Academic Level and Gender-based Mapping of High School Student's Genetic Literacy: A Cross Sectional Study in Indonesia

Nivel académico y mapeo basado en el género de la alfabetización genética de estudiantes de secundaria: un estudio transversal en Indonesia

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Abstract

[Objective] Genetic literacy is related to knowledge and skills in utilising genetic principles for solving various problems or issues related to genetics. Genetic literacy is very important for students because it relates to various current issues, especially in health and agriculture. However, study about genetic literacy is still not widely disclosed from various viewpoints, including academic level and gender. Therefore, this study aimed to measure the genetic literacy of students in Indonesia based on their academic level and gender. **[Methodology]** The data were collected through an analytic observational cross-sectional study. The research participants comprised 1102 students from 55 senior high schools in Indonesia. The participants filled in a test, which had been tested for validity and reliability. The data was analysed using the Mann-Whitney and Kruskal-Wallis test. The participants' genetic literacy levels were then categorised into adequate and inadequate. **[Results]** The results of this study showed that students' genetic literacy was relatively inadequate. In addition, academic level and gender have a significant effect on students' genetic literacy. However, the interaction between academic level and gender did not affect genetic literacy. **[Conclusions]** The results of this study further strengthen the fact that genetic literacy needs attention by considering academic level and gender. Thus, educators need to design strategies and appropriate learning media to empower and increase the genetic literacy of students in senior high schools.

Keywords: academic level; gender; genetic literacy; high school students; education

Resumen

[Objectivo] La alfabetización genética está relacionada con el conocimiento y las habilidades en la utilización de principios genéticos para resolver varios problemas o asuntos relacionados con la genética. La alfabetización genética es muy importante para los estudiantes porque se relaciona con varios temas actuales, especialmente en salud y agricultura. Sin embargo, el estudio sobre la alfabetización genética aún no se divulga ampliamente desde varios puntos de vista, incluido el nivel

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académico y el género. Por lo tanto, este estudio tuvo como objetivo medir la alfabetización genética de los estudiantes en Indonesia en función de su nivel académico y género. **[Metodología]** Los datos fueron recolectados a través de un estudio transversal observacional analítico. Los participantes de la investigación comprendían 1102 estudiantes de 55 escuelas secundarias superiores en Indonesia. Los participantes completaron una prueba, cuya validez y confiabilidad habían sido probadas. Los datos se analizaron mediante la prueba de Mann-Whitney y Kruskal-Wallis. Los niveles de alfabetización genética de los participantes se clasificaron luego en adecuados e inadecuados. **[Resultados]** Los resultados de este estudio mostraron que la alfabetización genética de los estudiantes era relativamente inadecuada. Además, el nivel académico y el género tienen un efecto significativo en la alfabetización genética de los estudiantes. Sin embargo, la interacción entre el nivel académico y el género no afectó la alfabetización genética. **[Conclusiones]** Los resultados de este estudio refuerzan aún más el hecho de que la alfabetización genética necesita atención al considerar el nivel académico y el género. Por lo tanto, los educadores deben diseñar estrategias y medios de aprendizaje apropiados para empoderar y aumentar la alfabetización genética de los estudiantes en las escuelas secundarias superiores.

Keywords: nivel académico; género; alfabetización genética; estudiantes de secundaria; educación.

Introduction

People are currently living in the genomic era. Numerous scholarly sources have indicated that genetic development has significantly influenced nearly all facets of life (Bernardo, 2020; Dumache & Enache, 2016; John & Anaya, 2015; Machová & Ehler, 2021). Genetics is a discipline that frequently intersects with other disciplines within the life sciences, rendering it significant to human existence (Adelana et al., 2023). It also interconnects with health and forensic sciences, agriculture, and technology (Boerwinkel et al., 2017; Machová & Ehler, 2021). Gene technology is progressively permeating the public domain, garnering heightened scrutiny toward genetic matters (Kampourakis et al., 2014).

An in-depth knowledge of contemporary genetics, encompassing genomes, traits, genetic technology, and genetic discrimination, helps address problems in genetics (Stern & Kampourakis, 2017). Many advertisements disseminate false information about genetic engineering, such as genetically engineered food, skin care products, and genetics issues related to the COVID-19 pandemic (Chapman et al., 2019; Gonzalez et al., 2020). The narratives catalyse for individuals to actively combat the proliferation of false information on various social media platforms, including Twitter (Krittanawong et al., 2020), Facebook (Ahmed et al., 2020), and WhatsApp (Bowles et al., 2020). Understanding genetics can foster an augmentation in genetic literacy and mitigate the prevalence of misconceptions among students (Cebesoy & Öztekin, 2016; Etobro & Banjoko, 2017; Kantahan et al., 2020). Thus, students must cultivate genetic literacy to address current genetic issues (Cebesoy & Öztekin, 2016).

Genetic literacy is part of scientific literacy (Boerwinkel et al., 2017). Scientific literacy encompasses more than merely acquiring scientific knowledge and attitudes; it entails understanding the appropriate contexts and methods for applying that knowledge. Genetic literacy refers to an individual's capacity to employ scientific reasoning in genetics (Chapman et al., 2017). Genetic literacy can enable individuals to make informed decisions on the discourse surrounding genetic applications and technology (Cebesoy & Oztekin, 2018). In addition, genetic literacy can be defined as an understanding of genetic principles and an individual's ability to comprehend, utilise, correlate, evaluate, and communicate genetic information to engage in logical argumentation, reasoning, and problem-solving related to genetic matters to preserve or enhance the well-being of oneself and society (Maghfiroh et al., 2023).

Genetic literacy is conceptualised as interconnected knowledge and skills (Maghfiroh et al., 2023). It assists individuals in implementing genetic knowledge in various aspects of life, such as understanding the characteristics of genetic material, gene transmission, and expression, the regulation of genes, gene evolution, and the broader implications of genetics within society. Some experts reduce or add elements to the concept of genetic literacy due to differing perspectives and to accommodate the needs of twenty-first-century society. For instance, Boerwinkel et al. (2017) contend that genetic literacy does not include evolution and natural selection. Thus, the fundamental principles of genetic literacy involve the characteristics of genetic material, the transmission of genetic information, the expression of genetic traits, and the regulation of genetic processes (Aivelo & Uitto, 2021; Boerwinkel et al., 2017; Fauzi et al., 2022).

Genetic literacy skills have a significant role in shaping an individual's way of thinking, especially in obtaining and using information related to genetic problems (Erduran et al., 2019; Fang et al., 2019; Sadler & Donnelly, 2006; Shea et al., 2015). The utility of information and knowledge has been called into question due to the potential inability of highly knowledgeable individuals to apply acquired genetic knowledge. Consequently, some researchers propose new genetic literacy skills to address this concern (Aivelo & Uitto, 2021; Fauzi et al., 2022; Shea et al., 2015).

During the COVID-19 pandemic in Indonesia, social media platforms have shown an extensive spread of misinformation (Fauzi et al., 2021; Liday & Liwag, 2021). Therefore, people need to develop situational skills to evaluate the accuracy of claims regarding a genetic issue and to make decisions concerning the issue (Fauzi et al., 2022). Based on the needs, genetic literacy skills consist of two key components: argumentation skills and decision-making skills. Argumentation skills are employed to substantiate a knowledge claim by presenting evidence and logical reasoning. On the other hand, decision-making skills involve using multiple reasoning strategies, including intuitive and analytical approaches, particularly in practical applications (Wimmer et al., 2022).

Based on the previously elucidated definitions of genetic literacy, genetic literacy refers to a corpus of knowledge of genetic principles and the skills to apply these principles to address diverse genetic quandaries. Genetics is a core concept of biology. It holds considerable significance in human health and warrants comprehensive understanding among all students (Ricciardi & Stefania, 2017). Hence, educational institutions should deliver pedagogical approaches that effectively facilitate students' comprehension of the principles and intricacies of genetics (Kılıç & Sağlam, 2014; Mohammed et al., 2022).

However, many students have difficulty synthesising knowledge and obtaining a deeper understanding of genetics (Machová & Ehler, 2021). Numerous students are "afraid" of studying genetics (Chattopadhyay, 2005; Paul, 2018). Students often misinterpret genetic concepts (Vlčková et al., 2016), as they consider genetic material overly abstract and devoid of context (Cebesoy & Tekkaya, 2012; Osman et al., 2017). Genetics encompasses a vast array of topics and employs abstract terms. Therefore, students' understanding and mastery of genetic concepts are relatively limited (Adelana et al., 2023; Altunoğlu & Şeker, 2015;

Cebesoy & Oztekin, 2018; Kılıç & Sağlam, 2014). Abstract concepts in genetics can affect students' interpretation of the material (Kantahan et al., 2020).

Academic level is one of the factors that may impact students' interpretation skills. It is closely connected to students' developmental stages and the complexity of the instructional materials presented by educators (Yu, 2021). Academic level is also associated with age (Gericke et al., 2017). The impact of age on genetic literacy can be attributed to the accumulation of factual and conceptual knowledge over time (Fitzgerald-Butt et al., 2016; Gericke et al., 2017). An increase in one's conceptual knowledge is attributed to their educational experiences. At the secondary education level, specifically in senior high schools (*SMA*), the curriculum entails more intricate subject matter, thereby presenting the possibility for variations in academic aptitude to impact students' literacy skills (Delic, 2020).

Educators commonly employ diverse instructional strategies to facilitate the comprehension of abstract concepts in genetics. However, there may be variations in the capacity of male and female students to comprehend and assimilate academic content (Aytekin & Isiksal-Bostan, 2019; Heo & Toomey, 2020; Liew et al., 2022). Gender differences influence the biological condition of male and female brains, resulting in cognitive and learning differences between genders (Szadvári et al., 2023).

Gender is a significant determinant of students' genetic literacy. Gender encompasses various aspects of an individual's identity, role, personality, and behavior, which can influence the individual's interpersonal interactions, decision-making capabilities, and responses to specific circumstances (Oertelt-Prigione & Mariman, 2020)Generally, women exhibit excellent proficiency in verbal communication and written expression. Women possess a cognitive orientation that prioritises emotional, tangible, individual, and pragmatic aspects. On the other hand, there is a tendency for men to exhibit superior numeracy skills and possess an intellectual mindset characterised by rationality and objectivity (Yu, 2021). Female students have greater propensity for comprehending and engaging in critical thinking, effectively structuring their thoughts, and assimilating information than their male counterparts (Saleh et al., 2023).

Several factors can affect students' genetic literacy based on the previous explanation. Due to the lack of information, an analysis of the factors that can influence students' genetic literacy must be conducted (Chapman et al., 2019). In addition, research on the influence of gender and academic level on genetic literacy is minimal. Thus, the current study sought to map the genetic literacy of students from senior high school and examine the impact of academic level and gender on their genetic literacy. It is essential to exinvestigate the profile of students' genetic literacy and the factors that may influence it, namely academic level and gender, because teachers and schools can use this information to determine strategic steps to increase students' genetic literacy.

Methodology

Research Design

The present study utilised an analytic observational cross-sectional study design (Creswell, 2012) to assess the genetic literacy level of high school students in Indonesia and its correlation with their academic level and gender. The cross-sectional design was selected based on its suitability as a quantitative, non-experimental research design frequently employed for gathering data from a cohort of participants at a single time point (Schmidt &

Brown, 2019). A cross-sectional study is cost-effective and easy to implement (Wang & Cheng, 2020). The cross-sectional research design is frequently employed to examine the association between demographic variables, such as academic level and gender, and literacy (Liu et al., 2023; Moshki et al., 2018; Nair et al., 2022; Özdemir et al., 2023; Protheroe et al., 2017).

Participants

The sampling process was initiated by distributing informed consent forms to 1,200 students across 55 senior high schools in Indonesia's Western, Central, and Eastern regions. We sent the forms to the students through the teachers from the respective schools. Some students needed to convey their approval. Thus, students who consented to participate in this study could promptly commence a test disseminated through the Google form after completing their personal information.

1102 out of 1200 students who had stated their consent to participate attended this study. The participants studied at Indonesia's senior high school (SMA) level. They were distributed into three high school academic levels, namely grades X, XI, and XII, and registered in the even semester of the 2022/2023 academic year. The data showed that the response rate amounted to 91.83 %. Table 1 presents the participants' characteristics.

Tabel 1. *Characteristics of the Participants*

<table>
<tr><th rowspan="2">Academic level</th><th rowspan="2">Gender</th><th rowspan="2">Number of students</th><th rowspan="2">%</th><th colspan="2">Total and Percentage (%)</th></tr>
<tr><th>Academic Level</th><th>Gender</th></tr>
<tr><td rowspan="2">X</td><td>Male</td><td>48</td><td>4.36</td><td rowspan="2">127 (11.52)</td><td rowspan="6">Male
343
(31.12)
Female
759
(68.88)</td></tr>
<tr><td>Female</td><td>79</td><td>7.17</td></tr>
<tr><td rowspan="2">XI</td><td>Male</td><td>37</td><td>3.36</td><td rowspan="2">147 (13.34)</td></tr>
<tr><td>Female</td><td>110</td><td>9.98</td></tr>
<tr><td rowspan="2">XII</td><td>Male</td><td>258</td><td>23.41</td><td rowspan="2">828 (75.14)</td></tr>
<tr><td>Female</td><td>570</td><td>51.72</td></tr>
</table>

Note: derived from research

Research Instruments and Data Collection

The research instrument consisted of 30 multiple-choice items developed on the dimensions and indicators of genetic literacy suggested by (Boerwinkel et al., 2017; Bowling et al., 2008). These items were translated into the Indonesian language and modified accordingly. We used the test to measure the participants' genetic knowledge and skills. The knowledge dimension comprised the following: nature of the genetic material (eight questions), gene transmission (four questions), gene regulation (four questions), and gene expression (six questions). Meanwhile, the skill dimension comprised argumentation skills (four questions) and decision-making skills (four questions). The examples of each item of the modified test are presented sequentially in Table 2.

The test that had been translated and modified was subsequently subjected to validity and reliability examinations. The validity test included both content and construct (empirical) validation. The content validity test determined the extent to which the test questions were aligned with the underlying theoretical framework. The content validity test enlisted the expertise of two geneticists to assess the appropriateness of the test items regarding genetic content within the genetic literacy dimension. The geneticists were asked to provide feedback on the questions' theoretical foundations. A proficient biology teacher also assessed the questions. The teacher was requested to offer input regarding the suitability of the question items with the student's level of knowledge and indicators of genetic literacy. The teacher then guided the organisation of each question item. The questions were reconstructed based on the experts' and teachers' inputs to ensure agreement and readability and to guarantee that all items adhered to predefined content specifications.

The test questions underwent construct (empirical) validation following the content validity test. Construct validation was done by distributing the questions to forty high school students. The result showed that the test was valid with a Pearson correlation p-value smaller than (<) 0.05. The instrument's empirical reliability showed a Cronbach's Alpha value of 0.94, with $\alpha = 0.78$ for the *nature of the genetic material* dimension, $\alpha = 0.71$ for the *transmission* dimension, $\alpha = 0.69$ for the *gene regulation* dimension, $\alpha = 0.77$ for the *gene expression* dimension, $\alpha = 0.67$ for the *argumentation skill* dimension, and $\alpha = 0.70$ for the *decision-making skill* dimension. The Cronbach's Alpha values indicated that instrument reliability was very high. The empirical validity and reliability tests showed that the instrument was ready to measure students' genetic literacy.

The instrument was then distributed to the participants via Google Forms. The link to the test was sent to Biology teachers from the participating schools through WhatsApp (WA). Test distribution via WhatsApp was considered the most feasible way in this scenario. The individuals who participated in this study were chosen using a random sampling method. Under ethical considerations, participants had the prerogative to abstain from completing the test. The submitted data were maintained confidentially.

The instrument's design and data collection were conducted from November 2022 to January 2023. Before commencing a survey targeting high school students, official letters of approval were dispatched to educational institutions in various regions across Indonesia. Upon receiving approval, we established a collaborative effort with biology teachers from each educational institution to facilitate disseminating the genetic literacy assessment.

Table 2. *The Examples of the Test Questions on Each Dimension of Genetic Literacy*

Genetic Literacy Knowledge:
Nature of the Genetic Material (Question Number 13) The relationship between DNA and chromosomes in higher organisms is... A. Chromosomes are found in DNA. B. DNA is found in the chromosomes. C. There is no difference between DNA and chromosomes. D. DNA and chromosomes are entirely separate structures. E. Chromosomes produce DNA.

Gene Transmission (Question Number 6)

Sometimes a trait disappears in a family and reappears in later generations. If neither parent has the trait, but some of the offspring do, what you can conclude about the inheritance of the trait is that ….

A. both parents are carriers of the recessive gene.
B. only one parent has two recessive gene breaks.
C. only one parent has the dominant form of the gene.
D. only one parent has the recessive gene.
E. this is the result of a new mutation in each parent.

Gene Regulation (Question Number 14)

Regarding complex traits such as IQ, lung cancer, prostate cancer, etc., the statement that describes the opinion of geneticists on the contribution of a person's genetic makeup and the environment is...

A. Environment determines the potential of a trait; how much that potential is realised depends on the individual's genetic makeup.
B. Everyone increases genetic potential; the amount of potential that can be realised depends on the environment.
C. Geneticists generally accept that most traits are primarily determined by genetics, with environment having little influence on complex traits.
D. Environment plays a significant role in determining complex traits, with genetics playing a relatively minor role.
E. The genetic differences among humans are so slight that essentially all the variation observed between individuals is due to the environment in which they were raised.

Gene Expression (Question Number 10)

A woman is told she carries a mutation associated with breast cancer. The following statement shows how this affects her chances of developing breast cancer is ....

A. The risk would be no different than that of any other healthy woman.
B. She is unlikely to get breast cancer.
C. She is at increased risk of breast cancer.
D. She will definitely get breast cancer.

Genetic Literacy Skills:

Argumentation (Question Number 24)

Based on data from the Global Cancer Observatory (Globocan) in 2020, cervical cancer is the second most diagnosed in women. The disease is caused by several factors, such as viral infection, smoking, consumption of highly carcinogenic foods, or various other mutagenic substances that cause mutations in the DICER1 gene, thus disrupting the process of cell division. Cells will divide uncontrollably and continuously. Based on this information, the most appropriate statement to explain the basic cancer process is ....

A. Carcinogenic substances stimulate cell mutations so that the cell multiplication process increases.
B. Carcinogenic substances stimulate tissue mutations so that the cell multiplication process decreases.
C. Mutagenic substances lead to DNA recombination so that cell proliferation is disrupted.
D. Carcinogenic substances lead to gene mutations so that cell proliferation becomes uncontrolled.

E. Carcinogenic substances lead to DNA recombination so that cell division is disrupted.

Decision-Making Skill (Question Number 30)
Woman X was diagnosed with terminal cervical cancer. The examination results showed that the cancer cells showed significant and uncontrolled division, which stimulated the formation of tumors that spread to several surrounding tissues. Based on this information, the best thing that can be done to stop the spread of cancer cells in this patient is ....
A. Surgery to remove cancer cells so they can stop spreading.
B. Administration of drugs to stimulate the immune system to reduce the spread of cancer cells.
C. Chemotherapy to stop the spread of cancer cells.
D. Radiotherapy to inhibit the spread of cancer cells.
E. Gene therapy using stem cells to reduce the spread of cancer cells.

Note:derived from research

Data Analysis

Before analysis, the data were checked and sorted. Data from two or more identical or similar identities were not used. Data from participants not from the science program in high school or non-science were discarded. The participants' genetic literacy level was categorised into adequate (>50 %) and inadequate (≤50 %) (Rodriguez et al., 2015). The data underwent descriptive and inferential analyses facilitated by the SPSS program. The descriptive analysis provided a comprehensive account of the participant's scores on the two dimensions of genetic literacy and the distribution of genetic literacy scores across different academic levels and genders. The descriptive analysis also showed an account of the dimensions and quantity of questions on the genetic literacy instrument that students responded to with the highest accuracy. After that, we conducted an inferential analysis using the Mann-Whitney test to ascertain the mean difference between the two groups segregated by gender. Furthermore, we employed the Kruskal-Wallis test to determine the mean difference among multiple groups categorised by academic level.

Results and Discussion

Participants Responses to the Dimensions and Indicators of Genetic Literacy

This study showed the percentage of participants' responses to a set of assessment indicators derived from the dimensions of genetic literacy, explicitly focusing on the areas that high school students typically found most challenging. The research findings showed the data on the proportion of participants who provide accurate answers to each question that represents each indicator in the genetic literacy dimension. According to the data presented in Table 3, 27.97 % of the participants accurately responded to the "gene expression" questions, which measures their level of knowledge of genetic literacy. The percentage exhibited the lowest value relative to the percentage of participants who provided accurate responses across various indicators, encompassing genetic literacy knowledge and skills. The analysis findings indicated that these participants needed a greater comprehension of gene expression concepts such as the number of genes, gene interference, gene-protein associations, and how these factors interact with the environment to influence phenotypic traits. The analysis also revealed that the participants showed a limited understanding of genetic variation and its association with disease, gene regulation, and genetic variation in natural selection. Specifically, only 33.30 % of the participants responded accurately to gene regulation questions.

Moreover, data analysis suggested that the participants understood gene transmission adequately. As many as 38.59 % of the participants responded accurately to the questions presented in this knowledge indicator. Based on the data, it can be inferred that the participants could comprehend Mendelian inheritance concepts and meiosis patterns. A significant proportion, precisely 38.68 %, of the participants showed an adequate understanding of the interplay between DNA, DNA and genes, and chromosomes, as well as gene activity and genetic variation. This result was evidenced by their ability to respond accurately to questions on the nature of genetic material.

Similarly, participants showed low argumentation skills, with 30.89 % answering the questions on that dimension correctly. Furthermore, the data revealed that a mere 32.65 % of the participants demonstrated proficiency in responding to questions about decision-making skills, thus suggesting a deficiency in genetic-related skills among the student population.

Table 3. *Percentages of Participants Answered the Test Questions Correctly*

Dimensions and Indicators of Genetic Literacy (Question Number)	**% Students with Correct Answer**
Dimension: Genetic Knowledge	
*Nature of the genetic material (1,4,7,8,11,12,13,18)**	38.68
*Gene Transmission (5,6,21,22)**	38.59
*Gene regulation (9,10,15,16)**	33.30
*Gene expression (2,3,14,17,19,20)**	27.97
Dimensions: Genetic Skills	
*Argumentation (24,26,27,28)**	30.89
*Decision-making skills (23,25,29,30)**	32.65

* Question Number. *Note:derived from research*

The questions frequently answered incorrectly by the test takers/research participants are discussed in this study. According to the data presented in Figure 1, 14.7 % of the participants accurately responded to question number 3. The data showed that question number 3 (gene expression- genetic knowledge) was the question for which participants most frequently provided incorrect responses (85.3 %). Data analysis indicated that the participants perceived " gene expression " as challenging. However, many participants demonstrated proficiency in responding accurately to questions about the nature of genetic material (question 1) and gene transmission (question 21). The results of this study indicated that the participants possessed an adequate level of understanding regarding the characteristics of genetic material and gene transmission, particularly concerning inheritance patterns and Mendelian traits.

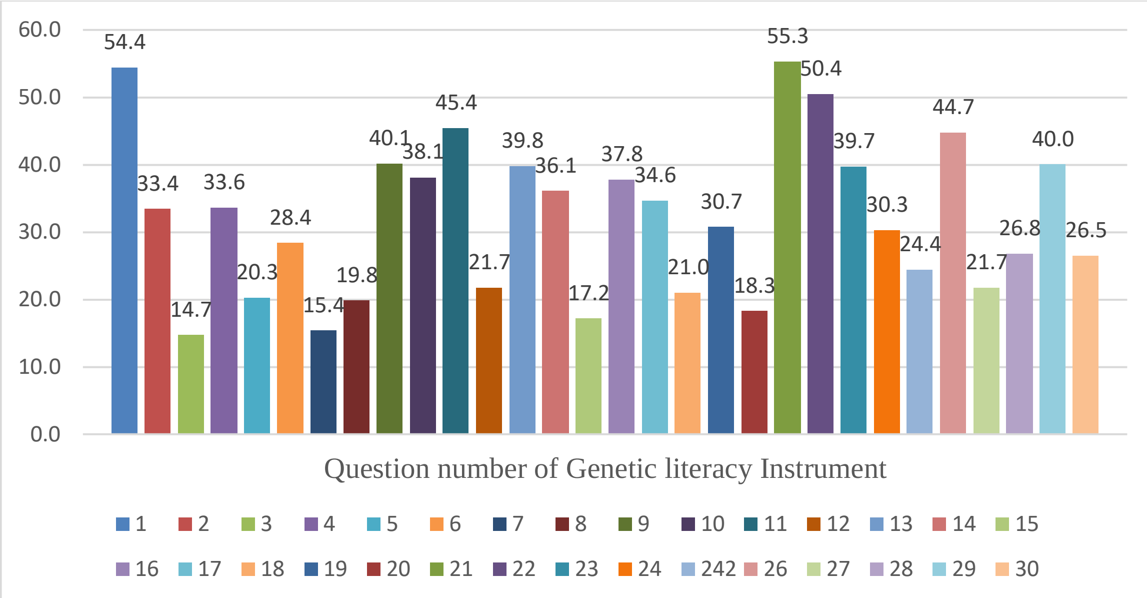

Figure 1. *Percentage of Participants who Answered Correctly to the Test Questions*

Genetic Literacy Based on Academic Level

Participants studying in grade twelve (XII) achieved the highest mean score in genetic literacy, with a percentage of 37.27 %. Conversely, grade eleven (XI) participants demonstrated the lowest mean score. In contrast, the proportion of twelfth-grade students classified as being in the adequate category was found to be higher (21.01 %) compared to the corresponding percentages for eleventh-graders (14.29 %) and tenth-graders (11.81 %). The study's findings revealed that the genetic literacy of twelfth-grade students surpassed that of students in the tenth and eleventh grades. A comprehensive overview of students' genetic literacy regarding their academic level, specifically in grades X, XI, and XII (Table 4). In addition, the inferential analysis showed that academic level significantly influenced genetic literacy, as evidenced by a p-value of 0.000 (Table 5).

Table 4. *Participants' Genetic Literacy Level based on their Academic Level*

Academic Level	Mean	Number of Students	Total Genetic Literacy Level (%)	
			Adequate	Inadequate
X	28.35	127	15 (11.81)	112 (88.19)
XI	28.12	147	21 (14.29)	126 (85.71)
XII	37.27	828	174 (21.01)	654 (78.99)

Note:derived from research

Table 5. *Analysis of the Effect of Academic Level on Genetic Literacy*

Variable	**Mean**		**SD**
Academic Level			
X	28.35		10.14
XI	28.12		9.75
XII	37.27		15.59
Kruskal-Wallis H		43.787	
Sig.		**.000****	

Note:derived from research

Genetic Literacy Based on Gender

The percentage of female participants classified as adequate was 21.74 %, whereas the corresponding percentage for male participants was 13.12 %. According to Table 6, women demonstrated a higher level of genetic literacy than men. The findings of the inferential analysis in Table 7 indicated that gender had a significant effect on genetic literacy.

Table 6. *Participants' Genetic Literacy Level based on Gender*

Gender	**Mean**	**Number of Students**	**Total Genetic Literacy Level (%)**	
			Adequate	**Inadequate**
Male	30.86	343	45 (13.12)	298 (86.88)
Female	35.04	759	165 (21.74)	594 (78.26)

Note:derived from research

Table 7. *Analysis of the effect of gender on genetic literacy*

Variable	**Mean**		**SD**
Gender			
Male	31.67		15.38
Female	37.27		15.59
z-score		-4.926	
Sig.		**.000****	

Note:derived from research

The results of the analysis showed that the academic level affected genetic literacy. Consequently, the Kruskal-Wallis test was conducted. The subsequent findings in Table 8 indicated that eleventh-grade students' mean genetic literacy score was the lowest. However, it was not statistically different from the mean score of tenth-grade students. In contrast, the twelfth-grade students exhibited the highest mean score on the genetic literacy test, significantly distinct from the mean scores observed among tenth and eleventh-grade students.

Table 8. *The Results of the LSD Test on the Effect of Academic Level on Genetic Literacy*

Academic level	Corrected Average	SD	LSD notation
X	28.35	10.14	a
XI	28.12	9.75	a
XII	37.27	15.59	b

Note:derived from research

The Interaction between Academic Level and Gender and Its Effect on Genetic Literacy

Based on Table 9, twelfth-grade female students belonged to the adequate category with the highest percentage (13.43 %), while tenth-grade male students fell into the adequate category with the lowest percentage (0.64 %). Table 10 indicates the interaction between academic level and gender and its effect on genetic literacy. The analysis showed that academic level and gender did not significantly affect genetic literacy (p = 0.126).

Table 9. *Analysis of the Interaction between Academic Level and Gender and its Effect on Genetic Literacy*

Genetic Literacy Level	Academic Level	Gender	Number of students	%	Total (%)		
					Academic level	Gender	Total
Adequate	X	Male	7	0.64	15 (1.36)	Male 45 (4.08) Female 165 (14.97)	210 (19.06)
		Female	8	0.73			
	XI	Male	12	1.09	21 (1.91)		
		Female	9	0.82			
	XII	Male	26	2.36	174 (15.79)		
		Female	148	13.43			
Inadequate	X	Male	41	3.72	112 (10.16)	Male 298 (27.04) Female 594 (53.91)	892 (80.94)
		Female	71	6.44			
	XI	Male	25	2.27	126 (11.43)		
		Female	101	9.16			
	XII	Male	232	21.05	654 (59.35)		
		Female	422	38.29			

Table 10. *Analysis of the Interaction between Academic Level and Gender and its Effect on Genetic Literacy*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Academic level * Gender	1516.442	2	758.221	3.667	0.126	0.007

Note:derived from research

Overall, this study's showed that the genetic literacy of high school students in Indonesia showed inadequate category, so it is needed to be improved. This finding aligns with the research conducted by Rujito et al. (2020), which posits that students possess a relatively limited comprehension of genetic concepts. Furthermore, genetic information disseminated through informal channels, such as diverse media formats, may not consistently provide accurate representations. Identifying accurate genetic information from erroneous information can pose challenges for individuals needing a firm grasp of fundamental concepts (Aivelo & Uitto, 2021). The observed outcome can be attributed to the limited exploration of key dimensions and concepts of genetic literacy within the classroom, impeding students' ability to understand these concepts. Genetic literacy is rarely discussed during classroom activities or seldom found in library books (Mohammed et al., 2022). Genetic literacy constitutes an integral component of general scientific literacy. This type of individual literacy deserves attention, especially since genetics is a cornerstone of biology (Mohammed et al., 2022; Samerski, 2014).

Even though it is positioned as a branch of biology that underlies many other branches, genetics is one of the most challenging materials for high school and college students to understand (Etobro & Banjoko, 2017; Kılıç & Sağlam, 2014; Machová & Ehler, 2021; Paul, 2018). Genetics is more often misconstrued when compared to other biological concepts (Gusmalini et al., 2020; Kılıç & Sağlam, 2014). Individuals with a strong command of genetics will likely demonstrate enhanced comprehension of diverse biological principles (Nurse & Hayles, 2019) because various biological concepts, such as cell division and the immune response, are closely related to genetics. Hence, the assessment of genetic literacy holds significant value in evaluating students' comprehension of biological principles and assessing the efficacy of the biology education curriculum within an educational institution (Rujito et al., 2020).

The Most Challenging Genetic Literacy Test Questions and Dimensions

The findings from the current study indicated that high school students perceived "gene expression" as one of the most challenging topics in genetics. In contrast, participants frequently demonstrated higher accuracy in their responses to questions 1 and 21, integral to genetic literacy's "knowledge" dimension. The first item pertains to the "nature of genetic materials," whereas the twenty-first question pertains to "gene transmission," which encompasses the study of inheritance patterns and Mendelian traits. The two topics are relatively more comprehensible for students than other topics (Machová & Ehler, 2021; Rujito et al., 2020).

This finding is consistent with Osman et al. (2017) and Machová & Ehler (2021), who explained that gene expression is complex for students to understand. However, as posited by

Haskel-Ittah et al. (2020), the interaction between genes and the environment in the formation of traits is an essential component of genetic literacy because it elucidates the plasticity of phenotypes. Recognising the significance of the developmental interplay between genes and the environment in shaping phenotypic traits holds relevance not only for scientific researchers and their inquiries but also for students and society as they navigate the complexities of genetic matters (Boerwinkel et al., 2017). Most research on genetics education focuses on identifying and analysing obstacles encountered by students in comprehending and rationalising genetic concepts. This research indicates that students struggle to grasp the subject matter (Haskel-Ittah et al., 2020; Puig et al., 2017). Understanding genetic mechanisms will empower students to offer causal justifications for genetic phenomena. However, the acquisition and comprehension of these mechanisms pose challenges regarding instruction and learning (Haskel-Ittah & Yarden, 2018).

In general, the data analysis results showed that this study's participants needed to gain genetic knowledge, resulting in poor genetics-related argumentation and decision-making skills. In addition, "argumentation" skills demonstrated a lower percentage than "decision-making" skills, indicating that high school students in this study possessed superior decision-making skills than genetic argumentation skills. Although these two skills are still lacking, students could make decisions better than arguing. This finding indicates that high school students struggle to say about genetics and tend to neglect their argumentation skills (Puig et al., 2017). Yet, according to Songsil et al. (2019), students need scientific argumentation skills to express their opinions and solve everyday problems. Argumentation and decision-making skills are interrelated. These are also objectives of genetic literacy. Students who engage personally in structured decision-making may develop more integrated argumentation skills (Sparks et al., 2022).

In addition, the intricate characteristics of genetic issues foster the cultivation of students' skills in making informed decisions on genetic problems (Stern & Kampourakis, 2017). Decision-making skills are one of the most important skills in genetic literacy. To actively engage in decision-making processes, students must possess a comprehensive understanding of genetic concepts, including but not limited to the fundamental nature of genetic material, principles of inheritance, mechanisms of gene expression, and gene regulation (Cebesoy & Oztekin, 2018). Students can use analytical techniques to exercise logical thinking and decision-making skills related to genetics (Fang et al., 2019).

Genetic Literacy Based on Academic Level

Data analysis showed that academic level affected genetic literacy. The academic level of an individual is positively correlated with their age, as older individuals tend to possess a more significant accumulation of knowledge, which in turn contributes to improved learning outcomes. Furthermore, there exists a distinction in the cognitive capacity to analyse and comprehend complex issues among students with varying academic levels (Delic, 2020). Students with high academic achievement are strongly inclined towards curiosity and sociability, significantly impacting their cognitive processes and learning abilities. Individuals with a lower academic level often exhibit diminished interest and frequently engage in social adaptations that can impact their cognitive outlook. There are disparities in the materials and assignments provided to students of varying academic levels. Assignments and study materials designed for students with high academic proficiency tend to exhibit greater complexity. The tasks mentioned above impact students' cognitive development (Gericke et al., 2017; Yu, 2021).

Furthermore, students with a higher academic level also demonstrate a greater capacity for comprehending and assimilating educational content than their counterparts with a lower level of academic proficiency (Almendingen et al., 2021). Individuals with a superior level of academic ability acquire a greater depth of knowledge of genetics through formal education, personal experiences, and exposure to various media sources. Therefore, this enhanced knowledge base can significantly impact their comprehension and interpretation of genetic concepts. Students' educational experiences at each academic level display notable distinctions. Students with a high academic level have gained more learning experience than those with a lower academic level (Gericke et al., 2017; Kurthen, 2014).

The findings of this study indicated that students with a higher academic level were more knowledgeable about genetics than those with a lower academic level. This conclusion is supported by the fact that students with a high academic level, particularly those in the twelfth grade, have studied genetics more thoroughly. Students in grade ten are more knowledgeable about genetics than those in grade eleven because there is a high likelihood that they retain the genetic knowledge that they learned in grade eight. Some experts(Chattopadhyay, 2005; Ezechi, 2021; Kılıç & Sağlam, 2014) argue that students can quickly recall learning material that is pertinent to their lives, such as genetics.

Genetic Literacy Based on Gender

According to data analysis, gender affected genetic literacy, with female students scoring higher on average than male students. This finding is consistent with Aytekin & Isiksal-Bostan (2019), Mukti et al. (2019), and Saefi et al. (2020) who reported that male and female students differed in their capacity to think, draw conclusions, and reason. The attitudes and abilities of female students are substantially higher than male students (Al-Balushi et al., 2022). Female students are more optimistic about science classes (Heng & Karpudewan, 2015). Female students consistently outperform male students on science tests(Al-Balushi et al., 2022; Egara & Mosimege, 2023). This interpretation is supported by a second study observing students in Singapore, which argues that female students' more positive self-concept and self-confidence influence their achievement compared to male students (Yoo, 2018).

Furthermore, Bugler et al. (2015) explain that female students have a higher level of motivation and better adaptation. Similarly, (Tsaousis & Alghamdi, 2022) found that female students showed more internal locus of control in academic performance than male students. Interestingly, Wrigley-Asante et al. (2023) state that female students can outperform male students partly because they are more disciplined. Meanwhile, Dubuc et al. (2020) conclude that female students are more inclined to seek adult approval and emphasise preparing for their academic evaluation to achieve superior outcomes than their male counterparts.

Gender is a social construct that distinguishes between individuals who identify as men and those who identify as women (Oertelt-Prigione & Mariman, 2020). The development of cognitive abilities, personality traits, and decision-making processes in individuals is shaped by various factors such as the environment, personal experiences, and educational opportunities. Consequently, it is generally observed that men and women exhibit differences in these aspects (García-Goñi et al., 2023; Van Der Vleuten et al., 2016; Zamora-Araya et al., 2022). The differentiation between men and women is attributed to a complex interplay of genetic and hormonal influences. Sex differences in brain anatomy, physiology, and neurochemistry cannot be disregarded in contemporary research. The

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variations mentioned above have implications for individuals in their adult lives, leading to disparities in physical, psychological, cognitive, and learning behavior traits (Reale et al., 2023; Szadvári et al., 2023; Xin et al., 2019). Besides, it has been observed that women typically have a larger hippocampus than men, which may contribute to enhanced capacity for long-term memory retention. Hence, it can be argued that women have a heightened memory retention capacity (Szadvári et al., 2023).

However, Piraksa et al. (2014) and Ganley & Lubienski (2016) present contrasting findings. According to the two researchers, gender does not significantly affect students' scientific reasoning and cognitive learning outcomes. Moreover, it has been argued that an individual's knowledge is not solely contingent upon gender (McKnight et al., 2021).

The Interaction between Academic Level and Gender and Its Effect on Genetic Literacy

The results of the data analysis showed that gender and academic level did not reveal any interaction in influencing students' genetic literacy. This finding aligns with the research conducted by Aguillon et al. (2020), which indicated that the interaction between gender and academic level did not significantly impact genetic literacy. This lack of effect can be attributed to individual students' inherent variations in cognitive abilities, learning styles, and learning experiences. Similarly, Yu (2021) discovered that the interaction between gender and academic level did not significantly impact student knowledge. However, when considering gender and academic level as independent variables, it becomes evident that both factors impact students' genetic literacy.

Various factors might contribute to disparities in knowledge, such as the individual's learning process, the surrounding environment, social interactions, and experiences that facilitate the acquisition of knowledge (Aguillon et al., 2020; McKnight et al., 2021). Hence, the impact of the interaction between gender and academic level on students' knowledge is negligible, as the acquisition of knowledge by male and female students is contingent upon the unique learning experiences encountered by each individual. The findings about the correlation between academic level and gender in this research align with the study conducted by Mohammed et al. (2022), which indicates no discernible disparity in genetic literacy resulting from the interplay between gender and students' academic level.

The findings of the current study, which indicate that the interaction between academic level and gender did not significantly impact students' genetic literacy, hold relevance in light of the prevalent reliance on lecture-based instruction for early-stage genetics education. The lecturing method could foster a misperception among students that genetics is solely a fundamental concept that can be readily committed to memory. The consequence of this phenomenon is that students' cognitive capacity is restricted solely to acquiring knowledge through memorisation (Chattopadhyay, 2005; Fitzgerald-Butt et al., 2016; Machová & Ehler, 2021).

Therefore, biology educators must possess the capacity to develop suitable instructional strategies to address these challenges effectively. It is essential to acknowledge that genetics encompasses numerous abstract concepts, which often pose difficulties for students regarding comprehension. To enhance students' understanding of abstract concepts, educators may employ instructional approaches that leverage digital learning media capable of visualising genetic principles (Ezechi, 2021; McKnight et al., 2021). This endeavor will significantly facilitate students' acquisition and comprehension of complex concepts in biology (Chin et al., 2019; Verdes et al., 2021; Wu et al., 2013)

Conclusions

This study comprehensively examines the genetic literacy levels among high school students in Indonesia while also exploring the potential influence of academic level and gender on genetic literacy. The study's findings indicated that most students exhibited a level of genetic literacy that fell within the inadequate category. The results of this study also demonstrated that students' genetic literacy was influenced by their academic level. In addition, gender was found to be a factor that could impact students' genetic literacy. Nevertheless, there was no evidence to suggest that academic level and gender had any significant interactions that could impact the genetic literacy of high school students in Indonesia. This study demonstrates a prevailing need for enhanced genetic literacy among high school students. Thus, educational institutions must assume a prominent position and prioritise cultivating genetic literacy among students, considering their needs, academic proficiency, and gender.

Despite the intriguing discoveries derived from this investigation, it is imperative to acknowledge and rectify several limitations. This study exclusively focused on senior high school education as the sole level of analysis. To obtain a more comprehensive understanding, it is crucial to incorporate a diverse range of educational levels from the broader region of Indonesia into the sampling process. Furthermore, this study specifically examined the impact of academic level and gender on genetic literacy, limiting its scope to these two factors. Hence, additional investigation may be conducted to examine other factors that may influence students' genetic literacy, including but not limited to age, ethnicity, school enrollment status, and geographical location. Additional investigation is required to explore the underlying factors contributing to variations in gender-specific genetic literacy across all academic levels within senior high schools.

Moreover, the inadequate level of genetic literacy observed across various academic levels and genders suggests that genetic education needs to be more effectively implemented. The findings of this study provide additional support for the notion that genetic literacy warrants attention. The incorporation of gender differences should be taken into account when implementing genetic learning in educational institutions. Therefore, educators and educational institutions must develop effective strategies for selecting appropriate learning materials. The potential of instructional media to enhance students' comprehension and proficiency in genetics has yet to be fully realised. Consequently, teachers must employ digital-based media to augment high school students' genetic understanding and literacy.

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Informed consent

The authors indicated that they obtained informed consent from the participants. The data are regarded as confidential information solely utilised for research purposes, with no possibility of identifying the participants based on the data.

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Conflict of Interest

No potential conflict of interest was reported by the authors.

Author contribution statement

All the authors declare that the final version of this paper was read and approved. The total contribution percentage for the conceptualisation, preparation, and correction of this paper was as follows: D.S. 40 %., S.Z. 20 %., A.G. 20 % and S.R.L. 20 %.

Data availability statement

The data supporting the results of this study will be made available by the corresponding author **[S.Z]**, upon reasonable request.

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