ASEAN Journal for Science Education 5(2) (2026) 103-120

ASEAN Journal for Science Education

Journal homepage: https://ejournal.bumipublikasinusantara.id/index.php/ajsed

Biology Teachers' Perceptions and Observed Technological Pedagogical Content Knowledge (TPACK) for Teaching Genetics: Implications for Professional Development

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ABSTRACT

This study examined biology teachers' perceptions of their competence in integrating technology into genetics instruction and compared these perceptions with their observed classroom practices. The investigation aimed to determine teachers' self-evaluated technological, pedagogical, and content knowledge (TPACK) and how these beliefs aligned with their actual instructional behaviour. A total of 42 biology teachers from 18 secondary schools in southern Nigeria participated in the survey phase using a 35-item TPACK perception scale, while eight teachers were subsequently observed during genetics lessons. Findings revealed that 88% of the teachers reported a high perception of their TPACK competence. Male teachers demonstrated significantly higher self-ratings than female teachers, although perceptions did not differ by age, qualifications, or years of teaching experience. Classroom observations largely confirmed teachers' self-reported competencies, except in the areas of cooperative learning strategies and real-world applications of genetics. The study recommends confidence-building initiatives for female teachers and strengthened professional development programs to enhance technology-supported genetics instruction.

ARTICLE INFO

Article History:

Submitted/Received 22 Aug 2025
First Revised 25 Sep 2025
Accepted 29 Nov 2025
First Available online 30 Nov 2025
Publication Date 01 Sep 2026

Keyword:

Gender in TPACK,
Science teacher development,
Teacher education,
Technology integration,
TPACK.

1. INTRODUCTION

Self-evaluation of teaching practice is essential because it enables teachers to assess their performance, identify areas for improvement, and set meaningful goals for professional growth. Through reflective self-assessment, teachers can recognize past successes, address weaknesses, and strengthen their career trajectories. A valid self-evaluation also provides insight into curriculum delivery and pedagogical development, particularly in contemporary classrooms where teaching expectations continue to evolve. Teachers commonly rely on perception-based assessments to identify their strengths and determine areas needing reinforcement (Schmidt *et al*., 2009; Keller *et al*., 2005). Before the widespread adoption of technology in education, teacher quality was largely defined by content mastery and subject matter expertise (Ngugi & Thinguri, 2014). To improve content-specific instruction, researchers have long investigated how individuals learn and developed corresponding theories of human learning, which in turn produced pedagogical approaches required for effective curriculum delivery (Gurl & Karamete, 2015). Shulman introduced the pedagogical content knowledge (PCK) framework to integrate subject knowledge and pedagogy into a unified professional knowledge base suitable for teaching (Shulman, 1986). He emphasized that pedagogical expertise involves balancing, organizing, and presenting subject matter to accommodate learners' diverse interests, traits, and learning styles to enhance understanding (Shulman, 1986).

As technology permeated all aspects of human activity, including education and teacher development, it became increasingly important for teachers to learn how to select, understand, and apply appropriate digital tools alongside their pedagogical and content knowledge. This shift paved the way for a more integrated framework that validates technological pedagogical content knowledge. Mishra and Koehler conceptualized TPACK as a constructive framework that supports teachers in integrating technology into their instructional practice (Mishra & Koehler, 2006). TPACK is a discipline-focused model that unites technological, pedagogical, and content knowledge, although it can be adapted across diverse teaching contexts. Post-pandemic teaching practice further demonstrates that technology integration in daily instruction is no longer merely a response to crisis but a key indicator of effective teaching. Mishra and Koehler also explained that pedagogical content knowledge involves understanding factors that make certain topics easier or more difficult to learn and recognizing students' assumptions and expectations across age groups (Mishra & Koehler, 2006).

The alignment between teachers' beliefs and their classroom practices has been examined for decades. Although perception studies have limitations, they remain relevant because teachers' beliefs influence their instructional decisions (Guler & Celik, 2023). However, several studies found inconsistencies in the relationship between teachers' beliefs and classroom practices (Yang *et al*., 2020; Purnomo, 2017; Francis, 2015). Blömeke *et al*. (2020) therefore recommend studying teacher competency using a conceptual model grounded in observable classroom behaviours. The present study adopts this perspective to address gaps concerning the congruence between teachers' beliefs about their technological pedagogical content knowledge and their observed practice. Understanding teachers' TPACK competence also requires examining whether gender plays a role. Gender differences in TPACK have been understudied, particularly in technology integration (Jordan, 2013). Some studies reported no gender-related differences in technology use among preservice science teachers, while others found substantial disparities, especially among preservice biology teachers (Chio & Hong, 2022; Astuti et al., 2019). Jordan (2013) similarly observed that male teachers tend to rate themselves higher in most TPACK domains except pedagogical knowledge.

Mastering TPACK requires teachers to integrate technology seamlessly into their teaching. Inadequate content knowledge, poor pedagogical skill, limited ability to select appropriate instructional tools, or weak understanding of technology can hinder teachers' capacity to integrate ICT effectively in biology instruction, thereby weakening TPACK mastery. In Nigeria, in-service biology teachers have not been extensively evaluated for their TPACK competence in teaching genetics. Given recurring concerns from the West African Examinations Council (WAEC) about students' poor performance in genetics, such evaluation is timely and necessary. Previous studies consistently show that students perceive genetics as a difficult and abstract aspect of biology, contributing to widespread underachievement in the subject (Zeidan, 2010; Çimer, 2012).

2. LITERATURE REVIEW

2.1. Theoretical Framework

The concept of TPACK gained prominence after pedagogical content knowledge (PCK) to incorporate technological knowledge as an essential dimension of teacher competence (Mishra & Koehler, 2006; Shulman, 1986) (**Figure 1**). TPACK represents the interdependent situational knowledge required for integrating digital tools and resources effectively into curriculum-based instruction, making it a critical component of contemporary pedagogical practice (Harris *et al*., 2017). Shulman's work initiated broader discussions about the comprehensive knowledge base expected of 21st-century teachers, prompting further examinations of what constitutes essential instructional competence (Nelson, 1992; Fenstermacher, 1994).

Prior to introduction of PCK, several studies examined isolated constructs such as integration literacy, ICT-related PCK, technological content knowledge, and e-PCK as foundational for effective teaching. Efforts to support skill development in these areas highlighted the importance of combining content, pedagogy, and technology to enhance instructional quality (Hughes, 2013; McCrory, 2004; Margerum-Leys & Marx, 2002; Niess, 2005). As technology increasingly permeated education and other sectors, the assumption grew that teachers require robust technological competence to meaningfully connect and apply other forms of professional knowledge.

Mishra and Koehler identified seven knowledge domains arising from the interaction of pedagogical knowledge (PK), content knowledge (CK), and technological knowledge (TK), along with their intersections—PCK, TCK, TPK, and the fully integrated model known as TPACK (Mishra & Koehler, 2006). Recognizing variations in teaching environments and their impact on effective instructional design, Koehler and Mishra (2006) later added an eighth construct, Context, to account for the situational conditions that shape teaching practice. Koehler and Mishra (2006) subsequently clarified that contextual knowledge (XK) refers to teachers' understanding of the instructional setting and its influence on teaching decisions. The TPACK framework therefore consists of three core knowledge domains (TK, PK, CK), four interaction domains (TCK, PCK, TPK, TPACK), and a contextual domain that situates these elements within real teaching environments (Zhang & Tang, 2021).

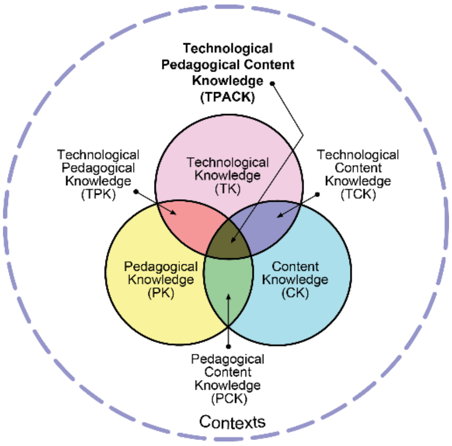

Figure 1. Technological Pedagogical Content Knowledge (TPACK) framework (adopted from http://tpack.org, published on 9 May 2011).

This spectrum enables teachers to integrate and align technology with instructional methods across different disciplines and contexts, thereby enhancing teaching effectiveness for diverse subject areas (Schmidt *et al*., 2009). TPACK is therefore central to effective instruction in all fields and should be continuously developed and evaluated as an indicator of high-quality teaching practice (Zhang & Tang, 2021).

A key factor in teacher preparation and competence development, particularly in science education, is the structured teaching and acquisition of TPACK. Although computer literacy and educational technology courses are commonly included in teacher education curricula, they are often taught as isolated skill-based programmes—emphasizing tools such as Microsoft Word, Excel, and PowerPoint—without linking them to subject-specific pedagogy or content (Angeli & Valanides, 2005). As a result, many teachers complete multiple training sessions without developing the ability to think creatively about integrating technology into domain-specific pedagogy. A further limitation is the relative absence of theoretical frameworks that support the contextual integration of technology, pedagogy, and content within actual classroom environments.

2.2. Science Teacher Education and TPACK

Technology use in science classrooms is fundamental to modern science education. Numerous studies have examined how TPACK-based models enhance the pedagogical performance of science teachers and promote technology-enriched instruction (Choi & Hong, 2022; Altuni & Akyildiz, 2017; Mishra & Koehler, 2006). Other study argued that science teacher education programmes must intentionally help teachers integrate knowledge from multiple domains to apply the TPACK framework meaningfully in classroom practice (Niess, 2005). They proposed a professional development model in which teachers use dynamic spreadsheets and other digital tools to scaffold learners' understanding of scientific and mathematical concepts. Such integration rests on:

(i) The teacher's beliefs and knowledge about technology use;
(ii) Understanding of technology-based science learning and its benefits;
(iii) Expertise in curriculum materials and digital resources used for teaching specific topics;
(iv) Knowledge of effective instructional strategies for achieving learning goals; and
(v) Proficiency in appropriate pedagogy.

Science teachers must continuously investigate, plan, practice, and reflect on their teaching experiences in order to transform their instructional thinking. Studying science teachers' TPACK competencies can therefore strengthen their instructional practices, enrich the knowledge base for technology-supported science teaching, and promote higher-order thinking and practical knowledge. Periodic diagnostic assessments, particularly those incorporating teachers' self-perceptions, are essential for supporting the remediation and further development of TPACK competence. The present study contributes to this diagnostic pathway by providing insights that may guide future improvements in teacher training programmes, especially in Nigeria and similar contexts.

Evidence from previous research indicates that teachers' pedagogical philosophy, motivation, readiness, personal beliefs, teaching experience, gender, and attitudes toward technology are significant predictors of TPACK competence (Ertmer, 2007; Varol, 2015; Sya'bandari et al., 2019). A survey in Nigeria further revealed that only 53% of preservice teachers in Lagos State possessed adequate technological skills for classroom instruction, highlighting a potential gap in teacher preparation (Adeoye & Ojo, 2014). Since the current study focuses on in-service teachers, it provides an opportunity to assess whether improvements have occurred among practising science teachers. Al-Fudail and Mellar emphasized that requiring teachers to use technology without adequate pedagogical preparation contributes to technostress, and reducing this stress can enhance TPACK competence (Al-Fudail & Mellar, 2008).

2.3. Teacher's Gender, Age, and Years of Teaching Experience and TPACK

Gender dynamics in science education have generated multiple research pathways. Several studies report that gender influences educational beliefs, self-efficacy, and attitudes, which collectively shape teachers' TPACK competence (Chio & Hong, 2022; Koh *et al*., 2010; Lin *et al*., 2013). Some evidence suggests that female teachers demonstrate greater participation in TPACK-related activities, while younger teachers tend to be more technologically inclined than older colleagues, particularly in the Turkish context (Altuni & Akyildiz, 2017). Other studies found that male preservice teachers rate themselves higher across most TPACK domains except pedagogical knowledge, prompting recommendations for confidence-building initiatives for female teachers (Jordan, 2013).

Findings are not always consistent, however. Moemeke and Mormah reported no gender differences in microblogging use among preservice science teachers, suggesting that technology-related behaviours may differ across contexts and may influence future classroom practice. The influence of age and teaching experience on in-service teachers' technology integration also remains inconclusive and warrants further investigation, making these variables relevant to the present study.

3. METHODS

This study employed a two-phase design consisting of a self-assessment survey and classroom observations. The first phase examined biology teachers' perceptions of their technological pedagogical content knowledge (TPACK) for teaching genetics. The second phase observed selected teachers' instructional practices to determine the extent to which their self-reported competencies aligned with their actual classroom performance. Together, these two phases enabled a comprehensive comparison between teachers' beliefs and behaviours.

The study was guided by the following questions:

(i) What are biology teachers' perceptions of their TPACK for teaching genetics, and are these perceptions consistent with observed classroom practice?

(ii) What are teachers' perceptions of their content knowledge (CK) of genetics, and are these perceptions congruent with observed practice?
(iii) What are teachers' perceptions of their technological knowledge (TK) for teaching genetics, and are these perceptions consistent with observed practice?
(iv) What are teachers' perceptions of their pedagogical knowledge (PK) for teaching genetics, and are these perceptions consistent with observed practice?
(v) Do teachers' perceptions of TPACK differ by gender?
(vi) Do teachers' perceptions of TPACK differ by years of teaching experience?
(vii) Do teachers' perceptions of TPACK differ by qualification?
(viii) Do teachers' perceptions of TPACK differ by age?

The following hypotheses were tested:

(i) There is no significant difference in teachers' perceptions of TPACK based on gender.
(ii) There is no significant difference in teachers' perceptions of TPACK based on years of teaching experience.
(iii) Teachers' perceptions of TPACK do not differ based on age.

3.1. Phase One: Self-Assessment of TPACK Competence

The first phase used a survey design to assess biology teachers' perceptions of their TPACK for teaching genetics. The study was conducted in the South–South geopolitical zone of Nigeria, which comprises six states: Akwa Ibom, Bayelsa, Cross River, Edo, Delta, and Rivers. Two states were selected through simple random sampling. From each selected state, three local government areas (LGAs) were chosen using stratified random sampling, resulting in six LGAs.

Within each LGA, three senior secondary schools offering Biology were randomly selected, yielding a total of 18 schools. All biology teachers (N = 42) in these schools participated in the survey.

The data collection instrument was the Biology Teachers' Perception of their Technological Pedagogical Content Knowledge for Genetics (BTP-TPACK). The instrument consisted of two sections:

(i) Part I collected demographic information.
(ii) Part II assessed the three core components of TPACK (CK, PK, and TK) using 35 items across three subscales.

Face and content validity were established by two experienced biology teachers and a measurement and evaluation expert. Items were refined based on their feedback, and the final version achieved a reliability coefficient of 0.72 (Cronbach's alpha). Permission to administer the instrument was obtained from school principals, and questionnaires were distributed and retrieved through designated contact persons.

3.1. Phase Two: Classroom Observation of Genetics Lessons

The second phase examined whether teachers' self-assessed TPACK aligned with their instructional practice. All teachers who completed the survey were grouped by gender, and four teachers from each group (two males and two females per state) were randomly selected, producing a sample of eight teachers for observation.

Two independent observers (biology teacher educators from a Nigerian university) were trained on the study objectives, ethical procedures, and use of the observation protocol. The observation schedule included six components:

(i) Teacher biodata, including age, gender, qualification, and teaching experience.

(ii) Pre-observation interview, with five items rated on a three-point scale (Yes, Moderately, No).
(iii) Lesson context, assessing the learning environment and availability of resources.
(iv) Technology integration, evaluating the use of digital tools during genetics instruction.
(v) Pedagogical strategies, assessing instructional approaches and student engagement.
(vi) Content knowledge, evaluating accuracy and clarity of genetics concepts taught.

The observers completed the schedule electronically after each lesson. Observations were carried out over a three-week period during regular genetics instruction in participating schools.

4. RESULTS AND DISCUSSION

4.1. First Study

Descriptive statistics (means, standard deviations, and percentages) were used to address the research questions. A t-test was employed to examine differences based on gender (Hypothesis 1), while one-way Analysis of Variance (ANOVA) was used to test differences based on teaching experience and age (Hypotheses 2 and 3). **Table 1** presents the descriptive analysis of teachers' TPACK perceptions across gender, teaching experience, age, and qualification.

Table 1. Descriptive analysis of biology teachers' perception of tpack by variables.

Category	Sub-category	N %	Mean (Ẍ)	SD	Std. Error
Gender	Female	3481.0	78.97	6.86	1.17
	Male	8 19.0	85.37	7.55	2.67
Years of Experience	0–5 years	2354.8	81.47	6.47	1.34
	6–10 years	1023.8	80.20	10.36	3.27
	11–20 years	8 19.0	76.62	5.23	1.85
	21–30 years	1 2.4	—	—	—
Age of Teacher	20–25 years	2252.4	80.40	6.75	1.44
	26–30 years	2 4.8	75.50	13.43	9.50
	31–40 years	1126.2	80.72	9.43	2.84
	41–60 years	7 16.7	80.00	4.89	1.85
Qualification	B.Sc (Ed)	4095.2	80.05	7.46	1.18
	M.Ed/M.Sc (Ed)	2 4.8	83.00	5.65	4.00

As shown in **Table 1**, a total of 42 biology teachers participated in the first phase of the study. The sample consisted predominantly of female teachers (81%), while males accounted for 19% of the participants. Most teachers (54.8%) had relatively limited teaching experience, ranging from 0–5 years, and an additional 23.8% had between 6–10 years of experience. Only 19% had taught for 11–20 years, and one teacher (2.4%) had over 20 years of experience.

In terms of academic qualifications, the majority of teachers (95.2%) held a Bachelor's degree in Biology Education, whereas 4.8% possessed a Master's degree. The age distribution shows that over half of the teachers (52.4%) were between 20–25 years old, indicating a young teaching workforce. The remaining participants were aged 26–30 (4.8%), 31–40 (26.2%), and 41–60 (16.7%), respectively.

Overall, the descriptive results indicate that the sample was composed mainly of young, early-career, and predominantly female biology teachers who possess the appropriate qualifications for teaching the subject.

4.1.1. Perception of biology teachers on their ck, pk, and tk for teaching genetics (revised)

To address Research Questions 1–4, the items measuring content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) were analyzed using descriptive statistics. **Table 2** presents the distribution of teachers' responses across the CK, PK, and TK items, while **Table 3** summarizes the aggregated mean scores for each TPACK component.

Table 2. Perception of biology teachers on their ck, pk, and tk for teaching genetics.

Item	SD (%)	D (%)	A (%)	SA (%)
Content Knowledge (CK)				
1. Good understanding of genetics concepts	0	14.3	54.8	31.0
2. Subject matter is simplistic/shallow	33.3	38.1	26.2	2.4
3. Teachers have obsolete genetics knowledge	21.4	33.3	42.9	2.4
4. Teachers do not study adequately before class	21.4	26.2	42.9	9.5
5. Genetics is too difficult to understand	47.6	40.5	11.9	0
6. Prefer other biology topics over genetics	28.6	38.1	28.6	4.8
7. Intrigued by practical evidence in genetics	14.3	7.1	52.4	26.2
8. Genetics is the favourite biology topic	0	33.3	28.6	38.1
9. Find genetics concepts difficult	38.1	54.8	7.1	0
10. Poor genetics understanding began in preservice years	42.9	23.8	26.2	7.1
Pedagogical Knowledge (PK)				
1. Teaching genetics poses no problem	4.8	2.4	59.5	33.3
2. Use the same methods as other biology topics	19.0	52.4	28.6	0
3. Genetics is too abstract	26.2	28.6	45.2	0
4. Often skip teaching genetics	26.2	69.0	2.4	2.4
5. Students still struggle regardless of the explanation	21.4	35.7	40.5	2.4
6. Hate genetics diagrams	38.1	47.6	9.5	4.8
7. Wish for alternative strategies	16.7	33.3	45.2	4.8
8. Do not know how to activate student participation	21.4	47.6	19.0	11.9
9. Enjoy teaching genetics due to practical relevance	0	4.8	50.0	45.2
10. Encourage students to construct knowledge	0	0	52.4	47.6
Technological Knowledge (TK)				
1. Tech tools improve genetics teaching	2.4	2.4	35.7	59.5
2. Students enjoy tech-supported lessons	2.4	2.4	40.5	54.8
3. Never involve students in internet searches	35.7	40.5	19.0	4.8
4. Not good with computers	33.3	35.7	31.0	0
5. Technology unnecessary for genetics	38.1	35.7	23.8	2.4
6. Internet lacks relevant content	50.0	50.0	0	0
7. Innovation is time-consuming	33.3	16.7	50.0	0
8. Teaching methods do not require technology	40.5	45.2	11.9	2.4
9. Students engage in online exercises	0	45.3	40.5	14.3
10. Do not own laptop or smartphone	52.4	31.0	16.7	0
11. Never shared online links	19.0	50.0	23.8	7.1
12. Do not know any OER sites	28.6	47.6	21.4	2.4
13. Avoid virtual platforms	19.0	54.8	26.2	0
14. Social media not ideal for biology teaching	31.0	59.5	9.5	0
15. Internet not good for students	52.4	35.7	9.5	0

As shown in **Table 2**, teachers reported generally positive perceptions across the three knowledge domains. High agreement rates were observed for items indicating enthusiasm for teaching genetics, recognition of its practical relevance, and confidence in explaining concepts. However, several negative trends emerged, particularly concerning technological integration. Many teachers acknowledged limited computer skills, unfamiliarity with online resources, and infrequent use of digital tools during instruction.

Table 3. Summary of mean scores for CK, PK, TK, and overall TPACK.

Component	N	Sum	Mean (Ẍ)	Std. Error	SD
Content Knowledge (CK)	42	973.00	23.17	0.49	3.21
Pedagogical Knowledge (PK)	42	1042.00	24.81	0.56	3.60
Technological Knowledge (TK)	42	1353.00	32.21	0.64	4.16
Overall TPACK	42	3368.00	80.19	1.14	7.33

To provide a clearer overview, **Table 3** summarizes the aggregated mean scores for CK, PK, TK, and overall TPACK. Biology teachers demonstrated strong perceptions of their content knowledge (M = 23.17, SD = 3.21), pedagogical knowledge (M = 24.81, SD = 3.60), and technological knowledge (M = 32.21, SD = 4.16). Their overall TPACK score was relatively high (M = 80.19, SD = 7.33), indicating perceived readiness to integrate technology into genetics instruction.

Consistent with findings presented earlier in **Table 1**, male teachers continued to exhibit higher mean TPACK scores (M = 85.37, SD = 7.55) compared to female teachers (M = 78.97, SD = 6.86), suggesting notable gender-related differences in self-assessed competence.

Following the descriptive summaries in **Tables 2** and **3**, the distribution of TPACK scores across specific demographic variables was further examined using graphical representations. Four graphical representations were used to visualize patterns in teachers' TPACK scores across demographic variables. **Figure 2** shows the distribution of TPACK scores across teacher age groups, **Figure 3** illustrates TPACK differences by years of teaching experience, **Figure 4** presents TPACK distribution by gender, and **Figure 5** shows TPACK differences by qualification.

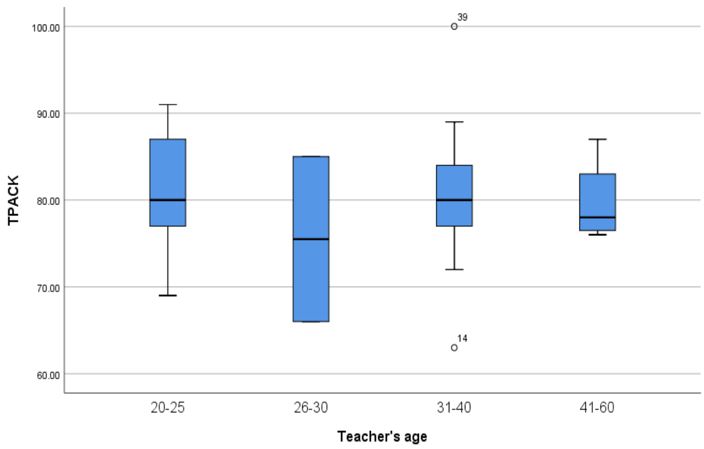

Figure 2. Box plot of TPACK scores by teacher age.

As shown in **Figure 2**, TPACK scores are relatively similar across the different age categories. Younger teachers (20–25 years) exhibit slightly higher median scores compared to teachers aged 26–30 years, but the differences are minimal across the groups. The distribution reflects narrow interquartile ranges across all age brackets, indicating consistent self-perception of TPACK competence regardless of age. This pattern corresponds with the ANOVA results, which show no statistically significant difference in TPACK based on teacher age.

These visualizations help clarify patterns observed in the descriptive statistics.

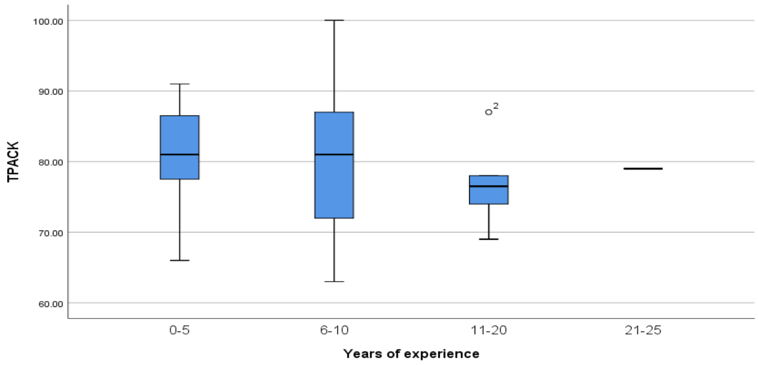

Figure 3. Box plot of TPACK scores by years of teaching experience.

As displayed in **Figure 3**, TPACK scores show relatively small variation across teaching experience groups. Teachers with 0-5 years of experience recorded slightly higher median TPACK scores compared to those with more than 10 years of teaching experience. This supports the ANOVA results later presented, which indicate no statistically significant difference in TPACK based on teaching experience.

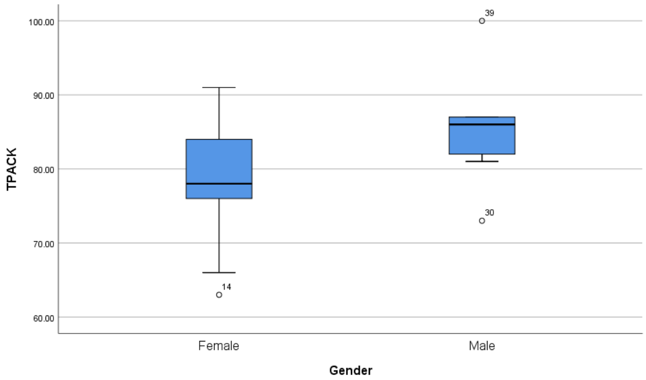

Figure 4. Box plot of TPACK scores by gender.

Figure 4 clearly shows higher median and upper-quartile TPACK scores among male teachers compared to female teachers. This visual pattern aligns with the results in **Table 1** and the t-test findings, confirming that gender differences in TPACK perception are statistically significant.

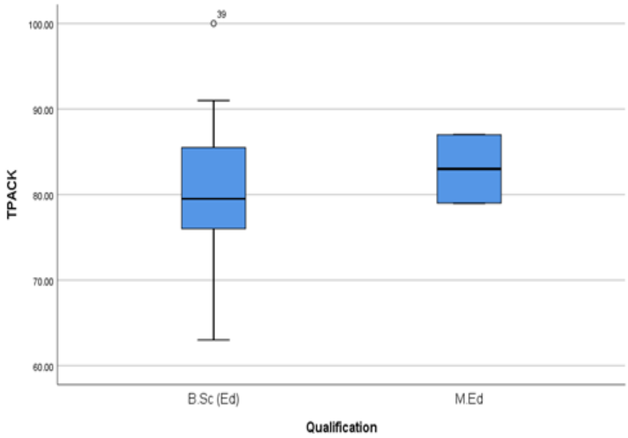

Figure 5. Box plot of TPACK scores by teacher qualification.

As shown in **Figure 5**, teachers with a Master's degree exhibited slightly higher TPACK scores than those with a Bachelor's degree. However, due to the small number of postgraduate participants (N = 2), this difference should be interpreted cautiously and is not statistically meaningful. This aligns with the conclusion that qualification does not significantly influence TPACK perception.

4.1.2. Significance of the difference in biology teachers' perception of tpack by gender

To determine whether gender influences teachers' perception of their TPACK for teaching genetics, an independent samples t-test was conducted. **Table 4** presents the results of the t-test, while **Figure 4** about TPACK by Gender illustrates the distribution pattern graphically.

The results revealed a statistically significant difference between female teachers (M = 78.97, SD = 6.87) and male teachers (M = 85.35, SD = 7.56), t(40) = 2.33, p = 0.025. Because the p-value is less than the .05 significance level, Null Hypothesis 1 is rejected. This indicates that biology teachers' perceptions of their TPACK differ significantly based on gender. The higher mean score among male teachers further reflects their stronger self-assessment of competence in integrating technology for teaching genetics.

Table 4. Independent samples t-test of biology teachers' TPACK scores by gender.

Group	N	Mean	SD	df	t	Sig. (2-tailed)	Std. Error
Female	34	78.97	6.87	40	2.330	0.025*	1.78
Male	8	85.35	7.56	—	—	—	2.67

*Significant at p < 0.05

4.1.3. Biology teachers' perception of TPACK by years of experience and age (revised)

One-way ANOVA was conducted to evaluate whether teachers' perceptions of their TPACK differ significantly based on (a) years of teaching experience and (b) chronological age. **Table 5** summarizes the ANOVA results, while the distribution patterns are displayed in **Figure 3** about Years of Experience and **Figure 2** about Age Groups.

The ANOVA results indicate that the effect of teaching experience on TPACK perception was not statistically significant, F(3, 38) = 0.86, p = 0.470. Although teachers with fewer years of experience (0–5 years) reported slightly higher TPACK perceptions (M = 81.47) than those with longer experience (6–10 years: M = 80.20; 11–20 years: M = 76.62), these differences were too small to reach statistical significance. Therefore, Null Hypothesis 2 is retained.

Similarly, teachers' age did not significantly affect their TPACK perceptions, F(3, 38) = 0.28, p = 0.838. TPACK scores were relatively consistent across age groups, supporting the finding that age does not independently predict self-perception of technological pedagogical competence. Thus, Null Hypothesis 3 is retained.

Table 5. ANOVA results for teachers' TPACK by teaching experience and age.

Source	Sum of Squares	df	Mean Square	F	Sig.
Years of Teaching Experience					
Between Groups	141.262	3	47.087	0.86	.470
Within Groups	2081.214	38	54.769	—	—
Total	2222.476	41	—	—	—
Age of Teacher					
Between Groups	48.476	3	16.159	0.28	.838
Within Groups	2174.000	38	57.211	—	—
Total	2222.476	41	—	—	—

4.2. Second Study: Classroom Observation (Revised and Improved)

To complement the self-assessment data, classroom observations were conducted to determine the extent to which teachers' perceived TPACK competence aligned with their actual instructional practices. **Tables 6** and **7** summarizes the descriptive results of the observation schedule.

Table 6. Summary of teacher characteristics.

Variable	Category	Frequency (F)	%
Gender	Male	4	50
	Female	4	50
Years of Experience	0–5 years	2	25
	6–10 years	4	50
	11–15 years	0	0
	16–20 years	1	12.5
	21–25 years	0	0
	26–30 years	1	12.5
Age	20–25 years	2	25
	26–30 years	3	37.5
	31–35 years	1	12.5
	36–40 years	1	12.5
	41–45 years	0	0
	46–50 years	1	12.5
Qualification	B.Sc (Ed)	6	75
	M.Ed / M.Sc (Ed)	2	25
	NCE / ND	0	0

Table 7. Summary of classroom observation results.

Item	Response	F	%
Pre-Observation Interview			
Coverage of teacher background and TPACK views	Yes	5	62.5
	Moderately	3	37.5
Expression of challenges in TPACK	Yes	2	25
	Moderately	4	50
	No	2	25
Enthusiasm for technology use	Yes	4	50
	Moderately	3	37.5
	No	1	12.5
Evidence of prior TPACK professional development	Yes	7	87.5
	Moderately	1	12.5
	No	0	0
Lessons Context			
Classroom setup observed	Yes	2	25
	Moderately	5	62.5
	No	1	12.5
Presence of technological resources	Yes	4	50
	Moderately	3	37.5
	No	1	12.5
Visual aids linking technology and genetics	Yes	5	62.5
	Sparsely	2	25
	Not at all	1	12.5

Table 7 (continue). Summary of classroom observation results.

Item	Response	F	%
Lessons Context			
Classroom conducive to collaboration	Yes	3	37.5
	Fairly	5	62.5
Use of technology to improve the learning environment	Yes	5	62.5
	Fairly	1	12.5
	No	2	25
Technology Integration			
Integration of technology tools	Yes	3	37.5
	Moderately	2	25
	No	3	37.5
Proficiency in using technology	Very well	3	37.5
	A little	3	37.5
	Not at all	2	25
Use of multimedia/simulations	Very well	2	25
	A little	4	50
	Not at all	2	25
Confidence using technology	Yes	6	75
	None	2	25
Technical challenges present	Yes	3	37.5
	No	5	62.5
Pedagogical Strategies			
Variety of instructional strategies	Yes	7	87.5
	No	1	12.5
Effective questioning	Very well	5	62.5
	Sparsely	3	37.5
Cooperative learning	Very well	1	12.5
	A little	4	50
	Not at all	3	37.5
Hands-on activities	Yes	6	75
	Not at all	2	25
Differentiated instruction	Yes	2	25
	Sparsely	6	75
Content Knowledge Demonstration			
Understanding of key genetic concepts	Very well	5	62.5
	Moderately	3	37.5
Clarity in explaining complex ideas	Reasonably	7	87.5
	Not at all	1	12.5
Struggling with genetics content	Many times	1	12.5
	A few times	5	62.5
	Not at all	2	25
Connecting concepts to real-world examples	Many times	1	12.5
	A few times	6	75
	Not at all	1	12.5
Providing additional resources	Yes	5	62.5
	No	3	37.5

As shown in **Table 6**, the eight observed teachers were evenly split by gender, and most (50%) had between 6 and 10 years of teaching experience. A majority (75%) held a Bachelor's degree in Biology Education, while 25% possessed a Master's degree. Teachers were predominantly young adults, with 37.5% aged 26-30 years.

Pre-observation interviews indicated high enthusiasm toward teaching (87.5% showing strong insight into technology-related pedagogy), although 75% acknowledged challenges related to TPACK integration.

Lesson context observations showed that most classrooms were fairly well organized and moderately equipped with technological resources. However, only 25% had a fully conducive physical setup for tech-supported genetics teaching.

Technology integration emerged as a notable weakness: 37.5% of teachers did not integrate technology at all, and half used multimedia resources only minimally. Technical challenges were reported in 37.5% of lessons.

In terms of pedagogical strategies, teachers performed better. Most used varied instructional strategies (87.5%) and effective questioning (62.5%), although cooperative learning was limited, and hands-on activities were used by only 25% of teachers.

Regarding content knowledge, 62.5% demonstrated a strong understanding of genetics, and 87.5% explained complex ideas effectively. However, 62.5% struggled occasionally with specific concepts, and 75% provided few real-world applications, revealing a gap between conceptual understanding and applied pedagogy.

4.3. Discussion

The findings of this study indicate that biology teachers exhibited a high perception of their content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) for teaching genetics. This high level of self-perceived competence was largely consistent with the classroom observations conducted in the second study, suggesting a strong alignment between teachers' beliefs and their actual instructional practices. The congruence observed across most domains supports earlier research showing that teachers' beliefs can be valid predictors of their classroom behaviours (Guler & Celik, 2023; Siswono *et al*., 2019). However, notable discrepancies emerged in two specific areas: the use of cooperative learning strategies and the ability to link genetics concepts to real-world applications. These gaps align with literature demonstrating inconsistencies between teacher beliefs and pedagogical enactment in certain instructional domains (Yang *et al*., 2020; Purnomo, 2017; Francis, 2015).

Gender-based differences in TPACK perception were pronounced in this study, with male teachers reporting significantly higher confidence levels than females. This finding corroborates previous results indicating higher technology-related self-efficacy among male science teachers (Jordan, 2013; Lin *et al*., 2013; Koh *et al*., 2010). The inconsistency with studies that report higher female engagement in TPACK-related activities among preservice teachers (Altuni & Akyildiz, 2017) may be due to differences in context, cultural expectations, and the professional status of the participants.

The results also show that neither age nor teaching experience significantly influenced teachers' perceptions of TPACK. This contradicts studies suggesting that younger teachers tend to have stronger technology integration confidence compared to their older colleagues (Altuni & Akyildiz, 2017). The observation results further revealed no systematic performance differences across age groups, despite expectations that younger teachers—often regarded as digital natives—might demonstrate superior technology use. These findings suggest that technology acceptance and integration may now be gradually normalizing across generations of teachers as digital tools become more embedded in educational practice. It may also indicate the important distinction between possessing technological knowledge and effectively integrating it into domain-specific instructional practice, warranting further investigation.

Compared with earlier reports in Nigeria showing limited technological competence among teachers (Adeoye & Ojo, 2014), the improved perceptions and observed practices documented in this study may reflect recent curriculum reforms and ongoing teacher training initiatives. The consistent TPACK scores across age and experience groups reinforce the notion that TPACK is not inherently age-dependent. Instead, differences in integration may reflect individual teachers' skills, training exposure, and personal attitudes toward technology use.

Overall, the alignment between self-perception and observable behaviours in this study reinforces the usefulness of perception-based assessments as indicators of teacher competence, particularly when complemented with classroom observations (Guler & Celik, 2023).

5. CONCLUSION

This study concludes that biology teachers possess a high level of TPACK for teaching genetics, with male teachers demonstrating significantly higher confidence in technology integration than their female counterparts. Despite the dominance of females in the biology teaching workforce, male teachers exhibited stronger perceptions of technological and content-related competencies. Professional development efforts may therefore need to place greater emphasis on confidence-building and technology-focused training for female teachers. The results also show that age, qualification, and years of experience do not significantly influence teachers' TPACK perceptions, suggesting that TPACK integration is more closely linked to individual disposition and exposure than to demographic variables. Overall, TPACK appears to be a deliberate and reflective teaching decision rather than one determined by credentials or length of service.

The findings underscore the need to position TPACK as an essential competency for effective genetics instruction, particularly because genetics is widely regarded as a difficult topic among students. Regular assessment of teachers' TPACK should be institutionalized as part of ongoing professional development to ensure sustained competence in modern science classrooms. Policymakers should strengthen existing structures for continuous teacher training, ensuring alignment with evolving technological demands and the instructional needs of the contemporary science learner. In addition, investment in the development, upgrading, and maintenance of technological infrastructure within schools is crucial for enhancing teachers' capacity to implement technology-rich lessons and for fostering greater compliance with TPACK-based instructional expectations.

This study was conducted with strict adherence to ethical research standards. Participation involved in-service biology teachers who voluntarily provided informed responses without coercion. Permission to involve the teachers was formally obtained from the Ministry of Education in the participating states. The study aimed to gain deeper insights into teachers' TPACK competence for teaching genetics, with the intention of informing future instructional and professional development initiatives in Southern Nigeria. The authors assume full responsibility for any scholarly criticism or interpretations that may arise from the publication of this work.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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