

Effects of Stem-Game-Based Learning on Genetics Achievement Among Northern Matriculation Students

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ABSTRACT - Game-based learning is an active learning method that uses games to help students learn by encouraging them to think critically and solve problems. In this work, the researchers employed a variation of STEM Game-Based-Learning that incorporates science, technology, engineering, and mathematics (STEM) components into the instruction of Genetics. This approach aligns with Sustainable Development Goal 4 (SDG 4), which emphasises inclusive and equitable quality education. The objective of the research was to investigate the impact of STEM-Game-Based-Learning on students' performance in the Genetics section of the Biology curriculum. A quasi-experimental research design was utilized, comprising two groups: an experimental group subjected to STEM-Game-Based-Learning and a control group undergoing traditional education. The sample comprised 45 randomly selected students from Penang Matriculation College (experimental group) and Perlis Matriculation College (control group). The control group's average score on the post-test was $M = 24.67$, $SD = 2.30$, whereas the experimental group's average score was $M = 27.22$, $SD = 2.10$. Analysis of covariance (ANCOVA) indicated a statistically significant disparity in accomplishment between the two groups, $F(1, 87) = 33.07$, $p = .001$, partial $\eta^2 = .28$, demonstrating that students engaged in STEM-Game-Based -Learning outperformed those subjected to traditional instruction.

INTRODUCTION

The Malaysian matriculation programmed biology syllabus is designed to provide students with a sound understanding and knowledge of Biology, which will accommodate the diversity in tertiary studies. Yet, this goal is difficult to reach, mainly due to students' enduring misunderstandings concerning basic genetic concepts. These misconceptions -related to genes, gene expression, inheritance, and mutation-constitute barriers to advance in learning of the biological sciences (Orcajo & Aznar, 2005). Recent systematic reviews support the view that misconceptions in biology are common, impede learning of ideas, and often prove resistant to remediation by conventional instruction. For example, Situmorang (2024) identified with a systematic literature review that digital game-based learning in biology education has implemented increasingly numerous simulation-based tools, but also many interventions do not clearly support deep conceptual change or lasting misconceptions for the most part (Situmorang, 2024). Students, in particular, have a hard time with genetics due to the abstract and symbolic nature of its content: it possesses complex and difficult vocabulary; it describes entities (genes, alleles, chromosomes) that are not directly visible; and mathematical or probabilistic thinking

is necessary in some aspects, such as Mendelian genetics (Williams et al., 2012). Because students have difficulty with abstract reasoning, concepts that are at the matriculation level may be learned with misconceptions or superficially.

Game-based learning (GBL), particularly within a STEM context, holds potential as an approach to tackle these issues. We use GBL to motivate, engage, and scaffold learning by applying gaming principles (story, challenge, feedback, interactive simulation). Trybus (2015) gives a broad concept of game-based learning as bringing gaming elements to real-world or curriculum-integrated environments, whereas Wilson, Colonge, and Henderson (2016) posit that games are beneficial in promoting collaborative and active learning, drawing on social constructivist theory. In recent years, empirical studies and meta-analyses have shown that game-based learning (GBL) in STEM can be more effective for learning outcomes than traditional instruction. Wang, Chen, Hwang, Guan, Wang (2022) conducted a meta-analysis and reported a moderated ES value for the overall effect sizes towards traditional in-class instruction for digital game-based STEM education; the pooled ES was 0.647 with an [95% CI=] interval [0.520– 0.814], from 33 studies involving 3,894 participants (Wang et al., 2022). Similarly, there are significant positive effects of digital game-based interventions on STEM learning outcomes, with stronger effects found in the areas of science and mathematics among primary school students (Behnamnia and Kamsin, 2024).

Further, the recent quasi-experimental study “Geneblock” examined student learning of fundamental biological concepts by gaming genetics and saw gains in conceptual understanding (Hue, 2025). Against this backdrop, the current research aims to explore the effects of STEM- Game-Based Learning in fostering matriculation students’ concepts regarding genetics, particularly focusing on conceptual accuracy, misconception replacement and development of scientific reasoning. The purpose is to contribute towards an understanding of whether or not STEM-Game-Based Learning is able to supplement and enhance the existing method of practice in the context of Malaysian matriculation for educators and curriculum developers. Thus, this study is to compare the STEM-Game-Based-Learning approach and the conventional approach on Matriculation students’ achievement in Genetics topic.

PROBLEM STATEMENT

Students in matriculation do not do well in Genetics. The candidate work report (LKC) for the PSPM (Matriculation Final Examination) shows that (1) 80% of candidates don't know how to find linked genes, (2) the candidate's weakness is that they don't write the steps correctly when calculating the distance between genes, (3) a small number of candidates are confused about incomplete dominance, (4) candidates are confused about the terms test-cross and self-cross, and (5) students didn't define linked genes. This LKC demonstrated that the poor scores of Matriculation students in Genetics are a little worrying for the teachers. So, there should be a way to fix things. Students find it hard to understand biological ideas, and genetics is one of these ideas. When students face problems, their motivation can drop (Etobro & Fabinu, 2017), and motivation is a key part of learning since it encourages and keeps the behaviors needed to finish learning activities and improves performance (Schunk, Pintrich, & Meece, 2012). Poor teaching of genetics is also partly to blame for the students' poor performance in the subject. Even though there have been several exploratory investigations on the problems of teaching and learning Genetics, there aren't any intervention solutions (Todd & Romine, 2018).

Recent literature corroborates and expands upon this worry. Meta-analyses of studies on game-based learning in STEM demonstrate that it can markedly enhance learning outcomes for young pupils relative to conventional teaching approaches (Arztmann et al., 2023). Another quasi-experimental project, “Geneblock,” likewise improved students’ conceptual grasp of genetics through a game-based method (Hue, 2025). A review of biology education indicates that games and simulations can effectively rectify students' misconceptions and enhance their academic performance; yet, numerous treatments do not accomplish the desired profound conceptual transformation (Situmorang, 2024). The absence of appropriate pedagogical strategies in Genetics instruction further exacerbates the low success levels among Matriculation students. Numerous exploratory studies have examined the challenges in the teaching and learning of Genetics; yet, the creation of methods to address these challenges remains insufficient (Todd & Romine, 2018). Consequently, this research must be

conducted to identify the most effective teaching tactics for this subject.

LITERATURE REVIEW

1.1 Concept in Science

The goal of Malaysia's biology curriculum is to teach students to be scientific-savvy, creative, and able to use what they learn about science to make decisions in their daily lives. It teaches how to learn, scientific skills, and values. The curriculum's goal is to give students information, skills in science and technology, and the ability to solve issues and make decisions based on scientific attitudes and good values (Ministry of Education Malaysia, 2012). Genetics is a field of biology that looks at genes, genetic differences, and how traits are passed down from one generation to the next. Gregor Mendel, a Moravian scientist from the 19th century, was the first to study genetics by looking at how features are handed down from parents to children through discrete units of heredity. This unclear definition of a gene is still in use today. Genetics can be hard to learn since it has many structures, processes, and procedures that make it hard for students to understand (Bahar, et al., 1999; Cimer, 2012; Duncan & Reiser, 2007; Schunk, et al., 2012).

1.2 Previous Research on Students' Performance in Genetics

A few studies in Southeast Asia also reported high levels of misconception and low genetics knowledge among pre-university or senior high school students. Gusmalini, Wulandari, & Zulfarina (2020) utilized the Blood CRI for Indonesian Grade XII science students, and 42.1% held misconceptions about Genetics related to the topic as a whole; 37.8% acquired an accurate understanding, and 22.4% did not know any concepts at all. Authors indicated that the lack of an overall scope and the hard genetics terminology that plays a role, particularly (Gusmalini et al., 2020). In Malaysia, Shukri (2022) developed a Three-Tiers Diagnostic Test in Genetics (3- TDTG) and implemented the test among 455 matriculation college students. Cohort data suggested the test was valid, reliable, and unveiled substantial misconceptions: false positive and false negative rates in student responses were non-trivial, indicating problems of understanding that persisted for students even upon matriculation (Shukri, 2022).

Outside South East Asia, a recent systematic review of the emerging literature from twenty-nine countries (Herak, Mahanal, Zubaidah & Novianti 2025) that span pre-university and secondary learners revealed biology students hold misconceptions in genetics (and other biological topics) which impede their capability to apply knowledge in new circumstances and limit depth on conceptual understanding. The review highlights that misconceptions are pervasive, especially if the instruction is in the traditional (lecture) mode and does not use either active or corrective feedback techniques (Herak et al., 2025). Similarly, the quasi-experimental study "Geneblock"(Hue, 2025) conducted with pre-university students reported that game-based learning resulted in significantly higher gains in Genetics concepts understanding compared to traditional teaching; however, at the end of it, some sub-concepts were found to be weak for which there is no answer and it highlights that achievement gap remain even after intervention (Hue, 2025).

1.3 STEM-Game-Based Learning

In the past science, technology and math used to be four different subjects in schools (Capraro & Slough, 2013). However, the two topics are interrelated in practice (Banks and Barlex 2014). STEM is a new field that brings together science, technology, engineering and mathematics. This interdisciplinary approach may help students apply STEM concepts in practical courses that contribute to improving cognitive and skill development. Teachers and legislators alike are embracing the current push for STEM education, largely because they believe that if we engage young people to become more proficient with STEM skills then there will be more professionals in those fields (Trna & Trnova, 2015). So, it's critically important that we provide students with the skills and deep conceptual base they need in STEM for overcoming hurdles and remaining competitive throughout their turbulent, unpredictable careers.

A mixed picture of progress and challenges are emerging from estimations on STEM education in Malaysia. According to new statistics, the proportion of students participating in STEM at upper

secondary school level has risen slightly from 45.7 percent in 2023 to 50.8 percent, but the national target ratio of 60:40 between stem and non-stem enrolment is still not reached. In addition, research and initiatives in STEM are dominated by selected states, and issues including sustainability and gender equity surface repeatedly. However, some limitations remain especially in terms of controlled interventional studies that assess the efficacy of instruction methods in STEM (Syed Taufiq Akmal Syed Nasiruddin et al., 2025).

1.4 Past Studies in STEM-Game-Based Learning

Recent worldwide evidence suggests that STEM-Game-Based Learning can enhance Genetics learning of students by linking interactive problem solving with immediate feedback and repeated retrieval. In a quasi-experimental study examining the effects of game-based productive failure versus direct instruction on conceptual understanding, statistically significant improvements were found in students' conceptual understanding through using game features to prompt student-generated solutions before formal instruction (Cao, Lai, & Yang, 2023). In Indonesia, results demonstrated that a secondary-educated digital game-based flipped-classroom model could enhance the Genetics concept mastery Level of lower-secondary students, showing that structured gameplay plus pre-class activity learning may reinforce symbolic-probabilistic reasoning in Mendelian problems (Ristanto, 2022). These domain-specific findings are consistent with larger reviews, which indicate that digital game-based learning in STEM elicits moderate and reliable cognitive benefits relative to non-digital alternatives, when games are instructionally aligned and feedback is informative (Barz et al., 2024; Wang et al., 2022).

In Malaysia, a new quasi-experimental intervention called *Geneblock* was tested as part of genetics curriculum instruction using a purpose developed digital game that led to significantly greater students' genetics knowledge than traditional teaching methods in which peer interaction and challenge, feedback cycles served as essential learning mechanisms (Hue & Lee, 2025). Related work from Malaysia revealed that biology notes when gamified had raised students' level of engagement as well motivation to learn at secondary and pre-university levels, suggesting the potential effect of structured game elements for genetics in classrooms, although genetics-specific efficacy studies are not common (Che Ahmad et al., 2021). Overall, these studies indicate an intervention, in the Malaysian scenario where appropriate STEM-Game-Based-Learning has been designed with genetics learning outcomes and assessment objectives, it is possible to improve students' achievement as well as overcome continued misconceptions hence justifying further RCTs at matriculation or A-Level (Hue & Lee, 2025; Che Ahmad et al., 2021).

1.5 Learning Theory

Psychologists have long recognized the significance of play in cognitive development and education. For instance, Piaget (1962) said that play is an important part of and changes with children's cognitive development. Piaget posited that play evolves into increasingly abstract, symbolic, and social forms as children progress through various developmental stages. One way that play is thought to help kids learn is by engaging their schemas in ways that help them go beyond their immediate reality. For instance, a child can believe that an eraser is a car, even if they know it isn't a car. Vygotsky (1978) posited that play is a "leading factor" in children's development, facilitating their achievement of tasks beyond their current capabilities. Vygotsky's constructivist theory posits that the interplay of interpersonal, cultural-historical, and individual elements is fundamental to human development. Interactions with individuals in the environment catalyze developmental processes and promote cognitive growth, however they do not serve to convey knowledge. Vygotsky's theory posits that learning and development are inextricably linked to their setting. He thought that kids with mental or physical difficulties learned in a different way than kids who didn't have those problems.

METHODS AND MATERIALS

2.1 Research Design

The research employed a quasi-experimental design to evaluate the efficacy of various teaching methodologies. Researchers chose a sample of 90 students from a class that was neither interrupted or changed, which allowed them to keep a close eye on outside risks. The research investigated the influence of independent variables on dependent variables within colleges, pedagogical approaches, and courses.

2.2 Sample and Population

The study focuses on 18 to 20-year-old matriculation students in two colleges in the north of Malaysia, who are studying for the One Year Programme (PST). Some are picked according to where they live and what they've studied, including physics, chemistry, biology, math and English. A total of 90 students in Penang Matriculation College and Perlis Matriculation College with similar cognitive and academic foundations participated in the study. In both schools, STEM-Game-Based-Learning was used as a means to teach and there was a control group. Two biology teachers were trained twice to ensure that they became familiar with STEM-Game-Based-Learning teaching strategies. Both of the lecturers were from the north of the peninsula.

2.3 Sampling Technique

The sample procedure is two stage: first, you choose two matriculation institutions that are the same in status, and then you randomly select one class from each. The study is designed with the simplification of briefing, training and implementation in mind. The biology at the two colleges is taught from the Matriculation Division's syllabus. The lecturers are qualified and the student's nationals of analogous culture, economy and society. The goal is to understand how those things influence student achievement in Genetics and other courses.

2.4 Data Collection

Google Drive and Google Form app would be applied for the scientific data collection in an orderly manner. The researchers have taken steps to ensure the study is real, like turning questions about genetics into a test that everyone must answer. Samples are also instructed that answering data collection is not a test/assessment and that the answer order changes every time you get asked a question on a new sample

2.5 Validity and Reliability

(IV) A pilot study was conducted on 45 Module I Matriculation Students to evaluate their level of understanding in Genetics. The purpose of the study was to determine the reliability of pre-test and post-test instruments, since dependability is needed in accurate assessment results. Specialists on the area reviewed the instrument and revised it after implementation of the pilot study, including question wording and types to ensure adequacy and proper reporting for validity.

The questionnaire was validated by three experts consisting of two Biology lecturers who serve in Penang Matriculation College and one English lecturer in Kedah Technical Matriculation College. They provided feedback on the content and constructions. The panel of experts ensures the evaluation is accurate and lucid. Reliability test Kuder Richardson 20 will be carried out for the reliability test since the item is of different level of difficulty. When the value of trust earned is calculated, it ends up being 0.92. Lim (2007) indicates the value of reliability coefficient from the pilot study results was observed and compared with those in table of reliability. An ICC greater than .7 is strongly supported. Therefore, they all are authorized to be used in this study.

RESULT AND DISCUSSION

3.1 Descriptive Analysis

Table 1. Descriptive Data of the Pre-Test

	Group	
	STEM-Game-Based-Learning	Conventional Approach
Mean	22.80	22.31
Standard Deviation	2.45	2.27
Minimum	19.00	19.00
Maximum	28.00	28.00
Skewness	.30	.72
Kurtosis Value	-1.07	-.37

Source: Researcher's Data from The Quasi-Experimental Study on The Effect Of STEM-Game-Based-Learning and Conventional Approaches on Genetics Achievement Among Matriculation Students (2023).

Table 1 displays descriptive statistics illustrating pre-tests for students from both groups. The average score for the experimental and control student groups shows that the Genetic Achievement Test results are quite similar ($M=22.80$, $SD=2.45$) and ($M=22.31$, $SD=2.27$). The pre-Test of Genetics Achievement has a skewness value that ranges from $-.30$ (STEM-Game-Based-Learning technique) to $-.72$ (Conventional approach). The kurtosis value for the pre-Test of Genetics Achievement falls between -1.07 (STEM-Game-Based-Learning approach) and -0.37 (Conventional approach). All of these skewness and kurtosis values are in a very good range (-1.96 and $+1.96$), which means they can be used for research (George and Mallery, 2018).

Table 2. Descriptive data of the post-test of Students' Achievement

	Group	
	STEM-Game-Based-Learning Approach	Conventional Approach
Mean	27.22	24.67
Standard Deviation	2.10	2.30
Minimum	23.00	20.00
Maximum	30.00	29.00
Skewness	-.46	-.20
Kurtosis Value	-.95	-.60

Source: Researcher's Data from The Quasi-Experimental Study on The Effect Of STEM-Game-Based-Learning and Conventional Approaches on Genetics Achievement Among Matriculation Students (2023).

The descriptive analysis indicates that the minimum post-test score for the Genetics Achievements Test is 23 for the STEM-Game-Based-Learning approach and 20 for the conventional technique. The maximum score is 30 for the treatment groups of students and 29 for the control group. The mean scores of the post-test shown a significant difference following the intervention, with values of ($M=27.22$, $SD=2.10$) and ($M=24.67$, $SD=2.30$). The descriptive analysis findings also showed that all of the shuffling and kurtosis values were in a very good range, between -1.96 and $+1.96$.

Table 3. Genetic Achievement mean score in the post-test between the group of students who took part in STEM-GBL teaching approach and Conventional approach

Group	Number	Mean score	Standard deviation	Difference in mean score (Compare with pre-test)
STEM-Game-Based-Learning approach	45	27.22	2.10	4.42
Conventional approach	45	24.67	2.30	2.36

Source: Researcher's Data from The Quasi-Experimental Study on The Effect Of STEM-Game-Based-Learning and Conventional Approaches on Genetics Achievement Among Matriculation Students (2023).

The average score for the experimental group on the post-test for the Genetic Achievement Test was (M=27.31, SD=2.10), while the average score for the control group was (M=24.67, SD=2.30). Students in the experimental group (STEM-Game-Based-Learning) have their post-test scores go up by 4.42 points, while students in the control group only have their scores go up by 2.36 points. The experimental group's students did better than the control group's students.

3.2 Statistic Inferential

Table 4. ANCOVA analysis for Students' Achievement between Treatment Group and Control Group

Dependent Variable: Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	256.285 ^a	2	128.143	35.231	.000	.447
Intercept	223.418	1	223.418	61.426	.000	.414
Pre-test	109.341	1	109.341	30.062	.000	.257
Group	120.289	1	120.289	33.072	.000	.275
Error	316.437	87	3.637			
Total	61153.000	90				
Corrected Total	572.722	89				

Source: Researcher's Data from The Quasi-Experimental Study on The Effect Of STEM-Game-Based-Learning and Conventional Approaches on Genetics Achievement Among Matriculation Students (2023).

F (1,87) = 33.07, p=.001, partial eta squared = .28; the result is significant as p<.05. After controlling for pre-test results, there is a significant difference in the mean scores for the post-test between the treatment group that employs the STEM-Game-Based-Learning teaching strategy and the control group. So, **H₀₁ is not accepted.**

Table 5. Univariate Tests- Effect Size (Students' Achievement)

Dependent Variable: Post-test

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	120.289	1	120.289	33.072	.000	.275
Error	316.437	87	3.637			

Source: Researcher's Data from The Quasi-Experimental Study on The Effect Of STEM- Game-Based-Learning and Conventional Approaches on Genetics Achievement Among Matriculation Students (2023).

The Partial Eta Squared score is .28, which is a medium effect size based on Cohen's 1988 recommendations. This number also shows how much of the change in the dependent variable can be explained by the independent variable. In this case, we can only explain 28% of the difference.

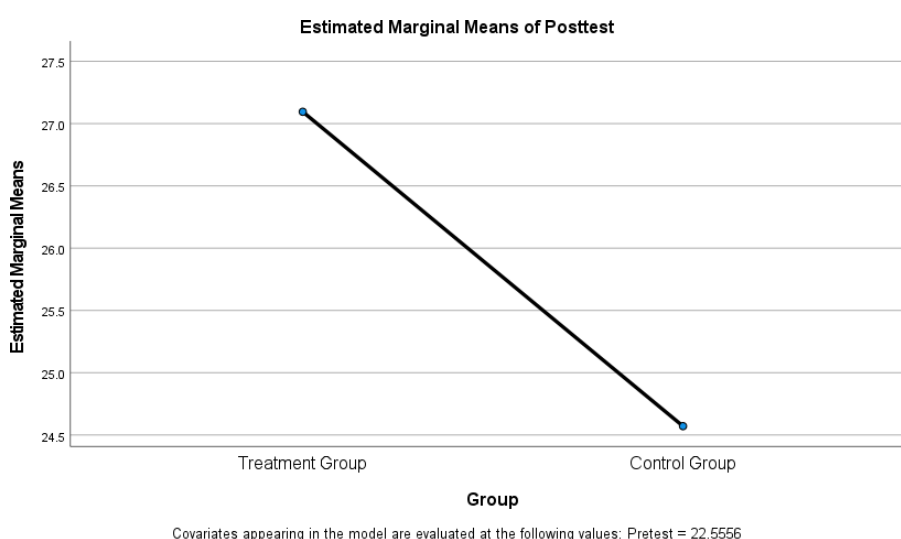


Figure 1. Estimated Marginal Means of Post-Test- (Students' Achievement)

Source: (Researcher's Data from The Quasi-Experimental Study on The Effect Of STEM-Game-Based-Learning and Conventional Approaches on Genetics Achievement Among Matriculation Students (2023).

The anticipated marginal effect of STEM-Game-Based-Learning on student achievement is 28 percent ($p < 0.05$). When pre-test scores are the same, students who use the STEM-GBL teaching method do 28% better than students who use the traditional method.

After the training is done for both the experimental and control groups, the post-test is given to evaluate if there has been any change in how well they learned Genetics. The investigation revealed a considerable enhancement in the experimental group's achievement in learning Genetics compared to the control group. The experimental group of students ($M=4.42$) did better than the control group of students ($M=2.36$), which revealed that the STEM-Game-Based-Learning teaching method worked well to improve the students' understanding of Genetics. The ANCOVA analysis yielded $F(1,87) = 33.07$, $p = .001$, and a partial eta squared value of .28, indicating a significant result as $p < .05$.

The research conducted by Ezeugwu, J.J.O., Onuorah, J.C., Asogwa, U.D., and Ukoha, I.P (2016) examined the impact of game-based instructional techniques on students' achievement and interest in Algebra at the fundamental educational level. The research employed a quasi-experimental, non-equivalent control group design, utilizing all JSS II students in Obio-Akpor. We employed Analysis of Covariance (ANCOVA) to evaluate the hypotheses at a $p < 0.05$ level of significance. The outcome indicated that the implementation of game-based instructional methodologies in education influences

student accomplishment.

These results are also in line with previous empirical research, which has shown that game-based teaching and learning can have a positive effect on students' academic performance. For instance, Ezeugwu et al. Effects of Game-based instructional techniques on students' achievement and interest in algebra at the junior secondary school using quasi-experimental, non-equivalent control group design were examined by (2016). Their research, which also used ANCOVA with a $p < .05$, found students instructed by game-based method performed significantly better than students who were on traditional method. These researchers concluded that games combined with practice contribute to a greater awareness and activated engagement of the learner, which results in better academic performance. Collectively, the results of both the current study and those of Ezeugwu et al. (2016), suggest that game-based learning, when embedded with STEM features is quite effective to enhance students' achievement. In small sample of Genetics students is suggested that the STEM-GBL approach can contribute to a deep cognitive involvement, a greater activity and motivation in learning, resulting to meaningful conceptualization aiding learning by understanding. These findings highlight the pedagogical implications of integrating high quality design game of playing learning in science teaching for improving students' academic performance.

CONCLUSIONS

This study examined the effects of the STEM–Game-Based Learning approach on matriculation students' achievement in Genetics, comparing it with conventional teaching practices and considering the density of lesson content. The findings indicate that the STEM-Game-Based Learning approach positively influences students' achievement by creating more engaging, interactive, and meaningful learning experiences. However, no significant differences were observed across gender groups. Further research is recommended to explore the instructional quality of STEM-Game-Based Learning, as well as its acceptance and readiness among lecturers, to ensure effective and sustainable implementation in the matriculation context.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHORS CONTRIBUTION

Author 1.: Conceptualization, Methodology, Data curation, Writing- Original draft preparation

Author 2.: Writing- Reviewing and Editing.

AVAILABILITY OF DATA AND MATERIALS

Data available on request due to privacy/ethical restrictions.

DECLARATION OF GENERATIVE AI

During the preparation of this manuscript, the authors used **ChatGPT (OpenAI)** to enhance the clarity and coherence of the writing. Following the use of this tool, the authors critically reviewed and edited the content as necessary and take full responsibility for the accuracy, originality, and integrity of the published work.

ETHIC STATEMENTS

Not applicable

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