

Integrating Digital Tools for Teaching Abstract Biological Concept: A Case Study of ENS Yaounde

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DOI: <https://doi.org/10.47772/IJRISS.2026.1026EDU0069>

Received: 21 January 2026; Accepted: 27 January 2026; Published: 09 February 2026

ABSTRACT

The teaching of abstract scientific concepts such as the gene concept in biology remains highly challenging for teacher educators and preservice teachers. This study examines how integrating digital tools—Learning Management Systems (Moodle, Google Classroom), virtual simulations, and video-based feedback—affects the understanding, teaching, and evaluation of these abstract concepts at the Higher Teacher Training College (ENS) of Yaoundé. Anchored in Technological Pedagogical Content Knowledge (TPACK) and constructivist frameworks, a cross-sectional design using a validated Likert-scale questionnaire was administered to 88 biology student-teachers. Reliability coefficients (Cronbach's α) for subscales ranged from 0.72 to 0.87, confirming internal consistency. Structural Equation Modelling (SEM) revealed that perceived usefulness and digital competence were the strongest predictors of the frequency of digital tool use, which in turn significantly influenced perceived success. The findings underscore the importance of fostering digital competence and demonstrating usefulness to enhance meaningful technology integration in teacher training.

Descriptive and correlational analyses revealed a striking utility-practice gap (2.03 points) between the high perceived usefulness of virtual simulations (Mean = 4.06) and their low frequency of use (Mean = 2.03). Similarly, a competence-application gap (0.86 points) emerged between general digital confidence (Mean = 3.35) and pedagogical integration ability (Mean = 2.49). Major obstacles include inadequate Internet access (Mean = 4.43) and insufficient institutional infrastructure (Mean = 4.07).

While preservice teachers show strong motivation and willingness for further training, effective digital integration remains constrained by systemic and curricular gaps. The study recommends targeted technopedagogical training and infrastructural investment to bridge the perception-practice divide in science teacher education.

Keywords: Digital Pedagogy, Virtual Simulation, Technopedagogical Competence, Biology Education, Teacher Training.

INTRODUCTION

Several studies have demonstrated the successes of digital integration in teaching and learning abstract scientific concepts. According to Muftifah et al., (2025), digital tools have been shown to increase student engagement and comprehension, particularly in genetics, by facilitating interactive learning experiences. Marzin-Janvier (2015) opined that technologies enable students to visualize abstract concepts, making them more relatable and easier to understand. To Toriany & Mironets (2024), the creation of varied digital resources, such as educational games and interactive exercises, supports diverse learning styles and promotes active learning.

While the integration of digital tools in teacher training presents significant opportunities for enhancing the teaching of complex scientific concepts, it also faces challenges that need to be addressed to maximize its potential. Funke et al., (2023) noticed a there is a notable disparity in digital competencies

among teacher trainees, which can hinder effective integration of technology in teaching. Limited access to technological resources and training can impede the successful implementation of digital tools in the curriculum (Menezes et al., 2020).

The integration of digital technologies into teacher education is essential for preparing preservice teachers for 21st-century classrooms.

In sub-Saharan Africa, where infrastructural and pedagogical transformations are ongoing, integrating virtual and online learning environments represents both an opportunity and a challenge (Bon, 2010, UNESCO 2023). At the Higher Teacher Training College (ENS) Yaoundé, the post-pandemic adoption of hybrid models has accelerated the use of digital tools in science education. However, it remains unclear whether these technologies are being used effectively to enhance conceptual understanding—especially for abstract biological concepts such as the gene.

This study investigates how digital tools support (or fail to support) the teaching and learning of abstract scientific concepts in biology within preservice teacher education, emphasizing both perceived benefits and systemic constraints.

Despite global advances in digital pedagogy, there is limited empirical evidence from African teacher training institutions regarding how digital integration influences conceptual learning in biology. Prior studies (e.g., Lai & Bower, 2020; Mbah et al., 2022) have shown that digital simulations and LMS can facilitate visualization and self-paced learning, yet few have examined the attitude-behaviour inconsistency where positive perceptions fail to translate into active digital engagement within this specific educational context.

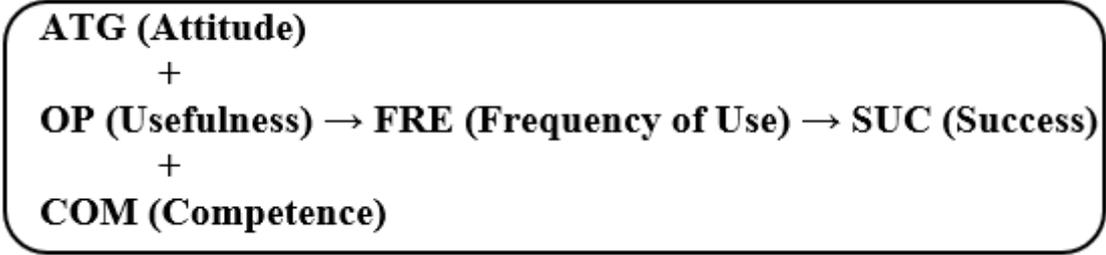
Thus this study is motivated by the research question: why does the integration of digital tools in biology teacher training at ENS Yaoundé remain suboptimal despite positive student attitudes toward their pedagogical value?

The following specific research questions are thus developed to tackle the research problem:

1. What are preservice biology teachers' perceptions of the usefulness of digital tools in understanding abstract concepts?
2. How frequently are these digital tools used in practical teacher training, and which factors predict the frequency of use?
3. What are the perceived levels of competence and confidence in using digital tools?
4. What systemic factors limit their effective integration?
5. How can these findings inform the redesign of teacher education curricula

Theoretical and Conceptual Framework

This study is grounded in two intersecting frameworks, Technological Pedagogical Content Knowledge (TPACK) and an adaptation of the Unified Theory of Acceptance and Use of Technology (UTAUT). According to Mishra & Koehler, (2006) and Williams et al., (2011) TPACK emphasizes that effective teaching with technology requires the integrated mastery of content, pedagogy, and technology knowledge. The UTAUT/TAM model is employed to enable the researcher structure the hypothesized causal relationships among the five variables / constructs in this conceptual framework developed below (Sarabadani et al., 2017; Dah & Hussin, 2021).



Inspired by the works of Teo (2011), postulated the following hypothesis to construct our SEM. A strong Attitude (ATG) and high perceived Usefulness (OP) and Competence (COM) lead to a strong Intention to Use digital tools. Limits (LIM) act as a negative moderator. High Limits weaken the link between Intention (OP, ATG, COM) and actual Frequency of Use (FRE). This is the primary dependent variable that determines the final outcome. High Frequency of Use (FRE) leads to greater perceived Successes (SUC).

These Successes, in turn, reinforce the initial Attitude (ATG) and Perception of Usefulness (OP), strengthening the entire cycle for future use. This model explains the transition from a positive mind-set to actual behavioural use, and ultimately, to perceived outcomes. To Naatu et al., (2024), the interplay between these frameworks highlights the necessity of addressing both mindset and systemic barriers to enhance the integration of digital tools in teacher education

METHODOLOGY

A cross-sectional quantitative design was adopted to assess preservice teachers’ perceptions, frequency of use, competencies, and challenges in digital integration. A total of 88 biology preservice teachers in the third and first year of ENS Yaoundé were chosen as this marks the end of the first and second cycle. The sample reflected both genders and a diversity of prior digital exposure. A structured questionnaire were used to measure the six constructs of the study. Descriptive statistics were used to calculate Mean and percentages, while Exploratory factor Analysis (EFA), Confirmatory Factor Analysis (CFA) and structural Equation modelling (SEM) permitted us to standardise our measuring instruments and test our conceptual model to improve successful usage of digital tools. The Jamovi software was used for data analysis.

RESULTS

The questionnaire was found to be reliable with an overall Cronbach alpha value of 0.82. The values of Cronbach alpha varied for the different construct range from 0.668 to 0.876.

Hypothesised Structural Equation Model (SEM)

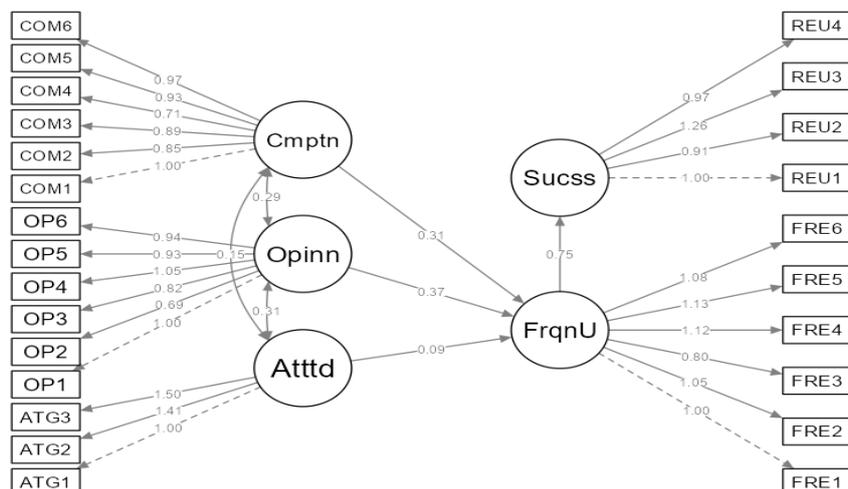


Figure 1. Hypothesised SEM model linking the five constructs.

The Structural Equation Model (SEM) shown in Figure 1 represents both the measurement and structural components linking five core constructs related to the integration of digital tools in practical teacher training: Attitudes (Attt), Opinion on Usefulness (Opinn), Competence and Digital Confidence (Cmptn), Frequency of Use (FrqnU), and Perceived Successes (Sucss). All constructs were measured by multiple indicators (FRE1 to FRE6; OP1 to OP6; COM1 to COM6; etc) with high standardized loadings (mostly above 0.70), confirming good convergent validity and reliability.

In the structural model, Opinion on Usefulness (Opinn) ($\beta = 0.37$) and Competence (Cmptn) ($\beta = 0.31$) emerged as strong positive predictors of Frequency of Use (FrqnU), whereas Attitude (Attt) showed a weak negative influence ($\beta = -0.09$). Frequency of Use (FrqnU) exerted a strong positive influence on Perceived Successes (Sucss) ($\beta = 0.75$). It confirms that consistent use of digital tools significantly contributes to perceived effectiveness in teaching abstract scientific concepts.

The correlations among exogenous variables were moderate: Competence and Opinion ($r = 0.29$) and Opinion and Attitude ($r = 0.31$), indicating interrelated psychological readiness toward technology use.

Perceived Usefulness of Digital Tools

Table 1 - Descriptive Statistics of Perceived Usefulness

Opinion on Usefulness (OP Items)	Mean	Mode	S.D.	SD	D	N	A	SA
OP1 - Digital tools facilitate the understanding of abstract scientific concepts like the gene.	3.90	4.00	1.09	6.8%	6.8%	3.4%	55.7%	27.3%
OP2 - Virtual simulations make invisible biological phenomena more concrete and understandable.	4.06	5.00	1.15	5.7%	6.8%	8.0%	35.2%	44.3%
OP3 - The use of Moodle or Google Classroom improves my learning in biology.	3.18	4.00	1.28	11.4%	22.7%	19.3%	29.5%	17.0%
OP4 - Educational videos help me better retain complex notions.	3.95	4.00	1.02	4.5%	4.5%	12.5%	47.7%	30.7%
OP5 - Digital tools promote better student participation in class.	3.57	4.00	1.27	5.7%	21.6%	11.4%	33.0%	28.4%
OP6 - The integration of digital technology in practical training makes courses more motivating.	3.93	4.01	1.0	2.3%	10.2%	9.1%	48.9%	29.5%

(N.B. 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

Preservice teachers demonstrated a high recognition of the pedagogical utility of visualizing tools. 79.5% of respondents belief in Virtual simulations (OP2, Mean = 4.06) and 78.4% in educational videos (OP4, Mean = 3.95) for making abstract phenomena concrete and understandable. In contrast, the use of LMS platforms (OP3) was rated only moderately useful (Mean = 3.18), suggesting perceived limitations in engagement.

Frequency of Use of Digital Tools

Table 2 - Descriptive Statistics of Frequency of Use of Digital Tool

Frequency of Use (FRE Items)	Mean	Mode	S.D	Never	Rarely	At times	Often	Always
FRE1 - I regularly use Moodle or Google Classroom to access course materials.	3.39	3.00	1.09	1.1%	23.9%	29.5%	26.1%	19.3%
FRE2 - I use educational videos to understand biology concepts.	3.64	3.00	1.10	2.3%	13.6%	29.5%	27.3%	27.3%
FRE3 - I use software or virtual simulations (e.g., Biolab, PhET, etc.) to study the concept of the gene.	2.03	1.00	1.13	40.9%	31.8%	13.6%	10.2%	3.4%
FRE4 - Exchange with my teachers via digital platforms (forums, academic WhatsApp, etc.).	3.83	5.00	1.20	2.3%	15.9%	19.3%	21.6%	40.9%
FRE5 - I evaluate my knowledge using interactive activities (online quizzes, Moodle tests, etc.).	3.36	4.00	1.18	5.7%	21.6%	21.6%	33.0%	18.2%
FRE6 - I integrate digital tools myself into my micro-teachings.	3.14	3.00	1.28	12.5%	19.3%	28.4%	21.6%	18.2%

(N.B. 1 = Never; 2 = Rarely; 3 = At times; 4 = Often; 5 = Always)

The actual frequency of use was highly inconsistent with perceived utility. While videos (FRE2, Mean = 3.64) and online teacher communication (FRE4, Mean = 3.83) were frequently used by almost 881.8% of respondent, virtual simulations (FRE3) were the least utilized tool (Mean = 2.03). A staggering 72.7% of respondents reported "never" or "rarely" using simulations.

Overall, the use frequency of digital tools was moderate.

Competence and Confidence in Use of Digital tools

Table 3 - Descriptive Statistics of Competence and Digital Confidence

Competence and Digital Confidence (COM Items)	Mean	Mode	S.D.	SD	D	N	A	SA
COM1 - I feel competent to effectively use digital tools in my learning.	3.35	4.00	1.17	2.3%	31.8%	11.4%	37.5%	17.0%

COM2 - I have a good mastery of Moodle or Google Classroom.	2.73	3.00	1.22	19.3 %	25.0%	27.3%	20.5 %	8.0%
COM3 - I know how to create or use digital resources (videos, quizzes, animations) to teach biology.	2.44	1.00	1.24	31.8 %	20.5%	22.7%	21.6 %	3.4%
COM4 - I can design a biology lesson integrating a virtual simulation.	2.49	2.00	1.21	26.1 %	28.4%	20.5%	20.5 %	4.5%
COM5 - I am confident in my ability to solve technical problems encountered when using digital tools.	2.52	1.00	1.26	27.3 %	25.0%	22.7%	18.2 %	6.8%
COM6 - I feel ready to teach using technopedagogical approaches.	3.13	4.00	1.29	12.5 %	23.9%	18.2%	29.5 %	15.9 %

(N.B. 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

Participants reported a moderate general digital confidence (COM1, Mean = 3.35). Half of the respondents (54.5%) agree or strongly agreed they felt competent to effectively use digital tools in their learning. However, self-efficacy dropped sharply when measuring the pedagogical application of these skills. Competence to design a lesson integrating a virtual simulation (COM4) was critically low (Mean = 2.49), as was the ability to create digital teaching resources (COM3}, Mean = 2.44), with only 25% of respondent competent.

Perceived Successes in Digital tool Integration

Table 4 - Descriptive Statistics of Competence and Digital Confidence

Perception of Successes (SUC Items)	Mean	Mode	S.D.	SD	D	N	A	SA
SUC1 - Digital tools promote autonomy in learning.	3.59	4.00	0.689	0%	11.4%	18.2%	70.5%	0%
SUC 2 - The use of digital technology has improved my results in biology.	3.18	4.00	0.941	8.0%	12.5%	33.0%	46.6%	0%
SUC 3 - Digital technology facilitates exchanges between teachers and students.	3.68	4.00	0.653	1.1%	6.8%	14.8%	77.3%	0%
SUC 4 - Digital tools allow for better evaluation of student learning.	3.13	4.00	1.00	8.0%	20.5%	22.7%	48.9%	0%

(N.B. 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

Majority of the respondents (70.5%) sees Students recognized autonomy (SUC1, Mean = 3.59) and teacher–student interaction (SUC3, Mean = 3.68) as key benefits of the use of digital tools. Less than half of the respondents thinks it improved results (SUC2) and enhance evaluation (SUC 4).

Limits and Resistance to Digital Tool

Table 5 - Descriptive Statistics of Competence and Digital Confidence

Perception of Limits and Resistance (LIM Items)	Mean	Mode	S.D.	SD	D	N	A	SA
LIM1 - Lack of Internet access is a major obstacle to the use of digital technology.	4.43	5.00	0.968	3.4%	4.5%	0%	29.5%	62.5%
LIM2 - Technological infrastructure at the ENS (Higher Teacher Training School) is insufficient for effective digital use.	4.07	5.00	1.10	3.4%	8.0%	12.5%	30.7%	45.5%
LIM3 - Some teachers resist the use of digital technology in their courses.	3.57	4.00	1.05	3.4%	13.6%	23.9%	40.9%	18.2%
LIM4 - Lack of technical training limits my ability to exploit digital tools.	4.22	4.00 ^a	0.89	1.1%	5.7%	6.8%	43.2%	43.2%
LIM5 - The use of digital technology increases my workload.	2.61	1.00	1.40	30.7%	19.3%	20.5%	17.0%	12.5%

(N.B. 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

The most significant constraints were perceived as systemic and infrastructural: Lack of Internet access (LIM1) had the highest mean score (4.43) according to 92% of respondent, closely followed by insufficient institutional infrastructure (LIM2, Mean = 4.07). The lack of technical training (LIM4, Mean = 4.22) was also cited as a major limitation by 86.4% of the respondents. Personal resistance (such as increased workload, LIM5) was the lowest mean (Mean=2.61), reinforcing the conclusion that external system failures are the primary inhibitors as expressed by 29.5% of respondents.

Descriptive Statistics Attitudes and Perspectives

Table 6 - Descriptive Statistics of Competence and Digital Confidence

General Attitudes and Perspectives (ATG Items)	Mean	Mode	S.D.	SD	D	N	A	SA
ATG1 - I consider the integration of digital technology to be essential for the training of	4.01	4	1.06	2.3%	12.5%	3.4%	45.5%	36.4%

biology teachers.								
ATG2 - I am willing to receive more training to improve my digital skills.	4.53	5	0.66	0%	2.3%	2.3%	35.2%	60.2%
ATG3 - I would recommend the use of digital technology to other future teachers.	4.56	5	0.79	1.1%	3.4%	1.1%	27.3%	67.0%

(N.B. 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

General attitudes were overwhelmingly positive: 81.9% agreed that digital integration is essential for training; 95.4% expressed willingness to pursue further digital skills training (ATG2).

Congruent amongst the Constructs

The following positive coherence was noticed amongst construct from their mean values or reliability:

- **Positive Mindset → Utility Perception** - a very high positive sentiment in ATG (e.g., 96% willingness for training ATG, Mean = 4.52) aligns with high means for OP (e.g., OP2 Mean=4.06). The pre-service teachers exhibit a positive Attitude or Mindset toward digital technology, which aligns perfectly with their high Perception of Usefulness. This is the fundamental premise of technology adoption models (e.g., TAM) as elaborated by Key (2024).
- **Usage → General Competence** - The moderate overall means for FRE (e.g., 3.39) align with moderate means for general COM (COM1 Mean=3.35). Higher frequency of general digital engagement (accessing materials, watching videos) leads to a moderate, expected level of general self-efficacy (Competence).
- **Usage → Perceived Success** - Moderate to high means for FRE align with high means for REU (e.g., REU3 Mean=3.68 for better exchanges). The moderate use of digital tools is perceived to yield tangible **Successes** in areas like communication and autonomy.

Incongruent amongst the Constructs

We noticed the following inconsistencies amongst certain items between constructs:

The Utility - Practice Gap was notice between OP2 (Mean=4.06) for simulations is diametrically opposed to FRE3 (Mean=2.03) for using simulations. This 2.03 point gap is the most significant incongruity. It demonstrates that positive attitudes toward a high-impact tool are overridden by external constraints, a finding that warrants a strong discussion on institutional policy and infrastructure deficits. Müller & Leyer, (2023), belief that to effectively bridge the perception-practice gap, ongoing professional development and supportive infrastructure must be prioritized, enabling preservice teachers to confidently integrate digital tools into their pedagogical practices.

The Competence - Application Gap was noticed as General COM1 (Mean=3.35) is significantly higher than Application COM4 (Mean=2.49). This represents an incongruity in the curriculum's effectiveness. Training provides general digital literacy but fails to foster technopedagogical content knowledge (TPACK) necessary for designing integrated lessons (Koh & Chai, 2014). These findings highlight the critical need for targeted interventions that not only enhance digital literacy but also focus on the practical application of TPACK in teacher training programs.

DISCUSSION

The SEM results reveal that the integration of digital tools in teacher training is primarily driven by teachers' perceived usefulness and digital competence rather than by their attitudes alone. The negative but weak path from attitudes to frequency of use suggests that favorable attitudes may not translate into consistent use without adequate skill and contextual support.

The strong predictive link between Frequency of Use and Perceived Success ($\beta = 0.75$) indicates that hands-on engagement with digital tools enhances the perceived effectiveness of teaching and learning. These findings align with technology acceptance theories emphasizing the role of perceived usefulness and self-efficacy in technology adoption.

Moderate correlations among competence, attitude, and opinion highlight a cluster of readiness factors that can be reinforced through teacher education programs. Building digital competence and promoting awareness of the usefulness of tools may therefore stimulate more frequent and meaningful integration of digital resources.

The Utility–Practice Gap (2.03) indicates that despite recognizing the pedagogical power of virtual simulations, preservice teachers rarely use them. This attitude–behaviour inconsistency underscores that external constraints—not motivation—are the main inhibitors.

The Competence–Application Gap (0.86) highlights that preservice teachers can use digital tools but struggle to integrate them pedagogically. This aligns with findings by Koehler et al. (2013) that TPACK competence requires active modelling and project-based learning.

The low Cronbach's α for the "Limits" scale (0.33) reflects diverse personal experiences—some students face infrastructural, others pedagogical, constraints—suggesting a multidimensional barrier structure.

These findings reaffirm that digital enthusiasm alone does not guarantee pedagogical integration. The results echo global literature emphasizing the importance of contextual support and targeted capacity building (Koehler & Mishra, 2009; Ertmer & Ottenbreit-Leftwich, 2010). In low-resource contexts like Cameroon, the challenge lies not in acceptance but in the enabling ecosystem: Internet reliability, access to hardware, and hands-on training.

Furthermore, the low LMS usefulness rating contrasts with international trends, suggesting that asynchronous platforms alone may not align with students' learning preferences in biology—an observation consistent with recent studies (Tondeur et al., 2022).

Perspectives and Recommendations

From the above results the following implication of this research could be considered to improve upon the integration of digital tools

- Teacher training institutions should focus on hands-on digital competence development rather than attitude modification alone.
- Institutional policies must enhance access, technical support, and ongoing mentoring to encourage actual use.
- Curriculum designers should integrate simulation-based and LMS-driven activities to make abstract biology concepts more tangible.
- Frequency of use can serve as a key indicator of success in evaluating digital integration outcomes.

CONCLUSION

The SEM demonstrates a well-fitting and conceptually coherent model of digital tool integration in teacher training. Competence and perceived usefulness were the primary drivers of digital tool use, which in turn predicted perceived success. The findings emphasize that practical, skill-based training and evidence of usefulness are essential for successful digital transformation in science teacher education.

Preservice biology teachers at ENS Yaoundé demonstrate strong motivation toward digital learning but face systemic, infrastructural, and curricular barriers that limit authentic digital practice.

Bridging the utility-practice and competence-application gaps requires coordinated institutional reforms that prioritize hands-on, constructivist, and contextually grounded technopedagogical training.

REFERENCES

1. Bon, A. (2010). Information and Communication Technologies in Tertiary Education in sub-Saharan Africa.
2. Dah, J., & Hussin, N. (2021). A Conceptual Framework of a Streamlined Extended Technology Acceptance Model for Mobile Application Adoption. *International Journal of Social Science Research*. <https://doi.org/10.5296/IJSSR.V9I2.18649>
3. Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education*, 42(3), 255–284.
4. Key, M. R. (2024). Acceptance of simulation technology and the influences for using simulation technology amongst teachers in higher education. *International Journal of Advanced Research*. <https://doi.org/10.21474/ijar01/18991>
5. Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60–70.
6. Koh, J. H. L., & Chai, C. S. (2014). Teacher clusters and their perceptions of technological pedagogical content knowledge (TPACK) development through ICT lesson design. *Computer Education*. <https://doi.org/10.1016/J.COMPEDU.2013.08.017>
7. Lai, J. W. M., & Bower, M. (2020). How is the use of technology in education evaluated? *Computers & Education*, 146, 103728.
8. Marzin-Janvier, P. (2015). Étayer la conception expérimentale par des environnements informatiques: études en génétique. 12, 87–112. <https://doi.org/10.4000/RDST.1135>
9. Mbah, M. F., & Ngwa, E. N. (2022). Challenges of ICT integration in higher education in Cameroon. *African Journal of Education and Information Technology*, 9(1), 45–62.
10. Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
11. Muftifah, K. N., Candramila, W., & Yuniarti, A. (2025). Teaching techniques inventory for explaining gene, DNA, and chromosome concepts in senior high school. *Pedagogical Research*, 10(3), em0241. <https://doi.org/10.29333/pr/16666>
12. Müller, W., & Leyer, M. (2023). Understanding intention and use of digital elements in higher education teaching. *Education and Information Technologies*. <https://doi.org/10.1007/s10639-023-11798-2>
13. Naatu, F., Selormey, F. S., & Naatu, S. (2024). Determinants of digital technology adoption in sub-Saharan Africa: Ghana. *International Journal of Emerging Markets*. <https://doi.org/10.1108/ijjem-09-2023-1503>
14. Sarabadani, J., Jafarzadeh, H., & ShamiZanjani, M. (2017). Towards Understanding the Determinants of Employees' E -Learning Adoption in Workplace: A Unified Theory of Acceptance and Use of Technology UTAUT View. *International Journal of Enterprise Information Systems*. <https://doi.org/10.4018/IJEIS.2017010103>
15. Teo, T. (2011). Factors influencing teachers' intention to use technology: Model development and test. *Computers & Education*, 57(4), 2432–2440.

16. Tondeur, J., Van Braak, J., Siddiq, F., & Scherer, R. (2022). Integrating digital technologies in education: Towards a research-informed framework for teacher professional development. *Computers in Human Behavior*, 128, 107126.
17. Torianyuk, V. M., & Mironets, L. P. (2024). Didactic possibilities of scientific and educational LabXchange online platforms for genetics learning in the pedagogical ZVO. *Faktori Eksperimental'noï Evolūcīi Organizmiv*, 34, 233–238. <https://doi.org/10.7124/feeo.v34.1646>
18. UNESCO. (2023). *Digital Learning for All: Policy Framework for Sub-Saharan Africa*. Paris: UNESCO.
19. Williams, M. D., Rana, N. P., Dwivedi, Y. K., & Lal, B. (2011). Is UTAUT really used or just cited for the sake of it? A systematic review of citations of UTAUT's originating article. *European Conference on Information Systems*.