| 7 | Self-Reflection and Regulation | 6 |
| 1 | Digital Ethics Literacy | 5 |
| 2 | Critical Evaluation of Content Usage | 4 |
| 3 | Cybersecurity | 3 |
| 6 | Copyright Awareness | 2 |
| 4 | Sustainable Digital Practices | 1 |

The MICMAC diagram determines the driving and dependent power of variables It is created by transforming the x-axis (dependence power) and y-axis (driving power) values into Cartesian coordinates (x, y), as shown in Table 4, and annotating each coordinate with the corresponding practice number. The coordinates are then plotted on a Cartesian graph, with each method assigned to a specific quadrant. Table 5 shows that each quadrant represents different aspects of driving and dependent power.

Table 4: Driving power and Dependence power

| Element | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| x | 3 | 4 | 5 | 7 | 1 | 6 | 2 |
| y | 5 | 4 | 3 | 1 | 7 | 2 | 6 |

The Cartesian graph, also known as the MICMAC diagram, is presented in Figure 2.

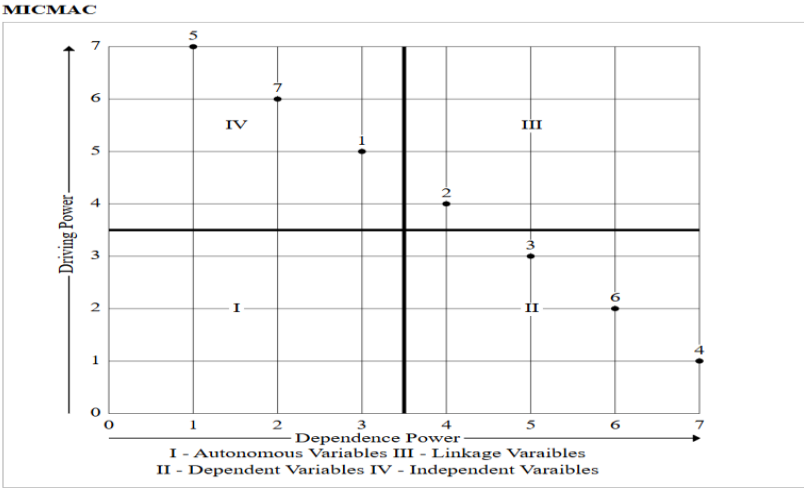


Fig. 2: MICMAC diagram

Practices are further categorized into quadrants based on their driving and dependent powers as shown in Table 5. The most critical practices fall into Quadrant IV (Independent), with others in Quadrants II (Dependent) and III (Linkage).

Table 5: Characteristics of Quadrant

| | | |
|---|---|---|
| Quadrant I | Autonomous. | Practice has low drive power and low reliance power. The practices in this quadrant are often unrelated to the system and may have a minimal relationship, even if it is robust. There is no practice for this attribute in this study. |
| Quadrant II | Dependent | Weak driver-strongly dependent practice. The practice in this quadrant is dependent on the independent practice. |
| Quadrant III | Linkage | Strong driver-strongly dependent practice. Practice must be addressed carefully because the relationship between the strategies is unstable. |
| Quadrant IV | Independent | Strong driver-weak dependent strategies. Strong strategies that drive the system. |

Therefore, the quadrants to be addressed are Quadrant IV, Quadrant II, and Quadrant III. By referring, seven independent strategies have strong driving powers. These strategies are shown in Table 6 as follows. There are three independent practices, as shown in Table 6, and three dependent practices, as shown in Table 7, as follows.

Table 6: Independent Strategies

| Elements | Practices |
|---|---|
| 5 | Ethical Use of Digital Resources |
| 7 | Self-Reflection and Regulation |
| 1 | Digital Ethics Literacy |

Table 7: Dependent Strategies

| Elements | Practices |
|---|---|
| 3 | Cybersecurity |
| 6 | Copyright Awareness |
| 4 | Sustainable Digital Practices |

Based on MICMAC analysis, three practices were categorized as having high driving power and low dependence, placing them in Quadrant IV (Independent Drivers) of the model. These are:
Element 5 Ethical Use of Digital Resources
Element 7 Self-Reflection and Regulation
Element 1 Digital Ethics Literacy

Their classification as independent strategies indicates that they significantly influence other variables in the system but are not themselves strongly influenced by others.

## 5.0 Discussion

The application of the Modified Nominal Group Technique (NGT) facilitated a structured, expert-driven consensus process that identified seven essential digital citizenship practices tailored to TPACK-driven mobile learning in Biology education. These include Ethical Use of Digital Resources, Digital Ethics Literacy, Self-Reflection and Regulation, Critical Evaluation of Content Usage, Cybersecurity, Sustainable Digital Practices, and Copyright Awareness. The exclusion of Media and Information Literacy emphasizes the necessity of discipline-specific conceptualizations of digital citizenship. Generic digital frameworks such as Ribble's (2015) Nine Elements offer foundational guidance but may lack contextual sensitivity in scientific domains requiring rigorous data handling and ethical interpretation.

Studies by (Ashaari et al., 2022) reinforce the need to align digital ethics with content-specific pedagogy. Similarly, Mardiana (2022) underscore the need for ethical conduct, especially in contexts where misinformation or misuse of intellectual property threatens the integrity of scientific learning.

Among the prioritized practices, the MICMAC analysis identified Ethical Use of Digital Resources, Digital Ethics Literacy, and Self-Reflection and Regulation as foundational. These independent drivers possess strong influence and minimal dependency, making them key enablers in the model. Ribble (2015) advocates responsible digital use, while Crompton & Burke (2024b, 2024a) emphasize the relevance of digital ethics, especially as AI and biotechnology become prevalent in science classrooms. Theories by Zimmerman (2002)) and Bandura (1986) on self-regulation, along with reflective practice models by Kolb (1984) Kolb and Machost & Stains (2023) further support the development of internal accountability in learners. Malaysian-specific curricular goals, such as those outlined in the Secondary School Standard Curriculum (KSSM) and Matriculation Biology syllabi, emphasize inquiry-based learning and socio-scientific issues (Ministry of Education Malaysia, 2017) providing fertile ground for embedding these constructs.

The integration of these constructs into Biology mobile learning holds both transformative potential and systemic challenges. Instructional strategies should include ethical dilemmas, simulation-based decision-making, and reflective digital journaling to foster ethical reasoning (Chansa Chanda et al., 2024). However, successful implementation depends on teacher readiness and institutional support. The Socio-Ecological Technology Integration (SETI) framework (Crompton et al., 2024) highlights that digital ethics integration must be supported by teacher training, infrastructure, and school culture. Empirical studies by Abd Manaf et al. (2024) and Akram et al. (2022) affirm that sustained professional development enhances teacher agency in guiding digital citizenship. As Malaysia moves toward digital transformation in education, initiatives such as the 2023 Digital Education Policy underscore the importance of embedding a digital conscience within STEM teacher training (Ministry of Education Malaysia, 2023).

The MICMAC analysis further supports the role of *Ethical Use of Digital Resources*, *Digital Ethics Literacy*, and *Self-Reflection and Regulation* as foundational levers that influence dependent constructs such as *Cybersecurity* and *Copyright Awareness*. Promoting these drivers enables the cascading development of responsible digital behavior. For instance, ethical content use not only prevents plagiarism but also instills habits that reinforce copyright compliance. Similarly, digital literacy fosters secure digital practices. The framework aligns with the Malaysian Education Blueprint's (2013–2025) emphasis on 21st-century skills and ethical citizenship and can be integrated into co-curricular programs, digital textbook development, and teacher professional learning communities across the country

Beyond the confines of Biology and Malaysia, this model has broader implications. It is adaptable to other STEM subjects where ethical use of data and technology is paramount, such as Physics, Chemistry, and Environmental Science. The methodological approach, grounded in Design and Development Research (DDR), offers replicability for researchers and policymakers globally, especially in the ASEAN and Global South contexts, where values-based digital education is emerging as a priority (UNESCO, 2024). Furthermore, the integration of emerging technologies such as generative AI, immersive virtual labs, and real-time analytics into mobile learning underscores the urgency to revisit digital citizenship beyond traditional compliance and move toward fostering moral agency in learners.

## 6.0 Conclusion & Recommendations

This study developed a discipline-specific digital citizenship framework integrated into TPACK-driven mobile learning for Biology education by identifying and prioritizing seven core practices through Modified NGT and ISM methods. *Ethical Use of Digital Resources*, *Self-Reflection and Regulation*, and *Digital Ethics Literacy* were found to be foundational drivers that influence other dependent practices like *Cybersecurity* and *Copyright Awareness*. While the model offers a structured, ethical approach to Biology education, particularly relevant for content involving genetic, environmental, and health-related issues, it is limited by its reliance on expert consensus from a small sample and has yet to be empirically tested. Future research should include classroom-based pilot studies, development of teacher training resources, and cross-disciplinary expansion to assess adaptability in other STEM fields. Additionally, exploring longitudinal impact, cultural applicability, and the integration of emerging technologies like AI can enhance the model's relevance and scalability. Ultimately, this research contributes a novel framework aligned with Malaysia's educational aspirations to cultivate digitally responsible, ethically aware learners in the 21st century.

## 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, for granting permission to conduct this research. Special thanks also go to everyone who provided valuable suggestions and encouragement for this publication.

## Paper Contribution to Related Field of Study

This study contributes to the field by developing a discipline-specific digital citizenship framework integrated into TPACK-driven mobile learning for Biology education. Unlike generic digital citizenship models, this framework is tailored through expert consensus (NGT) and hierarchical analysis (ISM), addressing the ethical, cognitive, and content-specific needs of Biology learners. It extends the TPACK model by embedding digital ethics literacy, self-regulation, and critical content evaluation as core competencies for responsible mobile learning. Additionally, the study offers a replicable model development approach using the Design and Development Research methodology, providing valuable insights for curriculum designers, teacher educators, and policymakers in STEM education.

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