MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2026, 22(9), em2900
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/19124

Game-based learning with Kahoot: Effects on grade 12 learners' anxiety, engagement, and academic performance in genetics

Nokuzola Dumile [1], Sakyiwaa Boateng [2*]

[1] Department of Continuous Professional Teacher Development, iYunivesithi Walter Sisulu, Mthatha, SOUTH AFRICA
[2] Department of Mathematics, Science and Technology Education, iYunivesithi Walter Sisulu, Mthatha, SOUTH AFRICA

Received 28 March 2026 ▪ Accepted 03 July 2026

Abstract

This study investigated the impact of Kahoot game-based learning on grade 12 life sciences learners' anxiety, engagement, and academic performance in genetics in selected schools in the Oliver Reginald Tambo Coastal District. Framed within the self-determination theory, the constructivist learning theory, and the control-value theory, the study employed an explanatory sequential mixed-methods design. The study combined a quantitative pre-/post-test ($n = 200$ learners across 4 schools) with qualitative inquiry. Instruments included interviews, classroom observation, the science anxiety scale (SAS), and the test on genetics (TOG) questionnaires. Quantitative results showed a statistically significant improvement in TOG achievement (pre mean [M] = 34.02, standard deviation [SD] = 11.02; post M = 64.54, SD = 20.89; paired $t(199) = -18.24$, $p < 0.001$; $dz = 1.29$), while overall science anxiety (SA) totals remained essentially stable (pre M = 29.45, SD = 3.19; post M = 29.71, SD = 2.10; $p = 0.319$). Qualitative findings showed that learners and teachers reported reduced anxiety during Kahoot activities, improved engagement, and clearer identification and correction of misconceptions when Kahoot responses were followed by teacher explanation. Although the SAS score shows no significant difference in SA, observation indicates otherwise. These findings indicate that Kahoot can substantially enhance genetics learning when embedded within reflective, teacher-mediated formative cycles and when infrastructural and facilitation challenges are managed. The study concludes with recommendations for inclusive facilitation, structured strategies, and further research that distinguishes between situational and SA and examines the longer-term retention of science concepts.

Keywords: Kahoot, learner anxiety, engagement, learning outcomes, genetics

INTRODUCTION

In South Africa, the curriculum and assessment policy statement (CAPS) for life sciences structures the subject around four knowledge strands: life at the molecular, cellular, and tissue levels; life processes in plants and animals; environmental studies; and diversity, change, and continuity (South African Department of Basic Education [DBE], 2011). These strands provide an integrated framework for understanding biological phenomena. Within this structure, genetics is embedded within diversity, change and continuity, and is a central topic because it focuses on inheritance, variation, and biotechnological applications. Genetics also carries substantial assessment weight, accounting for approximately 32% of the grade 12 life sciences paper 2 examination, making it a high-stakes component requiring sustained conceptual understanding and repeated practice.

However, the DBE (2021, 2022, 2023, 2024) diagnostic reports consistently identify genetics as a major concern among high school learners. The reports highlight recurring learner difficulties in content such as blood grouping, dihybrid crosses, and Mendelian inheritance. They also identify recurring misconceptions in the interpretation of genetic diagrams and the application of probability in genetic crosses. These difficulties are evident in the Oliver Reginald Tambo Coastal District

✉ 208140360@mywsu.ac.za ✉ sboateng@wsu.ac.za **(*Correspondence)**

Contribution to the literature

- This study advances the literature by demonstrating how Kahoot-mediated game-based learning reduces learner science anxiety (SA) in genetics, highlighting the importance of the affective dimension in STEM education and extending the application of motivational and emotional learning theories within rural school classroom contexts.
- This study also provides a holistic contribution by integrating learner engagement, conceptual understanding, and academic performance within a single intervention framework, offering nuanced evidence of how interactive digital tools can enhance both cognitive outcomes and meaningful learning in genetics.
- Lastly, the study contributes contextually grounded insights into the implementation of game-based learning, informing inclusive pedagogical practices and technology integration in similar underserved educational settings.

schools, where genetics performance and genetic engineering contribute to persistent underperformance in the final high school matriculation examination results (DBE, 2021, 2022, 2023, 2024). Evidence from the 2024 paper 2 sub-question analysis indicates that genetics remains a major challenge for learners to comprehend. While most sections in the examination paper achieved average scores between 40% and 70%, genetics recorded a low mean (M) performance of 19%, signaling persistent challenges with abstract and applied genetics content (DBE, 2025).

We situated our study within this body of literature that recognizes genetics as one of the most conceptually demanding areas in school biology. Across both global and South African contexts, learners encounter significant challenges due to the abstract nature of genetics, which requires the simultaneous coordination of symbolic notation, diagrams, probabilistic reasoning, and multiple representations (Duncan & Tseng, 2011; Hawes & Arya, 2023). These cognitive demands are often compounded by persistent misconceptions about genetics, which are not easily resolved through traditional instruction (Smith & Knight, 2012; Wang & Tahir, 2020).

In the South African schooling context, these challenges are further intensified by systemic constraints, including large class sizes, linguistic diversity, and limited access to resources. Consequently, learners frequently adopt procedural or memorization-based approaches rather than developing deep conceptual understanding (Ramnarain & Schuster, 2014). Teachers also report difficulties in teaching genetics effectively (Biyela & Ramaila, 2021; Silumesi, 2022). This often results in assessment-driven teaching practices that prioritize examination preparation over meaningful engagement, leaving misconceptions insufficiently addressed.

Nonetheless, the traditional pedagogical practices remain common in many classrooms, particularly teacher-centered approaches that rely on textbook instruction, lectures, and rote memorization. Research suggests that such approaches may reduce learner participation and limit opportunities for conceptual understanding (Tekkaya, 2002). These approaches have also been associated with reduced motivation and increased anxiety in the subject (Boateng & Kumi-Manu, 2026).

In contrast, educational technologies have been used to support interactive, inquiry-based learning experiences in science education. Kahoot has become particularly prominent because it enables real-time questioning, immediate feedback, and active participation through gamified assessment. Studies indicate that Kahoot can support engagement and reduce test-related anxiety when implemented as part of a supportive pedagogical and formative assessment approach (Cadet, 2023; Elkhamisy & Wassef, 2021). Recent evidence further suggests that Kahoot can strengthen learning by providing continuous feedback and promoting repeated retrieval practice (Ramaila, 2024).

Internationally, several studies have examined the effects of Kahoot on learner motivation, engagement, and achievement in science disciplines. In Turkey, Öden et al. (2021) investigated the use of Kahoot as a gamification tool in EFL vocational education classrooms, focusing on its effects on students' attitudes, motivation, and anxiety levels. Using a quasi-experimental design, the study found that students exposed to Kahoot-supported instruction demonstrated significantly more positive attitudes and higher motivation, alongside reduced learning anxiety, compared to those taught through traditional methods. The findings imply that student-centered, technology-enhanced pedagogies can improve engagement and reduce affective barriers to learning. A similar study investigated the use of Kahoot as a digital game-based learning tool to enhance student engagement and participation in pre-university biology classrooms in Malaysia (Asniza et al., 2021). The study found that Kahoot promoted active participation, increased learner motivation, and fostered positive classroom interaction by creating an interactive and enjoyable learning environment. However, international studies caution that Kahoot's design features may produce unintended effects. Wang (2015) notes that strict time limits may increase anxiety for some learners, while Plump and LaRosa (2017) highlight that technical disruptions can compromise lesson flow.

Across the African continent, Nabangi (2021) investigated the use of Kahoot as a digital game-based learning tool in Kenyan secondary school classrooms and found an increased learner participation and immediate feedback, while also reducing learner anxiety during lessons and assessments. Although international literature highlights Kahoot's potential, there remains a notable gap in subject and topic-specific research, where learners must engage with abstract reasoning, diagram interpretation, and probability, thus underscoring the need for studies that examine its impact on anxiety and engagement within life sciences contexts, especially given the limited continental evidence beyond language and general science domains.

In South Africa, the DBE's (2004) white paper on e-education articulated a national vision for integrating technology into teaching and learning to improve quality and equity. Despite investments in technology infrastructure, classroom utilization remains inconsistent, particularly in rural contexts where access and readiness vary (Mashile, 2017). Nevertheless, emerging South African studies indicate that gamified tools, such as Kahoot, may support learner engagement and achievement (Mdlalose et al., 2022; Ramaila, 2024). Mdlalose et al. (2022) reported that Kahoot improved academic performance, motivation, and engagement in science teacher education contexts. Mbete (2022) reported similar benefits in mathematics education, including increased enjoyment, participation, and immediate feedback in probability teaching. While these studies support the value of Kahoot, there remains limited empirical evidence on its effectiveness in grade 12 life sciences genetics, and no known studies have examined its impact on genetics in the Oliver Reginald Tambo Coastal District schools.

The study is guided by the following research questions:

1. How does Kahoot influence learner anxiety levels when learning genetics in grade 12 life sciences?
2. To what extent do age and gender influence learners' pre- and post-test SA levels?
3. To what extent does Kahoot affect learner engagement during genetics lessons in grade 12 life sciences?
4. How does Kahoot impact learners' academic performance and conceptual understanding of genetics in grade 12 life sciences?
5. How do learners and teachers experience Kahoot in teaching and learning genetics in grade 12 life sciences?

LITERATURE REVIEW

Within this context, game-based learning tools have emerged as potential pedagogical interventions. Kahoot integrates elements of gamification, including immediate feedback, competition, and time-bound responses, which have been shown to increase learner motivation and participation (Licorish et al., 2018; Wang & Tahir, 2020). Studies indicate that learners often perceive Kahoot as enjoyable and engaging (Yılmaz, 2023). The platform enables real-time feedback, allowing teachers to identify misconceptions and adjust instruction, accordingly, thereby supporting responsive teaching practices (Dellos, 2015). Furthermore, its interactive and collective nature promotes classroom dialogue and peer learning, as learners reflect on aggregated responses and discuss incorrect answers (Vickrey et al., 2015).

However, the literature consistently emphasizes that Kahoot's effectiveness is not inherent in the tool itself but depends on pedagogical mediation. Poorly designed activities may encourage superficial engagement or reinforce anxiety (Wang, 2015; Yılmaz, 2023). In South African contexts, studies such as Balele (2024) highlight that while Kahoot can enhance participation and lesson quality, its impact is shaped by teacher facilitation strategies. Thus, Kahoot's educational value lies in its integration into teaching rather than in its technological features alone.

Learner engagement, a central construct in this study, is widely conceptualised as comprising behavioral, cognitive, and emotional dimensions (Fredricks et al., 2019). Kahoot has been shown to enhance behavioral engagement by requiring active and synchronous participation, thereby reducing passive disengagement (Licorish et al., 2018; Wang & Tahir, 2020). It also promotes emotional engagement through its game-like features, which generate excitement and interest (Plass et al., 2015). Nevertheless, increased behavioral and emotional engagement does not necessarily translate into cognitive engagement. The fast-paced nature of Kahoot may lead to guessing and surface-level processing if questions are not designed to promote reasoning and conceptual understanding (Plump & LaRosa, 2017; Wang, 2015). Cognitive engagement, which involves deep processing and critical thinking, is more likely when Kahoot is embedded within instructional strategies that include reflection, discussion, and explanation (Dellos, 2015).

The relationship between engagement and anxiety is particularly significant in science education. Anxiety has been shown to negatively affect working memory, persistence, and overall academic performance (Mallow, 2006). Genetics, in particular, is associated with high anxiety due to its reliance on abstract reasoning and multi-step problem-solving (Hawes & Arya, 2023). Recent studies emphasize that SA is not merely an individual trait but is shaped by learning experiences and classroom environments (Boateng, 2024; Boateng et al., 2025). In multilingual contexts, such as many South African classrooms, this anxiety may be further intensified by language barriers and technological limitations (Balele, 2024; Mbete, 2022). Consequently, Kahoot can either alleviate or exacerbate anxiety depending on how it is implemented and experienced by learners.

In terms of academic performance and conceptual understanding, the literature suggests that Kahoot can be effective when used as part of formative assessment practices. By promoting repeated retrieval practice and providing immediate feedback, Kahoot supports knowledge consolidation and error correction (Wang & Tahir, 2020). Nonetheless, performance gains are not uniform and are influenced by contextual factors such as access to technology, connectivity, and the quality of question design (Mbete, 2022). While Kahoot shows promise as a tool for enhancing participation, reducing SA, and improving learning outcomes, its effectiveness depends on how it is implemented in specific classroom contexts. This creates a clear research gap, particularly in the teaching of grade 12 genetics in South African schools, where the interaction between these variables remains underexplored.

THEORETICAL FRAMEWORK

This study is underpinned by three complementary theoretical perspectives: self-determination theory (SDT) (Deci & Ryan, 1985; Ryan & Deci, 2020), constructivist learning theory (CLT) (Piaget, 1972; Vygotsky, 1978), and control-value theory (CVT) of achievement emotions (Pekrun, 2006).

SDT, developed by Deci and Ryan (1985, 2020) in the late 20th century, emerged as a critique of behaviorist and early cognitive perspectives that primarily explained motivation through external rewards and reinforcement. SDT foregrounds the role of individuals as active agents in their own learning, whose motivation is shaped not only by external conditions but also by internal experiences of control, interest, and meaning. Early empirical work by Deci (1971) demonstrated that external rewards could, in some cases, diminish intrinsic motivation, particularly when individuals were already engaged in inherently interesting tasks. This finding challenged dominant assumptions about reinforcement and highlighted the importance of understanding the quality, rather than merely the quantity, of motivation. Building on this, SDT evolved into a comprehensive framework for examining human motivation, development, and well-being, grounded in a humanistic view that emphasizes growth, autonomy, and the pursuit of competence and purpose (Ryan & Deci, 2017, 2020).

Central to the theory is the proposition that optimal motivation occurs when three basic psychological needs are supported: autonomy (a sense of choice), competence (a sense of effectiveness), and relatedness (a sense of belonging) (Deci & Ryan, 2000). When learning environments and instructional practices nurture these needs, learners are more likely to participate actively, persist through challenges, and experience reduced anxiety. Conversely, controlling or overly evaluative environments may undermine motivation and contribute to disengagement, regardless of learners' abilities.

SDT therefore provides a valuable lens for this intervention study, which was grounded to enhance both the emotional and motivational dimensions of learning. In the context of this study, it enables an understanding of how pedagogical strategies and digital tools can be structured to support learners' psychological needs, thereby improving engagement, reducing anxiety, and fostering meaningful learning experiences.

CLT serves as the primary foundation of this study. According to constructivists (Piaget, 1972; Vygotsky, 1978), learning is an active process in which learners construct knowledge through interaction with their environment, experiences, and peers rather than passively receiving information from teachers. In this study, Kahoot provides an interactive learning environment where learners actively engage with genetics concepts through quizzes, discussions, immediate feedback, and peer interaction. Through these experiences, learners are encouraged to confront misconceptions, reflect on their understanding, and reconstruct scientific knowledge. From a constructivist perspective, learning occurs when learners actively participate in knowledge construction, making Kahoot a valuable tool for promoting conceptual understanding and academic achievement in genetics.

While constructivism explains how learning occurs, this study also seeks to understand how Kahoot influences learner anxiety. For this purpose, the CVT of achievement emotions (Pekrun, 2006) provides a relevant theoretical perspective. CVT proposes that achievement-related emotions, such as anxiety, enjoyment, and pride, are influenced by learners' perceptions of control over learning activities and the value they attach to academic success. Learners are more likely to experience anxiety when they perceive a task as important but doubt their ability to perform successfully.

In the context of genetics, many learners perceive the topic as difficult due to its abstract nature, scientific terminology, and complex inheritance patterns. Such perceptions may contribute to increased SA and reduced confidence. Kahoot has the potential to alter these emotional experiences by increasing learners' sense of control over learning. Through regular practice, immediate feedback, and opportunities to correct misunderstandings, learners can develop greater confidence in their knowledge and abilities. As perceptions of competence and control increase, SA may decrease. Simultaneously, the enjoyable and game-like nature of Kahoot may transform learning experiences from threatening to enjoyable, fostering positive achievement emotions that support learning.

RESEARCH METHODOLOGY

The pragmatic paradigm foregrounds our study. A mixed-methods approach was adopted because neither quantitative nor qualitative methods alone could adequately address the research objectives. Specifically, the study followed an explanatory sequential mixed-methods design, in which quantitative data were collected and analyzed first, followed by qualitative data to explain and contextualize the statistical results (Ivankova, 2014). This design enabled the researchers to establish whether Kahoot was associated with changes in anxiety and achievement, and then to explore how learners and teachers experienced the intervention in the classroom. The integration of both strands strengthened the study through triangulation and enhanced interpretive depth (Saunders et al., 2023).

The quantitative phase employed a quasi-experimental one-group pre-/post-test design, in which the same learners were measured before and after the intervention. This design was selected because creating a control group was not feasible in grade 12 classrooms, where timetable demands, curriculum coverage, and examination preparation limited experimental manipulation (Cohen et al., 2018).

The study involved four purposively selected secondary schools in the Oliver Reginald Tambo Coastal District. The study further utilized purposive sampling to select four grade 12 life sciences teachers, with one teacher drawn from each of the four participating schools. Teachers were selected based on their responsibility for teaching grade 12 life sciences, their experience in teaching genetics, and their willingness to participate in the study. Following approval from school principals, eligible teachers were identified and invited to participate. This sampling approach ensured that participants had relevant knowledge and experience in teaching genetics and in using Kahoot as a game-based learning tool. One intact grade 12 life sciences class was selected from each school, yielding a quantitative sample of approximately 200 learners. For the qualitative phase, all four participating teachers and 20 learners (five per school) were purposively selected to capture diverse experiences of participation, engagement, and classroom interaction. The Kahoot intervention was implemented over four weeks during the teaching of genetics and Inheritance, with teachers integrating Kahoot activities as a pedagogical, formative learning and assessment tool. To improve implementation fidelity, all participating teachers followed a common intervention protocol aligned with the CAPS curriculum, while still allowing for normal classroom adaptation (Dede et al., 2018).

Data were collected using a test on genetics (TOG) achievement pre- and post-test, an adapted science anxiety scale (SAS) (Betz, 1978), structured classroom observations, and semi-structured interviews with teachers and learners. These instruments enabled the study to capture both measurable outcomes and rich contextual accounts of Kahoot use in practice (Cohen et al., 2018).

Prior to analysis, positively worded items in the SAS were reverse-coded to ensure consistent score interpretation. Reverse coding was necessary because some items reflected low levels of SA (e.g., positive feelings towards science [genetics]), whereas others reflected high levels of SA. For the positively worded items, responses were recorded such that a response of 5 became 1, 4 became 2, 3 remained unchanged, 2 became 4, and 1 became 5. On the SAS, items 2, 3, 5, 6, and 9 were positively worded and reverse-coded before analysis. Following this procedure, higher scores across all items consistently indicated higher levels of SA. The reverse-coded items were then included in the computation of total anxiety scores and reliability analyses.

Quantitative data were analyzed using descriptive and inferential statistics in R. Because normality assumptions were not met, the Wilcoxon signed-rank test was used to compare pre- and post-intervention scores for SA and academic performance. Cronbach's alpha coefficients were calculated separately for the pre- and post-test administrations, yielding $\alpha = 0.70$ (pre-test) and $\alpha = 0.74$ (post-test), indicating acceptable internal consistency (Field, 2022). The observed variation in reliability coefficients is expected, as internal consistency is influenced by changes in participants' understanding, response patterns, and score variability following the intervention. For the qualitative instruments, trustworthiness was ensured through member checking.

Qualitative data from interviews and observation notes were analyzed thematically through coding, categorization, and theme development, following a systematic process of identifying recurring patterns across participants' accounts (Nowell et al., 2017). Integration occurred during interpretation and discussions, in which qualitative findings were used to explain quantitative trends and illuminate the contextual conditions that shaped Kahoot's success and limitations in these classrooms.

Ethical clearance was obtained from the relevant university ethics committee (protocol number: FEDFREC 2533), with additional permission from the DBE and participating schools. Informed consent was

Table 1. Profile of participants

Participant group	Identifier format	Total	Notes
Teachers	T1–T4	4	Qualitative strand only
Learners	L1–L200	200 (20)	Both quantitative and qualitative strands

Table 2. Descriptive statistics

Measure	Pre-test M	Pre-test SD	Post-test M	Post-test SD
SA score	29.45	3.19	29.71	2.1
TOG achievement score	34.02	11.02	64.54	20.89

obtained from teachers, while parental consent and learner assent were secured for minors. Confidentiality, anonymity, and voluntary participation were maintained throughout the study (Cohen et al., 2018).

FINDINGS

Quantitative Data

Background profile of participants

The quantitative strand involved 4 life science teachers and their 200 grade 12 life sciences learners from the four selected secondary schools (school A-school D) that participated in the study (**Table 1**). Each school contributed 50 learners, ensuring balanced representation across the four sites and enabling comparability of outcomes across similar instructional contexts.

The gender distribution in the sample indicated that 112 learners were female and 88 were male. This reflects a slight female majority within the life sciences cohort. Presenting this distribution supported demographic transparency and enabled descriptive reflection on whether outcomes appeared similar across genders.

The age distribution across the sample showed that the majority of learners were 18 years old (n = 151), which aligns with the expected age for learners in their final year of secondary education. Smaller numbers of learners were in the following age categories: 17 years (n = 9), 19 years (n = 17), 20 years (n = 14), and 21 years (n = 9). The presence of learners aged 18 or older indicates normal variation.

The four teachers comprised two males (T1 and T3) and two females (T2 and T4). Teachers' ages ranged from 27 to 43 years, indicating a mix of early-career and more experienced educators. Teaching experience ranged from 5 to 17 years. The teachers' professional profiles indicated sufficient subject-matter knowledge and pedagogical experience to teach life sciences classes. For ethical compliance and confidentiality, all participants were anonymized. Schools were coded as school A-school D. Teachers were coded T1-T4 by school, and the learners sampled for the interviews were coded L1-L20.

The relationship between learners' science anxiety levels and performance in genetics

During data preparation, careful attention was paid to the directionality of item wording for the anxiety questionnaire to ensure conceptual clarity and consistent scoring. Because some items were positively worded, they were reverse-coded so that higher scores consistently represented higher levels of SA across the scale.

The positively worded items that were reverse-coded were Q2, Q3, Q5, Q6, and Q9.

The reverse-coding rule applied was: $Q_{rev} = 6 - Q$. Following reverse coding, a total SA score was computed for each learner using the formula: $TOTAL = Q1 + Q2_{rev} + Q3_{rev} + Q4 + Q5_{rev} + Q6_{rev} + Q7 + Q8 + Q9_{rev} + Q10$.

This scoring procedure ensured that the SAS functioned as a coherent measure, with higher total scores reflecting higher SA levels. Applying consistent scoring across pre- and post-intervention data enabled meaningful comparisons of SA levels over time and supported the validity of subsequent descriptive and inferential analyses.

Descriptive statistics

Descriptive statistics were calculated to provide an initial overview of patterns in learners' SA levels and TOG achievement before and after the intervention.

From **Table 2**, SA scores increased very slightly from the pre-test (M = 29.45, standard deviation [SD] = 3.19) to the post-test (M = 29.71, SD = 2.10), with a mean difference (MD) of only 0.26 points. This minimal change suggests that, at an aggregate level, learners' overall SA in sciences remained relatively stable across the intervention period. The reduction in SD from pre- to post-test further indicates a slight reduction in variability in SA scores after the intervention, suggesting a more clustered distribution of SA levels among learners.

In contrast, TOG achievement scores increased substantially from a pre-test M of 34.02 (SD = 11.02) to a post-test M of 64.54 (SD = 20.89). This represents an M gain of 30.52 percentage points, indicating a marked improvement in learner performance following the intervention. The descriptive statistics point to two distinct patterns: relative stability in overall SA and a pronounced improvement in genetics achievement. These patterns provide an important foundation for inferential analysis and raise analytically relevant questions regarding the nature of Kahoot's impact, specifically whether its influence was stronger on cognitive outcomes than on broader affective dispositions.

Inferential analysis

While descriptive statistics provide an overview of trends, inferential analysis was conducted to determine whether the observed changes were statistically significant and unlikely to be due to chance. Because the same learners completed both the pre- and post-intervention measures, paired-samples inferential techniques were appropriate. The paired-samples t-tests were used as the primary inferential method to examine changes over time. In addition, Wilcoxon signed-rank tests were conducted to address indications of non-normality and enhance the robustness of the findings. Although the data met the assumptions for parametric testing, nonparametric analyses were also conducted as a robustness check. The consistency of the findings across both analytical approaches provided additional support for the stability and reliability of the results.

Pairing method: Approximate pairing within gender × age groups.

Matched pairs used: n = 200.

SA (paired t-test): t (199) = -47.477, p = 0.0000; Cohen's dz = -3.357.

SA (Wilcoxon): W = 0, p = 0.0000.

Marks (paired t-test): t (199) = 18.242, p = 2.3872e-44; Cohen's dz = 1.290.

Marks (Wilcoxon): W = 568, p = 4.7522e-30.

The paired analyses show that the SA total score changed marginally from M pre = 34.51 to M post = 16.11 (MD = -18.40), with no statistically significant change detected t (199) = -47.477, p = 0.0000). In contrast, TOG achievement improved substantially: M marks increased from 34.02 to 64.54 (MD = 30.52), with a highly significant result *t*(199) = 18.242, p = 2.3872e-44) and a large effect size (dz = 1.290).

Science anxiety

The paired-samples *t*-test conducted on the SA totals indicated no statistically significant difference between pre- and post-intervention scores:

T (199) = -1.00, p = 0.319.

Effect size: dz = 0.071 (negligible).

The negligible effect size indicates that the magnitude of change in SA was very small and practically insignificant. To confirm this result, a Wilcoxon signed-rank test was conducted, which yielded a consistent outcome:

W = 6732.0, p = 0.184.

Effect size: r = 0.10 (small).

Non-zero pairs included in the analysis: n = 174.

The convergence of the parametric and non-parametric results provides strong evidence that the Kahoot-based intervention did not result in a statistically significant change in learners' overall SA totals when measured across the full scale. These findings suggest that, while Kahoot may influence learners' emotional experiences during specific classroom activities, such effects may not be sufficiently strong or broad to shift overall SA levels.

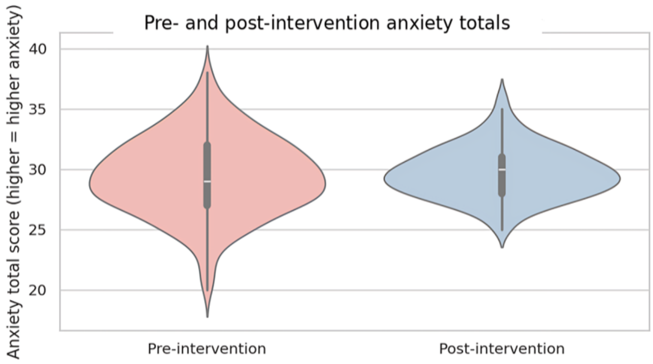

Figure 1. Pre- and post-intervention anxiety totals (the authors' own elaboration)

Figure 1 shows the pre- and post-intervention anxiety totals.

Figure 2 presents the pre- and post-intervention M SA scores for learners aged 17 to 21, disaggregated by gender. In the pre-test phase, both males and females exhibit similar SA levels with a noticeable dip at age 19, particularly among males. Female learners show a gradual increase in SA from age 19, peaking at age 21, whereas male learners show a slight decline after age 20. Females tend to report marginally higher SA levels than males across most age groups. Following the intervention, SA levels decreased substantially for both genders across all ages, indicating a clear positive effect. Male SA post-test scores remain relatively stable in the mid-teens, whereas female scores, though significantly reduced, display slightly greater variability. The lowest female SA is observed at age 20, with a slight increase at age 21. The findings suggest that the intervention effectively reduced SA across age and gender.

Genetics achievement

In contrast to the SA findings, inferential analysis revealed a statistically significant improvement in genetics achievement following the intervention. The paired-samples *t*-test produced the following result:

t (199) = -18.24, p < 0.001.

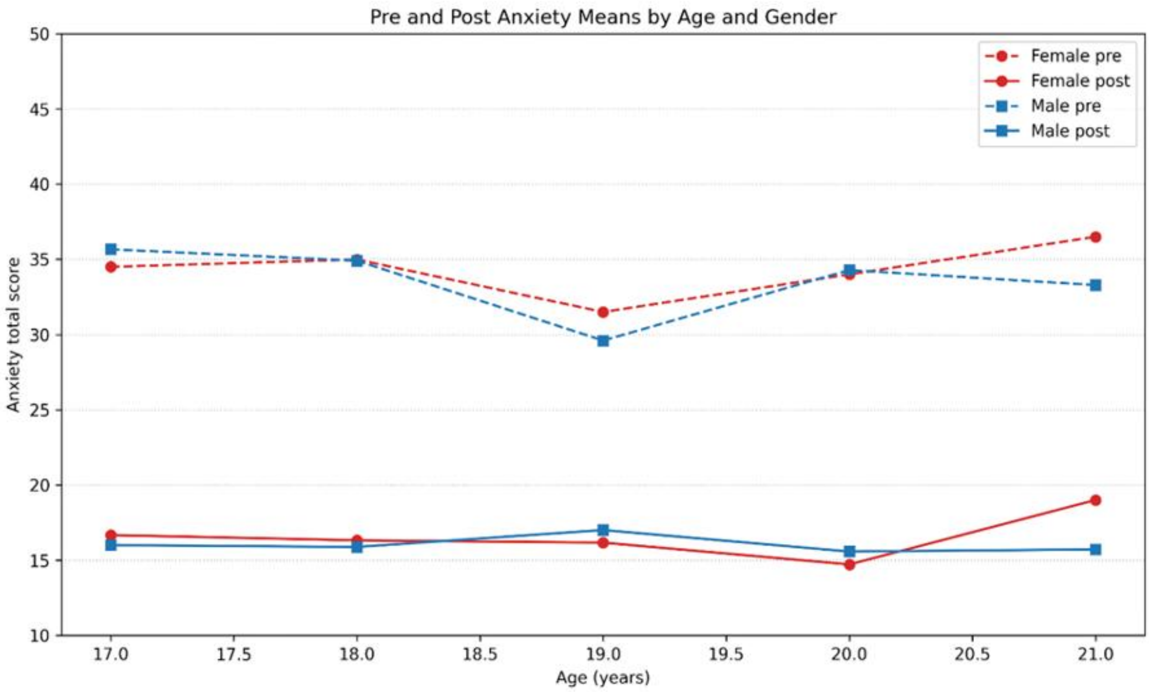

Figure 2. Pre- and post-science anxiety M by age and gender (the authors' own elaboration)

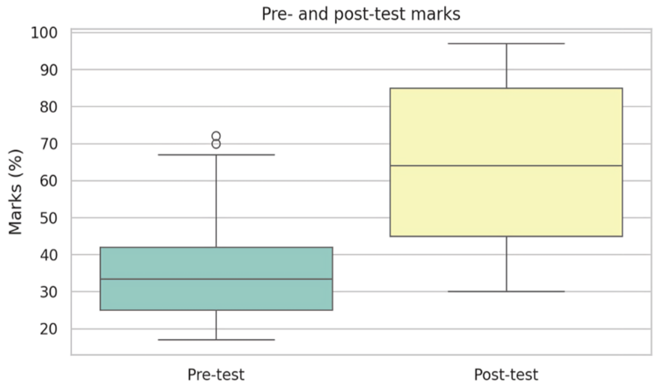

Figure 3. Pre- and post-test TOG scores (the authors' own elaboration)

Effect size: dz = 1.29 (large).

The large effect size indicates that the improvement in achievement was not only statistically significant but also educationally substantial. This result was confirmed using the Wilcoxon signed-rank test:

W = 568.5, $p = 4.75 \times 10^{-30}$.

Effect size: r = 0.816 (large).

Non-zero pairs included in the analysis: n = 195.

The consistency between the parametric and non-parametric tests provided strong evidence that learner performance in TOG improved significantly following the Kahoot-based intervention. The magnitude of the effect suggested that the observed gains were unlikely to be attributable solely to random variation and indicated a meaningful association between the intervention and learning outcomes (**Figure 3**).

The quantitative findings indicated a clear divergence between cognitive and affective outcomes: while genetics achievement improved substantially, overall SA remained statistically unchanged. These findings do not necessarily indicate long-term changes in overall SA; this pattern highlighted the importance of moving beyond numerical trends to explore how learners and teachers experienced Kahoot in classroom practice.

Qualitative Data

Four main themes emerged from the qualitative analysis. These themes included: *learner reduced SA during genetics and Inheritance lessons, learner engagement and participation during Kahoot-supported lessons, learning outcomes and conceptual understanding in genetics and Inheritance and learner and teacher experiences of implementing Kahoot.*

Theme 1. Learner reduced science anxiety during genetics lessons

Theme 1 captures learners' and teachers' experiences of SA during genetics lessons and how the Kahoot influenced this anxiety. Across schools, learners' responses indicated that Kahoot reduced SA by alleviating the pressure of answering genetics questions in public. Unlike traditional questioning, where individual learners may be singled out to answer in front of their peers, Kahoot requires all learners to respond simultaneously. This collective participation reduced personal exposure and shifted the meaning of mistakes from a visible personal failure to a shared learning process.

In practical terms, learners reported feeling less "spotlighted" and less judged, and therefore more willing to offer answers even when uncertain. Learner L1 from school A explained:

> Normally, genetics makes me panic because I always thought of getting the answer wrong. When the teacher asks questions, I feel everyone is watching me and judging my answer. With Kahoot, I felt less intimidated because everyone was answering at the same time, so it did not feel like the focus was on me alone. That made it easier for me to try, even when I was unsure (L1, school A).

Learner L12 similarly emphasized that mistakes did not feel embarrassing during Kahoot sessions and that errors were perceived as part of the learning process rather than personal failure. This response is significant because it suggests persistence: the learner continued participating despite mistakes, rather than withdrawing.

> When I got answers wrong on Kahoot, it did not feel embarrassing at all. Nobody pointed out that I was wrong, and we just moved on to the next question. I felt like mistakes were normal and part of the learning process. Because of that, I was willing to keep trying rather than give up (L2, school A).

Teachers corroborated these experiences. Teacher T1 observed increased participation among learners who were usually quiet, noting that Kahoot reduced the panic of public answering and encouraged broader involvement during genetics lessons.

> I noticed that learners who were usually very quiet became more willing to answer questions when Kahoot was used. They were participating without being forced to speak in front of the class. The pressure on learners to answer questions in class was reduced (T1, school A).

Classroom observation notes supported these accounts. During Kahoot activities, learners were more willing to attempt answers and showed fewer avoidance behaviors.

Theme 2. Learner engagement and participation

Theme 2 focuses on how Kahoot influenced learner engagement and participation during genetics lessons. Within the integrated SDT framework, engagement is strengthened when learning activities support competence, autonomy, and relatedness, while remaining manageable to implement in the classroom.

Teachers reported that Kahoot increased attentiveness and sustained learner focus across the lesson. The teachers' observations suggest that Kahoot created a structured cycle of questioning and responding that reduced opportunities for learners to drift off-task and kept them cognitively present. One teacher narrated:

> Engagement was noticeably higher during Kahoot lessons. Learners were attentive from the beginning to the end of the lesson. Even learners who usually lose focus stayed involved throughout the activity (T4, school D).

Learners echoed this experience. Learner L32 linked attentiveness to the interactive nature of the activity and to the desire to improve scores:

> Kahoot made the lesson exciting. I stayed focused because I wanted to see my score improve. Each question motivated me to pay attention and try harder (L32, school A).

Classroom observation notes corroborated these accounts and provided behavioral evidence of attentiveness. The observation notes further indicated that the projected display consistently anchored learners' attention, with them looking toward the projector. They remained alert as questions progressed, suggesting sustained time-on-task and reduced disengagement compared to more passive lesson segments.

In addition to attentiveness, participation increased noticeably. Learner L15 reported:

> Even learners who don't normally participate were shouting answers and discussing them with friends. The class felt more alive, and everyone wanted to be involved (L15, school C).

Teacher T2 similarly observed participation across ability levels.

> Participation increased across ability levels. Learners who are usually passive became involved and showed interest in answering questions (T2, school B).

Observation notes strengthened the evidence of peer interaction and competition. Learners appeared highly competitive and were visibly eager for the next question, which reinforced the motivational role of competition and leaderboards. However, the same observation notes also highlighted a key classroom management issue: noise levels increased substantially, and the class became "almost uncontrollable" as competition intensified.

Theme 3. Learning outcomes and conceptual understanding in genetics and inheritance

A dominant pattern across teacher interviews was that Kahoot enabled rapid diagnosis of misconceptions in genetics. Teachers explained that the immediate visibility of learner responses enabled them to identify misunderstandings. This is particularly important in genetics because misconceptions often persist when learners repeatedly practice incorrect procedures. When misconceptions are identified late, learners may have already internalized incorrect reasoning. Teacher T3 from school C explained:

> Kahoot helped me identify misconceptions immediately, especially with Punnett squares. I could see which options learners were choosing and quickly realized where they were confused. That made it easier to stop and explain before moving on (T3, school C).

Teacher T2 similarly emphasized that learning improved when concepts were revisited after Kahoot activities.

> Learners showed improved understanding when we revisited concepts after the Kahoot activity. The questions showed me exactly where they were struggling, and I could adjust my teaching straight away (T2, school B).

Teacher T1 observed that learners' reasoning improved after Kahoot sessions, suggesting that the tool supported deeper engagement when accompanied by follow-up explanation. The teacher noted that learners were increasingly able to justify answers, indicating a shift from concept listing to conceptual reasoning. This is an important finding because multiple-choice formats can encourage guessing under time pressure; however, teacher-led discussion can foster learning by requiring learners to explain why an option is correct or incorrect.

> After Kahoot, learners were able to explain their answers better. They were not just choosing options; they were also explaining why an answer was correct or incorrect (T1, school A).

Classroom observations supported these claims. Teachers observed pausing after incorrect answers, clustering incorrect answers, and using the item as a teaching moment to revisit key genetics principles. Learners were observed discussing their reasoning briefly in groups or with peers, especially when they realized their selection was incorrect. These observation patterns suggest that misconception correction occurred through a cycle of *question → response pattern → teacher diagnosis → explanation → learner discussion*, which is characteristic of formative assessment practice in which feedback is immediate and instructional rather than merely evaluative.

Learners consistently emphasized that Kahoot supported their understanding when paired with teacher explanations after each question. This suggests that the platform's learning value depended strongly on the feedback process and on how teachers used questions to unpack meaning. This indicates that Kahoot supported error-based learning, where mistakes became opportunities for clarification rather than sources of discouragement.

Learner L2 from school A explained:

> When the teacher explained after each question, I understood genetics better. The explanation helped me see where I went wrong and what I needed to change (L2, school A).

Learner L14 described how understanding mistakes strengthened memory and reduced the likelihood of repeating errors.

> Seeing why an answer was wrong helped me remember the correct one. After that, I did not make the same mistake again (L14, school C).

Learners also linked Kahoot to assessment preparation. Learner L20 from school D explained:

> Kahoot helped me practice before tests, so I felt more prepared. I was not shocked by the questions because we had already discussed similar ones (L20, school D).

This suggests that Kahoot supported exam readiness by increasing exposure to typical genetics question formats and reinforcing key reasoning steps through repeated retrieval and discussion.

Theme 4. Learner and teacher experiences of implementing Kahoot

Theme 4 captures the practical and experiential realities of implementing Kahoot in grade 12 life sciences classrooms. Across the four schools, teachers and learners generally reported positive experiences with Kahoot. They expressed a willingness to continue using it for revising and consolidating content. However, participants also emphasized that effective use required practical adjustments. Teachers generally reported that Kahoot was easy to use and supported instructional efficiency. Teachers described the platform as straightforward to prepare, quick to launch, and helpful for capturing learner responses without the administrative burden of paper-based testing. These experiences suggest that Kahoot is aligned well with the time pressures of grade 12 teaching, where teachers often need strategies that provide rapid feedback while maintaining curriculum coverage.

Teacher T1 from school A described:

> It was easy to set up quizzes because the system is simple. I could prepare questions at home and use them in class quickly. It helped me to test my understanding without photocopying papers. For revision, it was efficient, and the learners responded well (T1, school A).

Teacher T3 from school C highlighted:

> It saved time, and we revised quickly. Instead of marking many scripts, I could see results immediately. We could discuss mistakes in the same lesson while it was still fresh. That helped me manage the grade 12 pace better (T3, school C).

Teachers' accounts also suggest that Kahoot supported instructional planning by enabling flexible use across lesson stages. Teachers described Kahoot as useful for assessing baseline understanding, identifying confusion, summarizing key concepts, and preparing learners for assessment. Teacher experiences indicate high PU and PEOU, which are central conditions for sustained adoption in classroom practice. However, teachers also implicitly acknowledged that successful use required active classroom management, careful pacing, and appropriate question selection, especially in the grade 12 context.

Learners generally expressed positive attitudes toward Kahoot, describing it as enjoyable, motivating, reducing SA and more inclusive than traditional classroom questioning. Learner L8 from school A had this to say:

> I liked that we all had a chance to answer. In class, sometimes only the same learners answer questions. But with Kahoot, everyone must try, so it feels fair. It made me participate more than before (L5, school B).

However, teachers also reported constraints that affected inclusivity. T2 lamented:

> Even slow learners could catch up when we worked in groups. However, sometimes the network was unreliable, causing the game to stop. Also, not every learner had a phone, so we had to share. We managed, but it shows resources can affect the experience (T2, school B).

Observation notes confirmed repeated instances of device sharing, with small groups clustered around one phone. During Kahoot sessions, learners were highly energized: they cheered and clapped when names appeared on the projector, many were visibly alert and "on their toes," and there was sustained anticipation for the next question.

DISCUSSION

The first findings from research questions 1 and 2 show that learners experienced SA, and that more girls than boys did. The finding further shows that Kahoot significantly reduced SA during genetics lessons. This reduction was primarily associated with decreased fear of mistakes and the opportunity to participate simultaneously. Learners repeatedly described feeling less exposed and less judged, as Kahoot disrupted traditional teacher-centered questioning practices. These findings corroborate existing studies that argue that Kahoot transforms classroom moments into practice environments where mistakes are reframed as part of the learning process rather than indicators of failure (Dellos, 2015; Wang & Tahir, 2020). From an SDT perspective, the reduction in SA observed in this study reflects enhanced satisfaction of learners' needs for relatedness and autonomy. Relatedness is supported when learners perceive the classroom as a psychologically safe space characterized by belonging and reduced judgment (Deci & Ryan, 2000; Ryan & Deci, 2020). Autonomy, in turn, is strengthened when participation is experienced as voluntary and low-pressure rather than as coerced public performance. This finding is consistent with Boateng et al.'s (2025) "confidence trajectory" framework, which emphasizes that learner SA is shaped by cumulative participation experiences and perceptions of competence. The present study provides evidence in support of Boateng et al. (2024) by demonstrating that reduced SA did not stem from genetics becoming less complex, but rather from a classroom environment that enabled safe participation and iterative practice. However, in contrast to the qualitative findings, the quantitative analysis did not reveal a statistically significant reduction in overall SA scores following the intervention. This divergence does not contradict the qualitative evidence; rather, it highlights an important conceptual distinction between general subject-related anxiety. Similar discrepancies have been reported in previous mixed-methods studies, where learners report feeling more comfortable during specific learning activities while broader anxiety measures remain stable (Wang & Tahir, 2020; Yılmaz, 2023).

Secondly, the findings of research question 3 demonstrate a strong convergence between qualitative evidence and patterns of learner achievement, indicating that Kahoot substantially enhanced learner engagement during genetics lessons. Qualitative data revealed sustained attention, frequent participation across diverse ability levels, active peer interaction, and emotional involvement throughout Kahoot-supported activities. Classroom observations substantiated these findings. These findings align closely with previous studies that identify Kahoot as a powerful engagement catalyst capable of promoting repeated cycles of interaction, response, and feedback (Licorish et al., 2018; Wang & Tahir, 2020). Interpreted through SDT, the observed engagement patterns reflect enhanced satisfaction of learners' needs for autonomy, competence, and relatedness. Autonomy was evident as learners actively participated by making decisions and submitting responses, rather than passively receiving information (Deci & Ryan, 2000; Ryan & Deci, 2020). Competence was reinforced through immediate feedback and visible indicators of progress, such as scores and rankings, which signaled that success was attainable through effort. Relatedness emerged through shared excitement, collaborative discussion, and collective participation, particularly where learners engaged in dialogue while sharing devices. These findings corroborate prior SDT-informed studies showing that learner engagement increases when classroom activities support agency, feedback, and social connection (Ryan & Deci, 2020; Wang & Tahir, 2020). From a constructivist perspective, the increased learner engagement observed in this study suggests that Kahoot created opportunities for active participation, interaction, and knowledge construction during genetics lessons. Both learners and teachers reported that the platform sustained attention and reduced passive disengagement, thereby promoting active involvement in the learning process. Through immediate feedback, classroom discussion, and participation in quiz-based activities, learners tested their understanding, confronted misconceptions, and refined their conceptual understanding of genetics. These findings support the constructivist view that meaningful learning occurs when learners actively engage with content and interact with their learning environment (Piaget, 1972; Vygotsky, 1978).

The findings can also be interpreted through the lens of CVT, which posits that achievement emotions are influenced by learners' perceptions of control over learning tasks and the value they attach to those tasks (Pekrun, 2006). The interactive, supportive nature of Kahoot appeared to enhance learners' sense of control by providing a friendly environment and immediate feedback. As learners became more confident in answering genetics questions and monitoring their progress, they experienced reduced anxiety and greater enjoyment during lessons. However, the findings also suggest that excessive competition, classroom noise, and high excitement may at times distract learners from deeper engagement with the content. Such conditions could shift learners' attention from conceptual understanding towards performance outcomes, potentially reducing opportunities for meaningful learning. Therefore, while Kahoot can foster positive achievement emotions and engagement, its effectiveness depends on careful teacher facilitation to ensure that enjoyment and competition remain aligned with educational objectives and conceptual understanding.

However, consistent with cautionary perspectives in the literature, the findings also indicate that increased emotional and behavioral engagement does not automatically equate to deep cognitive engagement. Prior studies have warned that Kahoot's fast pace and competitive elements may encourage superficial responses or guessing over conceptual reasoning (Plump & LaRosa, 2017; Wang, 2015). The present study aligns with these concerns, as some lessons exhibited high noise levels and near-chaotic moments, suggesting that engagement was occasionally dominated by competitive energy rather than reflective thinking.

Although engagement was not measured using a standalone quantitative scale, the substantial improvement in learner achievement provides indirect evidence of productive engagement when interpreted alongside the qualitative data. The alignment between observed attentiveness, reported participation, and statistically significant learning gains suggests that engagement was not merely superficial across all sessions. Nevertheless, the findings reinforce a critical conclusion from the literature: engagement contributes most effectively to learning when teachers actively channel excitement into structured reasoning, feedback, and conceptual consolidation.

The findings from research question four demonstrated strong convergence between qualitative and quantitative evidence regarding learning outcomes, suggesting that Kahoot exerted a meaningful influence on learners' academic performance and conceptual understanding of genetics. Quantitative analyses revealed statistically significant improvements in learners' genetics scores from pre- to post-test, with large effect sizes confirmed through both parametric and non-parametric procedures. These performance gains are corroborated by the qualitative findings, which indicated that learners developed stronger conceptual understanding through immediate feedback, repeated exposure to key concepts, and teacher-led clarification during Kahoot-facilitated lessons. This corroborates existing evidence that classroom response systems can establish effective formative assessment loops when teachers actively respond to error patterns through reteaching and clarification (Dellos, 2015; Wang & Tahir, 2020). From an SDT perspective, the observed improvements in learning outcomes can be linked to enhanced satisfaction of learners' competence needs. Immediate feedback reduced uncertainty and helped learners regulate their understanding, while repeated opportunities to respond created experiences of success that reinforced perceptions of competence. These experiences, in turn, were likely to have supported persistence and effort in challenging genetic content. However, SDT also cautions that competence perceptions may be undermined by overly restrictive timing or repeated failure if activities are insufficiently scaffolded, reinforcing the importance of inclusive pacing and explicit explanation (Deci & Ryan, 2000; Ryan & Deci, 2020). The findings of this study therefore support SDT-based arguments that digital tools enhance learning most effectively when competence support is carefully managed.

Nonetheless, we also argue that Kahoot is most effective when integrated into broader pedagogical practices. There is therefore the need for teacher explanations, classroom discussions, feedback sessions, and peer interactions following Kahoot activities to facilitate deeper conceptual understanding of genetics concepts. Viewed through the lens of CLT, the observed improvements in academic performance suggest that Kahoot created opportunities for learners to actively engage with genetics concepts, receive immediate feedback, and refine their understanding through interaction and reflection. Rather than passively receiving information, learners actively constructed knowledge by responding to questions, discussing misconceptions, and connecting new information with prior understanding. These processes are central to constructivist learning and may explain the enhanced conceptual understanding and academic achievement observed in the study (Piaget, 1972; Vygotsky, 1978).

From the perspective of CVT, the gains in academic performance may be attributed to learners' increased perceptions of control over genetics learning and assessment tasks. The immediate feedback provided by Kahoot enabled learners to monitor their progress, identify areas requiring improvement, and experience success in manageable learning activities. As learners developed greater confidence in their ability to understand genetics concepts, their perceived control increased, contributing to more positive achievement emotions and reduced anxiety. According to CVT, such positive emotional experiences are associated with improved motivation, engagement, and academic outcomes (Pekrun, 2006). Furthermore, the platform provided teachers with timely insights into learners' understanding, enabling them to address misconceptions and support deeper conceptual learning, which ultimately contributed to improved academic performance (Mdlalose et al., 2022; Wang & Tahir, 2020).

Lastly, the findings of research question 5 indicated that learners and teachers experience several implementation challenges, including limited access to digital devices, intermittent internet connectivity, difficulties with lesson pacing, and increased classroom management issues arising from increased competition. These findings align with and corroborate existing literature that emphasizes the role of infrastructural readiness and contextual conditions in shaping the effectiveness of educational technology, particularly in under-resourced school environments (Balele, 2024; Mbete, 2022). From a CLT perspective, the contextual challenges experienced during the implementation of Kahoot constrained opportunities for active knowledge construction and meaningful learner engagement. Constructivism posits that learning occurs through interaction, participation, feedback, and social negotiation of meaning (Piaget, 1972; Vygotsky, 1978). Although teachers and learners viewed Kahoot as a valuable instructional tool, unstable internet connectivity and limited access to digital devices disrupted learner participation and interrupted the interactive learning processes necessary for effective conceptual development. These disruptions reduced opportunities for learners to engage collaboratively with genetics concepts, receive immediate feedback, and actively construct understanding, thereby limiting the pedagogical potential of the intervention.

The findings can also be interpreted through the lens of CVT (Pekrun, 2006), which emphasizes the role of perceived control and achievement emotions in learning. Technical interruptions diminished learners' sense of control over learning activities by creating uncertainty and frustration during Kahoot sessions. When learners were unable to participate consistently due to connectivity challenges or device shortages, feelings of enjoyment and confidence were often replaced by anxiety, disappointment, and disengagement. Similarly, teachers experienced frustration when technological disruptions interfered with lesson delivery and hindered the achievement of intended learning outcomes. According to CVT, such reductions in perceived control may negatively affect learners' emotional experiences and engagement, thereby limiting the motivational benefits of game-based learning. These findings are consistent with previous studies showing that technological and infrastructural barriers can undermine positive learning experiences and reduce the effectiveness of digital pedagogical innovations despite their educational potential (Balele, 2024).

Observations of device sharing further illustrate the dual nature of learners' experiences. On the one hand, shared-device participation enabled continued engagement in contexts of limited resources, reflecting learner adaptability and resilience. On the other hand, equitable participation within groups depended heavily on how collaboration was structured and managed. However, it can simultaneously undermine autonomy when a single learner dominates decision-making, reducing others' sense of agency despite physical participation. The findings, therefore, align with SDT-based literature, which argues that collaborative learning environments require intentional structuring to support autonomy, such as role rotation, clear turn-taking norms, and ongoing teacher monitoring (Ryan & Deci, 2020).

CONCLUSIONS

This study investigated the impact of Kahoot-based game learning on grade 12 learners' SA, engagement, and academic performance in genetics. Guided by the CLT, SDT and CVT, the study adopted a mixed-methods approach to examine both the intervention's measurable outcomes and learners' and teachers' experiences. Quantitative data were collected through pre- and post-intervention assessments and SA questionnaires, while qualitative data were generated through interviews, classroom observation and learner reflections to provide a deeper understanding of participants' experiences. The integration of quantitative and qualitative findings provided a comprehensive understanding of the educational value of game-based learning in life sciences classrooms. The study concludes that Kahoot game-based learning holds considerable promise for improving both learner engagement and academic performance, while reducing SA in grade 12 genetics. Evidence from the mixed-methods approach demonstrates strong convergence, showing that Kahoot enhanced learner attentiveness, encouraged wider participation, and fostered meaningful peer interaction, thereby creating a more dynamic and interactive classroom environment for genetics concepts. Quantitative findings further revealed a substantial improvement in learner achievement between the pre- and post-intervention assessments, as supported by both parametric and nonparametric analyses. While learners reported feeling more comfortable, less judged, and more willing to engage, these perceptions did not translate into statistically significant changes in SA levels. This indicates that broader and longer-term interventions may be necessary to meaningfully address SA.

The study findings further highlight that the educational value of Kahoot extends beyond the technology itself. Its effectiveness is influenced by the quality of implementation, including the design of questions, the integration of teacher explanations and peer discussions, and the management of classroom dynamics. Hence, the tool is most effective when used as part of a broader pedagogical strategy rather than as a standalone pedagogical tool. Hence, the study contributes to the growing body of evidence supporting the use of game-based learning in science education and demonstrates the potential of Kahoot to enhance learner engagement, improve academic performance, and create more interactive and supportive genetics learning environments to reduce SA.

Limitations

While this study provides valuable insights into the use of Kahoot as a game-based learning tool to enhance learner engagement, reduce SA, and improve academic performance in grade 12 genetics, several limitations should be considered when interpreting the findings: Firstly, the study was conducted within four schools in one school district in the Eastern Cape Province of South Africa, involving a relatively small sample of grade 12 learners and teachers. Although the mixed-methods approach yielded rich, comprehensive data, the findings may not be generalizable to all secondary school contexts.

Secondly, the intervention was implemented over a relatively short period. While the findings revealed improvements in learner engagement, classroom participation, and academic performance, the intervention duration may not have been sufficient to produce substantial long-term changes in SA.

Thirdly, the study focused specifically on genetics. Hence, the findings may not necessarily be transferable to other life sciences topics or scientific disciplines without further investigation.

Furthermore, the implementation of Kahoot was influenced by contextual factors, including internet connectivity, device availability, and classroom infrastructure. Occasional technological disruptions affected the smooth delivery of some learning activities and may have limited the full realization of the potential of the intervention. Despite these limitations, the study contributes meaningful evidence to the growing body of literature on game-based learning in science education.

Recommendations

Based on the findings, several recommendations are proposed. Teachers should strategically use Kahoot for didactics and as a formative assessment tool in science teaching rather than as a stand-alone activity. Its use should be accompanied by inclusive pedagogical practices to enhance learning in the sciences.

School leadership should seek partnerships with external stakeholders to strengthen digital infrastructure, while districts should support professional learning communities for sharing contextually relevant practices in rural areas. Teacher education programs should prioritize training in technology-enhanced assessment, grounded in relevant learning theories that promote autonomy, competence, and relatedness. Curriculum developers are encouraged to incorporate exemplar Kahoot-style questions aligned with grade 12 life sciences content to ease teacher workload and ensure consistency. Policy guidance should further emphasize the integration of digital formative assessment tools into routine science teaching.

Practical implications include establishing clear behavioral expectations, setting educational objectives before gameplay, regulating competition, facilitating reflective discussions after quizzes, and ensuring that learning remains the primary focus rather than merely achieving high scores. Future research should explore the long-term effects of Kahoot on learner anxiety, self-efficacy, and achievement, using more robust designs such as control groups. Additionally, studies should examine specific platform features and their differential impact on diverse learners, including those with higher SA.

Author contributions: ND: conceptualization, formal analysis, methodology, writing – original draft; **SB:** conceptualization, supervision, writing – review & editing. Both authors agreed with the results and conclusions.

Funding: This study received partial funding from the NRF (CSUR23042697530, with Dr. B Mudadigwa as the principal investigator).

Ethical statement: This study was approved by the Institutional Faculty Research Ethics Committee at iYunivesithi Walter Sisulu (formerly Walter Sisulu University) on 13 August 2025 with approval number FEDFREC 2533. Written informed consents were obtained from all participants.

AI statement: The authors stated that generative AI tools (Grammarly and ChatGPT) were used to improve the language and phrasing of this manuscript.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Asniza, I. N., Zuraidah, O. S., Baharuddin, A. R., Zuhair, Z. M., & Nooraida, Y. (2021). Online game-based learning using Kahoot! to enhance pre-university students' active learning: A students' perception in biology classroom. *Journal of Turkish Science Education, 18*(1), 145-160. https://doi.org/10.36681/tused.2021.57

Balele, S. (2024). *Exploring senior phase teachers' use of Kahoot! gamification as a formative assessment tool to scaffold mathematical understanding* [Master's thesis, Rhodes University].

Betz, N. E. (1978). Prevalence, distribution, and correlates of math anxiety in college students. *Journal of Counseling Psychology, 25*(5), 441-448. https://doi.org/10.1037/0022-0167.25.5.441

Biyela, T. E., & Ramaila, S. (2021). Pedagogical practices adopted by novice life sciences teachers when teaching genetics in grade 12 classrooms. *Official Journal of the International Organization for Science and Technology Education, 1*(1)185-192.

Boateng, S. (2024). Exploring the existence of mathematics-sciences anxious-endemic equilibrium among pre-service physical sciences teachers: A pathway to building resilience among STEM students. In M. Carmo (Ed.), *Education and new developments 2024: Volume 1* (pp. 361-365). inScience Press. https://doi.org/10.36315/2024v1end083

Boateng, S. D., & Kumi-Manu, R. N. (2026). Assessing pre-service science teachers' academic knowledge and misconceptions about evolution and genetics concepts. *European Journal of STEM Education, 11*(1), Article 8. https://doi.org/10.20897/ejsteme/17966

Boateng, S. D., Mudadigwa, B., & Johnston-Wilder, S. (2025). Examining gendered patterns in mathematics and science anxiety levels among physical science pre-service teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 21*(1), Article em2564. https://doi.org/10.29333/ejmste/15800

Cadet, M. J. (2023). Application of game-based online learning platform: Kahoot as a formative evaluation tool to assess learning. *Teaching and Learning in Nursing, 18*(3), 419-422. https://doi.org/10.1016/j.teln.2023.03.009

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge. https://doi.org/10.4324/9781315456539

DBE. (2004). *Draft white paper on e-education: Transforming learning and teaching through ICT*. South African Department of Education. https://www.gov.za/sites/default/files/gcis_document/201409/e-education1.pdf

DBE. (2011). *Curriculum and assessment policy statement (CAPS): Life sciences grades 10-12*. South African Department of Basic Education. https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20FET%20_%20LIFE%20SCIENCES%20_%20GR%2010-12%20Web_2636.pdf

DBE. (2021). *2021 National Senior Certificate diagnostic report Part 1: Content subjects*. South African Department of Basic Education. https://www.education.gov.za/Portals/0/Documents/Reports/2021NSCReports/2021%20Diagnostic%20Report%20Part%201%20Content%20Subjects.pdf?ver=2022-02-08-103527-000

DBE. (2022). *National Senior Certificate 2022 diagnostic report part 1: Content subjects*. South African Department of Basic Education. https://www.education.gov.za/Portals/0/Documents/Reports/Diagnostic%20Reports%202022/Diagnostic%20Report%20PART%201%20Non-languages.pdf?ver=2023-02-14-125540-000

DBE. (2023). *2023 diagnostic report: Book 1*. South African Department of Basic Education. https://www.education.gov.za/Portals/0/Documents/Reports/Diagnostic%20Reports%202022/Diagnostic%20Report%202023%20Book%201.......pdf?ver=2024-02-27-144522-073

DBE. (2024). *2024 National Senior Certificate (NSC) diagnostic report: Book 1*. South African Department of Basic Education. https://www.ecexams.co.za/2025_Assessment_Instructions/Diagnostic%20Reports/2024%20NSC%20Diagnostics%20Book%201.pdf

DBE. (2025). *2025 diagnostic report: Book 1*. South African Department of Basic Education. https://www.ecexams.co.za/2025_NSC_Exam_Results/2025%20Diagnostic%20Report%20-%20Book%201.pdf

Deci, E. L. (1971). Effects of externally mediated rewards on intrinsic motivation. *Journal of Personality and Social Psychology, 18*(1), 105-115. https://doi.org/10.1037/h0030644

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Springer. https://doi.org/10.1007/978-1-4899-2271-7

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227-268. https://doi.org/10.1207/S15327965PLI1104_01

Dede, C., Richards, J., & Saxberg, B. (2018). *Learning engineering for online education: Theoretical contexts and design-based examples*. Routledge. https://doi.org/10.4324/9781351186193

Dellos, R. (2015). Kahoot! A digital game resource for learning. *International Journal of Instructional Technology and Distance Learning, 12*(4), 49-52.

Duncan, R. G., & Tseng, K. A. (2011). Designing project-based instruction to foster generative and mechanistic understandings in genetics. *Science Education, 95*(1), 21-56. https://doi.org/10.1002/sce.20407

Elkhamisy, F. A. A., & Wassef, R. M. (2021). Innovating pathology learning via Kahoot! game-based tool: A quantitative study of students' perceptions and academic performance. *Alexandria Journal of Medicine, 57*(1), 215-223. https://doi.org/10.1080/20905068.2021.1954413

Field, A. (2022). *Discovering statistics using IBM SPSS statistics* (5th ed.). SAGE.

Fredricks, J. A., Reschly, A. L., & Christenson, S. L. (2019). *Handbook of student engagement interventions: Working with disengaged students*. Academic Press.

Hawes, D., & Arya, A. (2023). Technology solutions to reduce anxiety and increase cognitive availability in students. *IEEE Transactions on Learning Technologies, 16*(2), 278-291. https://doi.org/10.1109/TLT.2023.3239985

Ivankova, N. V. (2014). Implementing quality criteria in designing and conducting a sequential QUAN→QUAL mixed methods study of student engagement with learning applied research methods online. *Journal of Mixed Methods Research, 8*(1), 25-51. https://doi.org/10.1177/1558689813487945

Licorish, S. A., Owen, H. E., Daniel, B., & George, J. L. (2018). Students' perception of Kahoot!'s influence on teaching and learning. *Research and Practice in Technology Enhanced Learning, 13*, Article 9. https://doi.org/10.1186/s41039-018-0078-8

Mallow, J. V. (2006). Science anxiety: Research and action. In J. J. Mintzes (Ed.), *Handbook of college science teaching* (pp. 3-4). National Science Teachers Association.

Mashile, T. Z. (2017). *Technology integration and the digital divide: Understanding factors that impact on educators' ability to integrate technology in South African classrooms* [Master's thesis, University of Pretoria].

Mbete, A. (2022). *Gamification technology in teaching: Exploring how mathematics teachers make use of Kahoot! gamification to facilitate learning of probability in classrooms* [Master's thesis, Rhodes University].

Mdlalose, N., Ramaila, S., & Ramnarain, U. (2022). Using Kahoot! as a formative assessment tool in science teacher education. *International Journal of Higher Education, 11*(2), 43-51. https://doi.org/10.5430/ijhe.v11n2p43

Nabangi, L. N. (2021). *Exploring the use of gamification in the teaching and learning of English grammar in a private secondary school classroom in Mombasa County* [Unpublished master's thesis]. Aga Khan University.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1-13. https://doi.org/10.1177/1609406917733847

Öden, M. S., Bolat, Y. İ., & Goksu, İ. (2021). Kahoot! as a gamification tool in vocational education: More positive attitude, motivation and less anxiety in EFL. *Journal of Computer and Education Research, 9*(18), 682-701. https://doi.org/10.18009/jcer.924882

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*, 315-341. https://doi.org/10.1007/s10648-006-9029-9

Piaget, J. (1972). *The principles of genetic epistemology*. Basic Books, Inc.

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist, 50*(4), 258-283. https://doi.org/10.1080/00461520.2015.1122533

Plump, C. M., & LaRosa, J. (2017). Using Kahoot! in the classroom to create engagement and active learning: A game-based technology solution for eLearning novices. *Management Teaching Review, 2*, 151-158. https://doi.org/10.1177/2379298116689783

Ramaila, S. (2024). Harnessing Kahoot! as an educational tool to foster meaningful teaching and learning: A systematic review. *African Journal of Teacher Education, 13*(2), 1-12. https://doi.org/10.21083/ajote.v13i2.8017

Ramnarain, U., & Schuster, D. (2014). The pedagogical orientations of South African physical sciences teachers towards inquiry or direct instructional approaches. *Research in Science Education, 44*, 627-650. https://doi.org/10.1007/s11165-013-9395-5

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Press. https://doi.org/10.1521/978.14625/28806

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology, 61*, Article 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

Saunders, M., Lewis, P., & Thornhill, A. (2023). *Research methods for business students* (9th ed.). Pearson.

Silumesi, L. (2022). *An investigation of the difficulties in teaching and learning of genetics and related topics* [Master's thesis, University of South Africa].

Smith, M. K., & Knight, J. K. (2012). Using the genetics concept assessment to document persistent conceptual difficulties in undergraduate genetics courses. *Genetics, 191*(1), 21-32. https://doi.org/10.1534/genetics.111.137810

Tekkaya, C. (2002). Biyoloji kavramlarının anlaşılmasında kavram yanılgısı etmeni [Misconceptions as barrier to understanding biology]. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, 23*, 259-266.

Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M., & Stains, M. (2015). Research-based implementation of peer instruction: A literature review. *CBE – Life Sciences Education, 14*(1), Article es3. https://doi.org/10.1187/cbe.14-11-0198

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wang, A. I. (2015). The wear out effect of a game-based student response system. *Computers & Education, 82*, 217-227. https://doi.org/10.1016/j.compedu.2014.11.004

Wang, A. I., & Tahir, R. (2020). The effect of using Kahoot! for learning: A literature review. *Computers & Education, 149*, Article 103818. https://doi.org/10.1016/j.compedu.2020.103818

Yılmaz, S. S. (2023). Investigation of traditional and Web 2.0 supported (a sample of Kahoot) formative assessment and evaluation in science course. *Shanlax International Journal of Education, 11*(S1), 145-152. https://doi.org/10.34293/education.v11iS1-Oct.6689

https://www.ejmste.com