JOURNAL OF BIOLOGY EDUCATION
J O B E
E-ISSN 2656-3436/ P-ISSN 2615-3947
IAIN KUDUS
http://journal.iainkudus.ac.id/index.php/jbe

Descriptive Evaluation of Artificial Intelligence in Solving Problems Related to Basic Concepts of Population Genetics

Priyambodo[1]*, Nindy Permatasari[2]
[1]Department of Biology, Universitas Lampung, Indonesia
[2]Department of Crops Cultivation, Politeknik Negeri Lampung, Indonesia
*Corresponding Author: priyambodo@fmipa.unila.ac.id

ABSTRACT

Population genetics is a study area in genetics that requires not only knowledge of genetic concepts, but also the numerical ability to predict the condition of allele frequencies in the population. In recent years, artificial intelligence (AI) has become part of the technological advances that humans utilize, including in studying population genetics. Therefore, it is necessary to ascertain that the information provided by AI has high accuracy and consistency. This research aimed to analyzed accuracy and consistency of several number of AI to solved the problem related to population topics. This research has been conducted using five different AIs (ChatGPT, Gemini AI, Deep AI, ChatSonix AI, and Perplexity AI). These five different AIs tested on two different laptops that connected to different accounts with different search histories. Each AI on the two laptops was asked by questions at six different levels of Bloom's taxonomy. All responses given by the AIs were manually corrected by two separate genetics lecturers from different institutions independently. Results showed that all AIs were highly accurate in their responses to all questions. On to the other side, each type of AI on two different laptops gave responses with different sentence structures, however, they had the same meaning. This research contributes to the development of the use of AI in population genetics studies.

Keywords: AI, accuracy, consistency, population genetics.

INTRODUCTION

Genetics is among the essential studies of the biological discipline. Genetics study a various aspect of heredity and variation. The genetics further categorized into several branches of genetics study, such molecular genetics, Mendelian genetics, quantitative genetics, and population genetics (Táriba, 2023). The study of population genetics deals with has been a genetic diversity in population and related to mechanisms of evolution (Hartl and Clark, 2007). Population genetics is the study of genetic diversity in populations, studied from the very basic concept of the emergence of variation to how this condition of this genetic variation from one generation to the following generation. The state of variability in a population can either

remain stable or fluctuate. The fluctuation of the genetic variation in population over generation could be influenced by various factors, including genetic drift (Láruson & Reed, 2021).

Accordingly, population genetics reflects a number of studies of basic concepts and factors that make population fluctuation possible. Basic concepts include gene flow, mutation, genetic drift, and natural selection (Charlesworth and Charlesworth, 2010). Concepts and principles of population genetics are fundamental for understanding the dynamics of genetic variation within populations and the processes shaping the evolutionary trajectories (Nielsen and Slatkin, 2013). Analysis of those dynamics of population was so complex and complicated. Computation is needed in explaining the intricacy of population genetic models by analyzing and giving meaning to the high volumes of genomic data generated by modern technologies of sequencing (Kelleher et al., 2018). As we move closer to the era of big data and artificial intelligence (AI), the integration of these technologies into the field of population genetic research offers both exciting prospects and challenges (Libbrecht and Noble, 2015).

The rapid development of AI has affected changes in several areas of biological science, such as bioinformatics and computational biology (Lai et al., 2018). This condition refers to enhancing the methodology for the use of AI in meaningful ways while analyzing complex genetic datasets, estimating evolutionary trends, and solving intricate problems in population genetics (Schrider and Kern, 2018).

The use of AI, characterized by its expertise in identifying patterns, mining data and building predictive models, offers a promising path to overcome computational barriers in the field of population genetics (Sheehan and Song, 2016). Machine learning techniques have proven particularly effective in a variety of applications, including inference over demographic history, selective sweep identification, and phylogenetic tree reconstruction (Schrider and Kern, 2018). However, the integration of AI to solve issues that emanate from the fundamental theory in population genetics is a field that also needs extensive research and robust criticism (Laland et al., 2015).

The phenomenon of Artificial Intelligence (AI) as a pedagogical support mechanism is fundamentally centered around the enhancement of educational experiences by strategically leveraging the capabilities of machine intelligence to thoroughly analyze and adeptly utilize data in a highly effective manner. The significance of AI within the educational realm is crucial, particularly in its ability to effectively address and mitigate the inherent limitations associated with traditional educational methodologies, which frequently fail to adequately accommodate the varied and diverse needs of all students enrolled in academic programs. Through the process of personalizing educational experiences tailored to individual learning styles and needs, AI possesses the capacity to profoundly enhance student engagement as well as significantly improve overall educational outcomes, thereby contributing positively to the learning environment. In the subsequent sections, a more detailed exploration of the multifaceted impact that AI has as an educational aid will be presented and discussed comprehensively. Among the various AI tools available, ChatGPT serves as a notable example,

as it not only facilitates rapid information retrieval but also provides immediate responses to inquiries posed by students, thereby enhancing the level of student engagement and making the overall learning experience considerably more interactive and dynamic (Wiyono et al., 2024). Moreover, the integration of such advanced technological tools into the educational framework symbolizes a transformative shift that holds the potential to redefine the landscape of learning for future generations. Ultimately, the relentless pursuit of research and advancements in the domain of AI keeps unveiling new possibilities for enhancing educational methods, thereby accentuating the pressing necessity for educators and academic institutions to welcome these advancements for nurturing a more efficient and inclusive learning landscape for every student.

The application of AI within population genetics brings new avenues for novel extensions in the study of genetic relationships and evolutionary trends (Sanchez et al., 2020). Moreover, AI agents operating in simulated contexts exhibit population dynamics similar to natural systems, providing valuable insights into collective behavior and evolutionary adaptation (Yang et al., 2017). Moreover, artificial neural networks (ANN) have demonstrated improved classification capabilities in assessing genetic diversity compared to traditional statistical approaches (Sant'Anna et al., 2015). These below-mentioned innovations outline the role of AI in addressing basic challenges to population genetics and facilitate the elaboration of new techniques and applications.

While AI has huge potential to advance the state of research in population genetics, we have to become aware of shortcomings and challenges with its use-including huge dataset requirements and over-application risks with sophisticated models. Balancing these considerations is critically going to be important for the effective integration of AI into science. This article attempts to assess the effectiveness and capabilities of various artificial intelligence methodologies in addressing problems related to basic principles of population genetics. By examining the advantages and limitations of AI algorithms in this area, we aim to provide insight into the ability of AI algorithms to improve our understanding of the mechanisms of evolution and genetic variability (Lazaridis et al., 2014). Furthermore, this research will help identify areas where AI can complement traditional analysis techniques in population genetics and highlight potential shortcomings or biases that may arise from the application of this technology (Libbrecht and Noble, 2015).

Although there is a notable trend toward the assimilation and use of artificial intelligence tools, in multiple educational frameworks and settings, the extent to which these tools manifest pedagogical reliability and preserve consistency across a wide array of cognitive domains, especially in niche areas like computational biology centering on complex issues such as population genetics, is still a field that has not been adequately investigated or analyzed in detail.

This review focuses on five AI platforms modeling central challenges in population genetics, namely frequency of allele inference, genetic drift modeling, and selection pressure simulation. We aim to provide an overall picture with regard to the current capabilities of AI methodologies, comparing the effectiveness of these AI methodologies to existing theoretical

frameworks and empirical observations, as well as their possible contributions in the future to population genetics.

The findings from this review will add to the current debate on the role of AI in biological research and will inform future developments in computational infrastructure for population genetics. As we further tease apart the complexity of genetic variation and evolutionary dynamics, the interaction of artificial intelligence with population genetics may outline discoveries and methods that enhance our understanding of basic life processes.

METHOD

Research Design

The research was conducted in 6 stages (Figure 1). The research was performed by manually testing the accuracy and consistency of the answers presented by the chatbox feature provided by 5 different types of artificial intelligence on 2 different laptop brands. The problems given were in the form of 6 questions in different categories of Bloom's taxonomy. The problems that were asked were straightforward questions, without any specific prompts for each problem. Furthermore, the answers given by 5 types of artificial intelligence on 2 different laptop brands were tested separately by two genetics lecturers from two different institutions who have more than 2 years of experience each. The correctness and consistency of the answers presented by the artificial intelligence were displayed as percentages and analyzed descriptively.

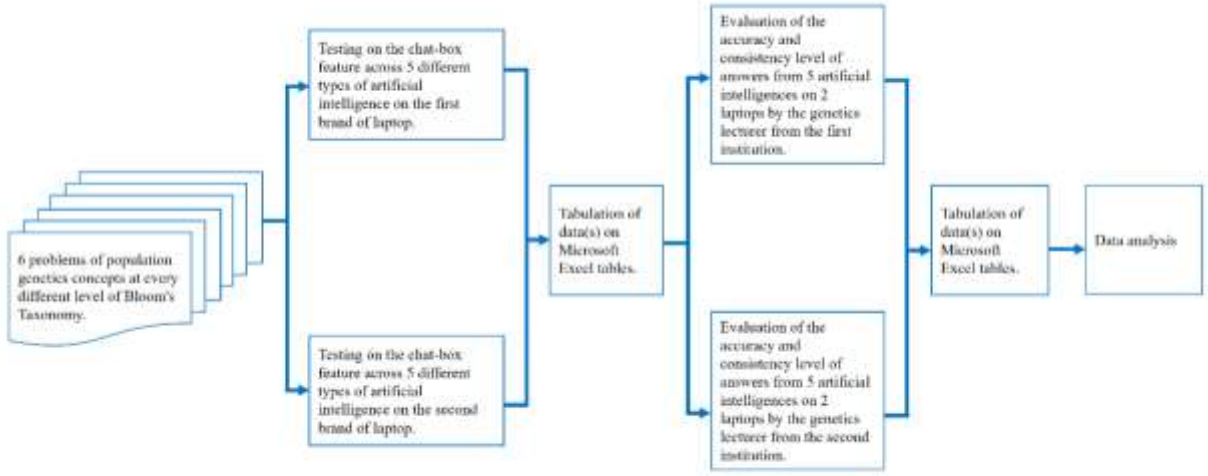

Figure 1. Research design chart

Problems to be solved

The problems to be solved by artificial intelligence are problems about the basic concepts of population genetics. The selected problems on the topic of population genetics are six questions with different levels of difficulty based on Bloom's Taxonomy. The six questions are related to the study of Hardy-Weinberg Law, which is one of the important concepts in the

study of population genetics. The scientific questions presented were 1 question for each category of Bloom's taxonomy, (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation (Table 1).

Table 1. Problems to be solved

Problem Number	Categories in Bloom's Taxonomy	Problems to be solved
1	Knowledge	Given the Hardy-Weinberg equation define term: p^2, q^2, 2pq; If given p + q = 1, and p = 0.7, please calculate q!
2	Comprehension	Describe the assumptions of the Hardy-Weinberg equation and its uses as a null hypothesis. What does 2pq represent in the Hardy-Weinberg equation?
3	Application	Determine the expected number of homozygous recessive individuals in a population if the recessive allele is represented in 30% of that population
4	Analysis	Determine if the following population is in HW equilibrium: 100 individuals of which 37 are SS, 8 are ss, and 55 are Ss. Defend your answer!
5	Synthesis	Create a new version of the Hardy-Weinberg equation that incorporates 3 alleles
6	Evaluation	Analyze Chi-square resuts to weigh predicted evolutionary flux

Source: (Crowe et al., 2008).

Type of Artificial Intelligence, Laptop Brand, and Prompt Structure Used

The five types of artificial intelligence used include (1) ChatGPT, (2) Gemini AI, (3) Deep AI, (4) ChatSonix AI, and (5) Perplexity AI. While the laptop brands used are (1) MSI Modern 14 B4MW with AMD Ryzen 3 4300U Processor specification, and (2) ASUS Vivobox M3400QA with AMD Ryzen™ 5 5600H Mobile Processor specification. The two laptops are connected to their respective artificial intelligence accounts, so they have different search histories on search engines, social media, and other history.

The prompts given to each artificial intelligence on the two different laptop brands consisted of 4 types of prompts (Table 2). The four types of prompts include, (1) initial prompt, (2) main prompt in the form of problems discussed (Table 1), (3) intermediate prompt, and (4) closing prompt.

Table 2 Structure of Prompts Used

Prompt-	Prompt Type	Prompt Description
1	Initial prompt	Hello <types of artificial intelligence>! Nice to meet you. I would like to ask for help to solve a problem about

Prompt-	Prompt Type	Prompt Description
		Hardy Weinberg's Law which is one of the basic concepts in population genetics.
2	Main prompt 1	My first question is stated bellow: Given the Hardy-Weinberg equation define term: p^2, q^2, 2pq; If given p + q = 1, and p = 0.7, please calculate q!
3	Intermediate prompt 1	Great! Thank you! I have another question.
4	Main prompt 2	And my second question stated bellow: Describe the assumptions of the Hardy-Weinberg equation and its uses as a null hypothesis. What does 2pq represent in the Hardy-Weinberg equation?
5	Intermediate prompt 2	Wow, you are deserved to get my two thumbs up!
6	Main prompt 3	My third question is: Determine the expected number of homozygous recessive individuals in a population if the recessive allele is represented in 30% of that population
7	Intermediate prompt 3	Many thanks. I have two more questions.
8	Main prompt 4	My 4th question, is bellow: Determine if the following population is in HW equilibrium: 100 individuals of which 37 are SS, 8 are ss, and 55 are Ss. Defend your answer!
9	Intermediate prompt 4	Thanks <types of artificial intelligence>. Now, lets move to my next question.
10	Main prompt 5	The question stated bellow: Create a new version of the HardyWeinberg equation that incorporates 3 alleles
11	Intermediate prompt 5	You are so nice. Actually, i have one more question.
12	Main prompt 6	Please resolve this question, Analyze Chi-square resuts to weigh predicted evolutionary flux
13	Closing prompt	Thank you <types of artificial intelligence>! Your answer so valuable.

Data Tabulation, Evaluation, and Data Analysis

The responses displayed by each artificial intelligence for each question (for main prompt) were tabulated in 1 systematic table in order to proceed to the next process. The tabulated responses were evaluated manually by two genetics lecturers. The requirements of the lecturers who provide assessments are that they have at least 2 years of experience teaching genetics courses, do not belong to the same institution, and perform assessments separately.

The accuracy and consistency of each AI's answer to each question was assessed based on a modified Likert scale. The accuracy of the answer is assessed based on the correctness of the answer given by the chatbox engine of each AI. The accuracy of the answer is scored as follows:

Score 0 : if the answer is wrong,
Score 1 : if the answer is correct but the reason/explanation is not correct, and
Score 2 : if the answer is correct and the reasoning/explanation is correct.

Consistency of answers is assessed by comparing chatbox machine answers from the same intelligence on different laptop brands. The consistency score is as follows:

Score 0 : if the answers displayed are different in sentence structure and meaning,
Score 1 : if the answer is different in sentence structure, but has the same sentence meaning,
Score 2 : if the answer is correct and the reason/explanation is correct.

Analysis of the results of the manual evaluation is presented with percentage numbers on each item and the analysis is done descriptively.

RESULT AND DISCUSSION

Accuracy of Responses Provided by AI

A total of 5 different AI types were tested with 6 different main-prompts at different Bloom's Taxonomy levels on the concept of population genetics. The tests were conducted in parallel on 2 different laptops with different accounts and different search histories. The results of the assessment of the responses given by the 5 AIs on the 2 different laptops to the 6 questions on the concept of population genetics showed perfectly accurate answers (Table 5).

Table 5. Tabulation of the evaluation on accuracy of responses provided by AI

Maint Prompt-	Types of Artificial Intelligence	Laptop Brand	Accuracy of Response	
			Manual Assessment by Genetics Lecturer 1	Manual Assessment by Genetics Lecturer 2
1	ChatGPT	MSI	2	2
1	ChatGPT	ASUS	2	2
1	Gemini AI	MSI	2	2
1	Gemini AI	ASUS	2	2
1	Deep AI	MSI	2	2
1	Deep AI	ASUS	2	2
1	ChatSonix AI	MSI	2	2
1	ChatSonix AI	ASUS	2	2

Maint Prompt-	Types of Artificial Intelligence	Laptop Brand	Accuracy of Response	
			Manual Assessment by Genetics Lecturer 1	Manual Assessment by Genetics Lecturer 2
1	Perplexity AI	MSI	2	2
1	Perplexity AI	ASUS	2	2
2	ChatGPT	MSI	2	2
2	ChatGPT	ASUS	2	2
2	Gemini AI	MSI	2	2
2	Gemini AI	ASUS	2	2
2	Deep AI	MSI	2	2
2	Deep AI	ASUS	2	2
2	ChatSonix AI	MSI	2	2
2	ChatSonix AI	ASUS	2	2
2	Perplexity AI	MSI	2	2
2	Perplexity AI	ASUS	2	2
3	ChatGPT	MSI	2	2
3	ChatGPT	ASUS	2	2
3	Gemini AI	MSI	2	2
3	Gemini AI	ASUS	2	2
3	Deep AI	MSI	2	2
3	Deep AI	ASUS	2	2
3	ChatSonix AI	MSI	2	2
3	ChatSonix AI	ASUS	2	2
3	Perplexity AI	MSI	2	2
3	Perplexity AI	ASUS	2	2
4	ChatGPT	MSI	2	2
4	ChatGPT	ASUS	2	2
4	Gemini AI	MSI	2	2
4	Gemini AI	ASUS	2	2
4	Deep AI	MSI	2	2
4	Deep AI	ASUS	2	2
4	ChatSonix AI	MSI	2	2
4	ChatSonix AI	ASUS	2	2
4	Perplexity AI	MSI	2	2
4	Perplexity AI	ASUS	2	2
5	ChatGPT	MSI	2	2
5	ChatGPT	ASUS	2	2
5	Gemini AI	MSI	2	2
5	Gemini AI	ASUS	2	2
5	Deep AI	MSI	2	2
5	Deep AI	ASUS	2	2
5	ChatSonix AI	MSI	2	2
5	ChatSonix AI	ASUS	2	2
5	Perplexity AI	MSI	2	2
5	Perplexity AI	ASUS	2	2
6	ChatGPT	MSI	2	2
6	ChatGPT	ASUS	2	2
6	Gemini AI	MSI	2	2

Maint Prompt-	Types of Artificial Intelligence	Laptop Brand	Accuracy of Response	
			Manual Assessment by Genetics Lecturer 1	Manual Assessment by Genetics Lecturer 2
6	Gemini AI	ASUS	2	2
6	Deep AI	MSI	2	2
6	Deep AI	ASUS	2	2
6	ChatSonix AI	MSI	2	2
6	ChatSonix AI	ASUS	2	2
6	Perplexity AI	MSI	2	2
6	Perplexity AI	ASUS	2	2

All the answers given by each AI on the concept of population genetics were highly precise and accurate. In answering the first main prompt, where the question was more related to the basic understanding of the concept of population genetics, AIs gave answers systematically. In this first main prompt, the five AIs each described what was known based on the question, and then applied the equation to the basic concept of calculating allele frequency. In inquiries that involve elevated tiers of Bloom's taxonomy, particularly within the fifth and sixth principal queries, each of the five categories of artificial intelligence articulated accurate and methodical responses. The responses provided by the AIs exemplify their profound comprehension of the parameters established by the information within the question, allowing them to synthesize contextually relevant answers.

The capability of AI to deliver precise and reliable responses is attributable to its sophisticated methodologies and the amalgamation of various techniques that augment understanding and reasoning. For example, frameworks such as Dynamic Neural Networks employ compositional temporal attention, facilitating a more nuanced interpretation of intricate questions and furnishing justifications for their predictions (Bendre et al., 2021). Moreover, Large Language Models (LLMs) have demonstrated efficacy in clinical environments, exhibiting enhanced readability and dependability, which are vital for patient education (Lim et al., 2024). In addition, the utilization of AI in embryo quality evaluation illustrates its accuracy in scrutinizing heterogeneous data, attaining elevated accuracy levels through rigorous training on extensive datasets (Gunjan et al., 2024). These developments emphasize the value of personalized strategies and the talent to efficiently manage extensive data sets, yielding better outcomes in numerous sectors, including promotion (Yang et al., 2021) and academia (Singh et al., 2021).

AI systems, particularly those grounded in sophisticated machine learning methodologies, have exhibited extraordinary proficiency in delivering precise and accurate responses across a diverse array of disciplines, notably within the domain of biology, specifically population genetics. This adeptness can be ascribed to several pivotal elements intrinsic to the architecture and operational capabilities of AI. At the outset, AI systems are equipped to examine and evaluate extensive datasets at speeds that significantly outpace human skills, thus assisting in the discovery of complex patterns and relationships that could

easily evade observation (LeCun et al., 2015). Secondly, these systems demonstrate a remarkable consistency in their decision-making mechanisms, devoid of the fatigue or cognitive biases that may influence human judgment. AI's potential, notably through deep learning techniques, to detect and understand sophisticated patterns in information further increases their reliability in tasks spanning from visual recognition to linguistic processing (Goodfellow, 2016). Additionally, the swift computational power of AI permits the simultaneous exploration of multiple solution trajectories, frequently resulting in more favorable outcomes (Mitchell, 2019). It is essential to understand that the correctness and trustworthiness of artificial intelligence technologies are profoundly affected by the standard and representativeness of their training information, along with the applicability of their algorithms to the particular issues they strive to tackle. While AI can yield remarkable performance in numerous domains, particularly those characterized by well-defined problems and extensive datasets, its limitations in addressing nuanced, context-sensitive situations or ethical quandaries must be duly acknowledged (Marcus and Davis, 2019).

ChatGPT's capacity to render accurate responses concerning the issue of genetic population is likely derived from its foundation in the Generative Pre-Trained Transformer (GPT) architecture, which employs deep learning methodologies to process substantial volumes of textual data. This model is pre-trained on a variety of datasets, thereby equipping it with the ability to comprehend and produce human-like text across a multitude of subjects (Sarode & Bhamare, 2023). Its applications within the educational sphere have evidenced significant advantages, such as the enhancement of communication, critical thinking, and logical reasoning capabilities among learners (Michalon & Camacho-Zuñiga, 2023). Moreover, ChatGPT's comprehensive training on internet-derived content enables it to partake in natural language dialogues, rendering it appropriate for customer support, virtual assistance, and educational applications (Serdaliyev, 2023). The model's widespread appeal is further attributed to its adaptability and efficacy in a variety of natural language processing tasks, which have been extensively embraced across numerous sectors (Schulze-Balhorn et al., 2024).

The emergence of GeminiAI establishes it as a fundamental tool for academic pursuits due to its sophisticated multimodal functionalities, which enable it to assimilate and produce content from diverse inputs including text, images, audio, and video. This adaptability augments its relevance in pedagogical environments, where it can accommodate a multitude of learning modalities and requirements (Imran & Almusharraf, 2024). Moreover, the architecture of GeminiAI integrates pioneering methodologies that enhance its generative proficiencies, rendering it efficacious in tasks that span from image creation to intricate problem-solving (Islam & Ahmed, 2024). Empirical investigations have substantiated its exceptional performance in generating precise diagnostic inventories within medical contexts, surpassing the capabilities of alternative models such as Bard (Hirosawa et al., 2024). The incorporation of GeminiAI into academic discourse and research has been favorably acknowledged, as it not only refines skills but also addresses potential ethical dilemmas (Esplugas, 2023).

Deep AI, especially through progressions in Deep Learning and Large Language Models (LLMs), has become an essential resource in the academic sphere due to its capacity to process extensive datasets, identify intricate patterns, and improve communication and educational outcomes. These technological advancements facilitate tailored learning experiences, enhance assessment efficacy, and bolster research by delivering prompt feedback and insights (Sánchez, 2023) (Esplugas, 2023) (Bobula, 2024) (Qurbonova & Yusupova, 2024). For instance, AI-empowered platforms such as WebMicroscope employ deep learning methodologies to aid pathologists in the diagnostic processes of cancers, exemplifying the practical implementations of AI in medical research (Tibbetts, 2018).

Chat Sonix AI demonstrates remarkable proficiency in the analysis of genetic populations, attributable to its intelligent, adaptable, and collaborative characteristics, which enable it to process extensive datasets while offering instantaneous feedback. Its capability to integrate and synthesize information from a variety of sources significantly bolsters research productivity and precision, thereby rendering it an indispensable resource within academic circles. The incorporation of generative AI into research methodologies provides prompt access to pertinent data, organized guidance, and responsive feedback, thus revolutionizing conventional methodologies in genetic research (Ekellem, 2023). Moreover, the AI's ability to assist in the formulation of hypotheses and in the analysis of data streamlines the research process, fostering both efficiency and rigor in academic endeavors (Grimes et al., 2023). Consequently, Chat Sonix AI is extensively utilized within academic environments, where it aids researchers in navigating intricate genetic inquiries and contributes to the enhancement of the overall integrity of scientific output (Lin, 2023).

The efficacy of Perplexity AI in delivering precise responses is rooted in its sophisticated natural language processing capabilities, which empower it to analyze large datasets and produce contextually pertinent information. This AI instrument is embraced widely within academia due to its potential to augment instructional support, optimize administrative functions, and enable personalized learning experiences. Empirical studies suggest that AI-enabled tools such as Perplexity can substantially enhance educational outcomes by cultivating adaptive learning environments and offering timely feedback to learners (Zekaj, 2023) (Pinzolits, 2023). Furthermore, its integration into the research paradigm facilitates both data analysis and literature reviews, thereby transforming traditional academic practices (Mulally, 2024) (Triberti et al., 2024). The increasing dependence on such AI instruments signifies a transition towards more efficient and effective educational methodologies; however, concerns regarding personalization and inherent biases persist (Esplugas, 2023).

Nevertheless, despite the promising potential of AI, challenges persist in guaranteeing context-specific responses and addressing the intricacies of individual cases, which may hinder its effectiveness in particular situations. Thus, while AI offers powerful mechanisms for generating precise and accurate responses across various domains, it is imperative that its

outputs be scrutinized with critical analysis and an awareness of the system's limitations and possible biases.

Consistency of Responses Provided by AI

A review of the answers given by the five AIs to the six different questions on the two laptops showed that each AI gave responses that were structurally/grammatically different, but intended the same meaning (Table 6).

Table 6. Tabulation of the evaluation on consistency of responses provided by AI

Maint Prompt-	Types of Artificial Intelligence	Consistency of Answers	
		Manual Assessment by Genetics Lecturer 1	Manual Assessment by Genetics Lecturer 2
1	ChatGPT	1	1
1	Gemini AI	1	1
1	Deep AI	1	1
1	ChatSonix AI	1	1
1	Perplexity AI	1	1
2	ChatGPT	1	1
2	Gemini AI	1	1
2	Deep AI	1	1
2	ChatSonix AI	1	1
2	Perplexity AI	1	1
3	ChatGPT	1	1
3	Gemini AI	1	1
3	Deep AI	1	1
3	ChatSonix AI	1	1
3	Perplexity AI	1	1
4	ChatGPT	1	1
4	Gemini AI	1	1
4	Deep AI	1	1
4	ChatSonix AI	1	1
4	Perplexity AI	1	1
5	ChatGPT	1	1
5	Gemini AI	1	1
5	Deep AI	1	1
5	ChatSonix AI	1	1
5	Perplexity AI	1	1

Based on the empirical data delineated in the aforementioned table, it is evident that each artificial intelligence system operating on two distinct laptop configurations has rendered responses to an identical inquiry utilizing disparate sentence constructions, albeit conveying congruent content. This phenomenon is consistent across all inquiries spanning six diverse tiers of Bloom's taxonomy. The occurrence of AI presenting varied syntactic structures while preserving equivalent meanings across multiple instances can be ascribed to its foundational

algorithms and natural language processing proficiencies. Artificial intelligence frameworks, such as those elucidated in the extant literature, engage intricate models that scrutinize context, syntax, and semantics to formulate responses. This adaptability is paramount within educational environments, whereby AI instruments can individualize learning experiences through the customization of content to meet specific learner requirements (Cano & Troya, 2023). Furthermore, the capacity of AI to generate heterogeneous linguistic outputs augments engagement and accessibility, as it is capable of accommodating diverse learning modalities and preferences (Duque et al., 2024).

Key determinants influencing this variability encompass, (1) Natural Language Processing: AI employs sophisticated algorithms to comprehend and produce human-like text, thereby facilitating multiple legitimate articulations of the same concept, (2) Contextual Awareness: AI frameworks evaluate the context of inquiries, resulting in varied yet contextually relevant responses, (3) User Interaction: Distinct user inputs may yield disparate outputs, reflecting the dynamic character of AI interactions (Abdelaal & Sawy, 2024), and (4) Algorithmic Flexibility: The intrinsic architecture of AI permits a spectrum of syntactic configurations, thereby enriching the generated content (Silva-Sánchez, 2022). While the variability in AI-generated responses may be perceived as an asset, it simultaneously engenders apprehensions concerning consistency and dependability in educational settings, where clarity and precision hold paramount importance. This duality underscores the necessity for continued scholarly inquiry into the ramifications of AI's linguistic adaptability within the academic sphere.

The constraints that are inherently linked to the methodological approach taken for this research investigation, which includes the likelihood of different types of bias arising from the intentional choice of prompts as well as the fundamentally subjective essence of evaluations conducted manually, can significantly and deeply influence the overall dependability, along with the legitimacy, of the resulting insights that emerge from this specific research strategy, thus requiring a thorough analysis of these elements to guarantee the validity of the conclusions made. The exploration of potential avenues for future research concerning the subject at hand, particularly focusing on the incorporation of prompt engineering within the realm of artificial intelligence as it pertains to the education and understanding of genetic principles, presents a multitude of intriguing possibilities that warrant thorough investigation and academic discourse.

CONCLUSION

Based on the findings and discourse articulated herein, it is evident that the five categories of artificial intelligence employed in this investigation are capable of delivering responses with considerable precision concerning issues pertaining to population genetics. Each artificial intelligence system on the respective laptop may generate responses characterized by distinct syntactic constructions, despite retaining an equivalent semantic interpretation.

REFERENCES

Abdelaal, N. M., & Al Sawi, I. (2024). Perceptions, Challenges, and Prospects: University Professors' Use of Artificial Intelligence in Education. *Australian Journal of Applied Linguistics*, *7*(1), n1.

Barthélémy, M., Claudia, C. (2023). 2. ChatGPT, a brand-new tool to strengthen timeless competencies. Frontiers in Education, doi: 10.3389/feduc.2023.1251163

Bendre, N., Desai, K., & Najafirad, P. (2021, October). Show why the answer is correct! towards explainable ai using compositional temporal attention. In *2021 IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (pp. 3006-3012). IEEE.

Bobula, M. (2024). Generative Artificial Intelligence (AI) in higher education: a comprehensive review of challenges, opportunities, and implications. *Journal of Learning Development in Higher Education*, (30).

Cano, C. A. G., & Troya, A. L. C. (2023). Artificial Intelligence applied to teaching and learning processes. *LatIA*, *1*, 2-2.

Charlesworth, B., & Charlesworth, D. (2010). Elements of evolutionary genetics.

Crowe, A., Dirks, C., & Wenderoth, M. P. (2008). Biology in bloom: implementing Bloom's taxonomy to enhance student learning in biology. *CBE—Life Sciences Education*, *7*(4), 368-381.

Duque, R. D. C. S., da Silva, J. S., Loureiro, V. J. S., Darcanchy, M., Eccard, A. F. C., Durigon, S., ... & de Oliveira, E. A. R. (2024). Tecnologias digitais associadas a ia na formação docente. *Caderno Pedagógico*, *21*(4), e3651-e3651.

Ekellem, E. A. F. (2023, October). Conversational AI in Academia: A Practical Exploration with ChatGPT. In *2023 7th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)* (pp. 1-4). IEEE.

Esplugas, M. (2023). The use of artificial intelligence (AI) to enhance academic communication, education and research: a balanced approach. *Journal of Hand Surgery (European Volume)*, *48*(8), 819-822.

Garant, D. (2007). Hartl, DL & AG Clark, 2007. Principles of Population Genetics. *Écoscience*, *14*(4), 544–545.

Goodfellow, I. (2016). Deep learning. MIT press.

Gunjan, D., Rapheal, M., Asif, M., & Usha, R. (2024). P-256 AI-enhanced precision: unveiling the future of blastocyst quality assessment. *Human Reproduction*, *39*(Supplement_1), deae108-626.

Grimes, M., Von Krogh, G., Feuerriegel, S., Rink, F., & Gruber, M. (2023). From scarcity to abundance: Scholars and scholarship in an age of generative artificial intelligence. *Academy of Management Journal*, *66*(6), 1617-1624.

Hirosawa, T., Harada, Y., Tokumasu, K., Ito, T., Suzuki, T., & Shimizu, T. (2024). Comparative Study to Evaluate the Accuracy of Differential Diagnosis Lists Generated by Gemini Advanced, Gemini, and Bard for a Case Report Series Analysis: Cross-Sectional Study. *JMIR Medical Informatics*, *12*, e63010.

Imran, M., & Almusharraf, N. (2024). Google Gemini as a next generation AI educational tool: a review of emerging educational technology. *Smart Learning Environments*, *11*(1), 22.

Islam, R., & Ahmed, I. (2024, May). Gemini-the most powerful LLM: Myth or Truth. In *2024 5th Information Communication Technologies Conference (ICTC)* (pp. 303-308). IEEE.

Kelleher, J. D., & Tierney, B. (2018). *Data science*. MIT press.

Lai, K., Twine, N., O'brien, A., Guo, Y., & Bauer, D. (2018). Artificial intelligence and machine learning in bioinformatics. *Encyclopedia of Bioinformatics and Computational Biology: ABC of Bioinformatics*, *1*(3).

Laland, K. N., Uller, T., Feldman, M. W., Sterelny, K., Müller, G. B., Moczek, A., ... & Odling-Smee, J. (2015). The extended evolutionary synthesis: its structure, assumptions and predictions. *Proceedings of the royal society B: biological sciences*, *282*(1813), 20151019.

Láruson, Á. J., & Reed, F. A. (2021). *Population genetics with R: an introduction for life scientists*. Oxford University Press, USA.

Lazaridis, I., Patterson, N., Mittnik, A., Renaud, G., Mallick, S., Kirsanow, K., ... & Krause, J. (2014). Ancient human genomes suggest three ancestral populations for present-day Europeans. *Nature*, *513*(7518), 409-413.

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *nature*, *521*(7553), 436-444.

Libbrecht, M. W., & Noble, W. S. (2015). Machine learning applications in genetics and genomics. *Nature Reviews Genetics*, *16*(6), 321-332.

Lim, B., Lirios, G., Sakalkale, A., Satheakeeerthy, S., Hayes, D., & Yeung, J. M. (2024). Can AI answer my questions? Using Artificial Intelligence to help provide information for patients with a stoma.

Lin, Z. (2023). Why and how to embrace AI such as ChatGPT in your academic life. *Royal Society open science*, *10*(8), 230658.

Marcus, G., & Davis, E. (2019). *Rebooting AI: Building artificial intelligence we can trust*. Vintage.

Mitchell, M. (2019). Artificial intelligence: A guide for thinking humans.

Mulally, T. (2024). An experiential journey: A year of a professor using AI in the classroom and research. *International Journal of Studies in Education and Science*, *5*(3), 246-256.

Nielsen, R., & Slatkin, M. (2013). *An introduction to population genetics: theory and applications* (p. 298). Sunderland, MA: Sinauer Associates.

Pinzolits, R. (2023). AI in academia: An overview of selected tools and their areas of application. MAP Education and Humanities, 4, 37–50.

Qurbonova, B., & Yusupova, A. (2024, May). The Deep Investigation of the Part of AI Integ in The Field of Education: A Technical Review. In *2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)* (pp. 503-507). IEEE.

Sanchez, T., Cury, J., Charpiat, G., & Jay, F. (2021). Deep learning for population size history inference: Design, comparison and combination with approximate Bayesian computation. *Molecular Ecology Resources*, *21*(8), 2645-2660.

Sánchez, L.J.L. (2023). Inteligencia artificial en la academia. *Acta Médica Costarricense*, *65*(3), 111-112.

Sant'Anna, I. C., Tomaz, R. S., Silva, G. N., Nascimento, M., Bhering, L. L., & Cruz, C. D. (2015). Superiority of artificial neural networks for a genetic classification procedure.

Sarode, V., & K., Bhamare. (2023). Chat GPT and its Capabilities. International Journal for Research in Applied Science and Engineering Technology, doi: 10.22214/ijraset.2023.56355

Schrider, D. R., & Kern, A. D. (2018). Supervised machine learning for population genetics: a new paradigm. *Trends in Genetics*, *34*(4), 301-312.

Schulze-Balhorn, L., Weber, J. M., Buijsman, S., Hildebrandt, J. R., Ziefle, M., & Schweidtmann, A. M. (2024). Empirical assessment of ChatGPT's answering capabilities in natural science and engineering. *Scientific Reports*, *14*(1), 4998.

Serdaliyev, Y. (2023). Applications of «chatgpt»: where it can be used and what can we solve with chatgpt. Қ.А. Ясауи атындағы Халықаралық қазақ-түрік университетінің хабарлары, doi: 10.47526/2023-1/2524-0080.12

Sheehan, S., & Song, Y. S. (2016). Deep learning for population genetic inference. *PLoS computational biology*, *12*(3), e1004845.

Silva-Sánchez, C. A. (2022). Psychometric properties of an instrument to assess the level of knowledge about artificial intelligence in university professors. *Metaverse Basic and Applied Research*, *1*, 14-14.

Singh, S., Manchekar, O., Patwardhan, A., Rote, U., Jagtap, S., & Chavan, D. H. (2021, May). Computer application for assessing subjective answers using AI. In *Proceedings of the 4th International Conference on Advances in Science & Technology (ICAST2021)*.

Laurentin Táriba, H. E. (2023). Introduction to Genetics. In *Agricultural Genetics: From the DNA Molecule to Population Management* (pp. 3-7). Cham: Springer Nature Switzerland.

Tibbetts, J. H. (2018). The Frontiers of Artificial Intelligence: Deep learning brings speed, accuracy to the life sciences. *Bioscience*, *68*(1), 5-10.

Triberti, S., Di Fuccio, R., Scuotto, C., Marsico, E., & Limone, P. (2024). "Better than my professor?" How to develop artificial intelligence tools for higher education. *Frontiers in Artificial Intelligence*, *7*, 1329605.

Wiyono, E., Setyawan, A., & Mucholifah, U. H. (2024, August). Improving the quality of learning with ai as a learning assistant. In *International Conference on Aplied Social Sciences in Education* (Vol. 1, No. 1, pp. 661-666).

Yang, Y., Yu, L., Bai, Y., Wang, J., Zhang, W., Wen, Y., & Yu, Y. (2017). An empirical study of AI population dynamics with million-agent reinforcement learning. *CoRR*.

Yang, X., Li, H., Ni, L., & Li, T. (2021). Application of artificial intelligence in precision marketing. *Journal of Organizational and End User Computing (JOEUC)*, *33*(4), 209-219.

Zekaj, R. (2023). AI language models as educational allies: Enhancing instructional support in higher education. *International Journal of Learning, Teaching and Educational Research*, *22*(8), 120-134.