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TRENDS IN GENETICS EDUCATION RESEARCH IN INDONESIA: ENHANCING GENETIC LITERACY FOR SOCIETY

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Abstract: Genetics is a rapidly growing branch of biology, playing a crucial role across various disciplines, emphasizing the importance of genetic literacy for students. Like other forms of literacy, genetic literacy has emerged as a societal trend, highlighting the need for a foundational understanding of genetics among academics and the general public. However, students often perceive genetics as challenging due to its abstract molecular concepts, making effective teaching strategies essential. This study employed content analysis to analyze articles from Indonesian biology education journals indexed by SINTA from 2013 to 2024, focusing on efforts to enhance the quality and effectiveness of genetics instruction. The analysis reveals a general increase in publication numbers each year, with slight declines in 2017 and 2020. The most common research designs were R&D studies, which produced educational tools such as media, modules, and other instructional resources. Genetic materials, especially at the high school level, were the most frequently researched topic, as they provide essential foundational concepts for understanding biology. Descriptive analysis (percentage) was the most prevalent data analysis method, although it could have been more effective in generalizing findings. Digital media applications emerged as the most popular teaching strategy, reflecting the complexity of genetics, which benefits from visible aids. Recommendations for future research include employing more precise data analysis techniques and further exploration using qualitative or mixed-method approaches for a more comprehensive understanding of genetics instruction.

Keywords: genetic, teaching and learning, biology education journals

Introduction

Genetics is a branch of biology that studies heredity and hereditary variation (Campbell, 2010). Genetics deals with the inheritance of traits and the expression of heritable traits (Klug et al., 1981), which examines genetic material related to structure, reproduction, expression, change, and recombination, its presence in the population, and its engineering (Corebima, in Nusantara, 2014). Genetics is one of the branches of biological science that has grown over time. Its integrated role with various fields of knowledge is proven to affect our daily lives (Russell, 1996), making it essential for students to learn. Early detection of fetal abnormalities, genetic engineering, and the development of bioinformatics technology are inseparable from the principles of genetics. Parish (1985) and Simmons & Snustad (2006) put genetics as the main core of modern biology. Therefore, future genetic technology may continue to develop along with global problems, such as the increasing human population, loss of most germplasm, scarcity of biodiversity, and global climate change, which require multisectoral handling. Genetic technology can accelerate progress in all biology fields, including cell biology, physiology, developmental biology, behavior, and ecology (Campbell, 2010). The development of genetic technology not only requires sufficient knowledge related to the basics of genetics, but the development of ethical and social issues in society has become a serious debate that needs to be addressed through comprehensive genetics education.

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The prospect of genetic technology in the future is also a *concern* in the pillars of sustainable development (Bappenas, 2020). The responsible application of gene technology is one of the indicators of the *Sustainability Development Goals* (SDGs). This fact implies that the development of gene technology will always grow along with the times, which underlies the need for the SDGs pillar to ensure the safe development and use of gene technology in the future. In addition, Genetics itself is also part of the knowledge content that is consistently tested in the PISA assessment, a program designed to measure the science literacy of 15-year-old students (OECD, 2017). The results of the PISA measurement reflect each country's education quality and human resources' readiness in global competition. Genetics is an essential literacy content for students in developing worldwide science and technology.

The massive development of genetics and its integration into various sectors of life presents new literacy demands called genetic literacy (Chapman et al., 2019). Genetic literacy is the ability to be literate in the context of basic knowledge of genetics and its relation to real life. Genetic literacy can be defined as the adequacy of knowledge and understanding of genetic principles in solving social problems involving genetic issues (Bowling et al., 2008), especially problems commonly found in society. Thus, genetics is a part that is not only important to be understood by academics; various levels of society are expected to have sufficient basic knowledge of genetics. The development of genetics that exists in every segment of life is the reason for the importance of basic genetic knowledge for the community. In addition, the rise of issues related to the safety of genetically modified products needs to be followed up seriously so that the public can be guaranteed safety and aware of the importance of developing genetic technology with proper handling.

One of the efforts to equip genetic literacy is through learning at school. The characteristics of literacy that are loaded with the application of knowledge in various phenomena require learning strategies involving real contexts (Chapman et al., 2019). Learners are expected to engage in discussions and problem-solving related to complex issues. Thus, the learning process is part of information processing, and the use of knowledge learners possess in responding to learning problems/topics. Various curricula implemented worldwide contain genetics content in biology teaching in schools. Generally, it consists of basic genetic knowledge that starts to be taught in middle school. (Kılıç & Sağlam, 2014; Knippels et al.,2005) . Genetics in biology learning in Indonesia is explicitly introduced starting from the secondary school education level. Genetics lessons taught include material about the structure of genetic material, reproduction of genetic material, the work of genetic material, changes in genetic material, genetics in populations, and engineering genetic material (Corebima, 2010)

In addition to the development of science that demands a *literate* society with genetics, implementing genetics learning is also not easy. The characteristics of abstract material with molecular-level learning objects that are generally microscopic make it quite challenging to construct the knowledge that students learn. This is one of the causes of students' low genetic literacy. The low level of genetic literacy is reflected in research conducted by Chapman* et al. (2017) and (Lanie et al., 2004), who almost agree that the level of genetic literacy is still relatively low. Misconceptions in understanding genetics topics are also found in students related to student factors, learning methods, and learning media (Rufus et al., 2021; Syamsiar et al., 2021).

To overcome the low level of genetic knowledge and genetic literacy, the biology learning strategy that needs to be developed at this time is to consider student-centered learning based on information technology, contextual, focus on essential material, and according to the stage of student development. Various efforts are made to develop genetic knowledge and literacy, ranging from innovations in learning strategies, using real contexts, and the development of worksheets and learning resources to innovations in teaching media and technology. Smith et al. (2016, 2009) stated that complex genetics learning must deal with learner-centered active learning strategies. In Indonesia, many studies have been conducted to improve students' genetic knowledge, but few examine efforts to improve genetic literacy. Various studies have been conducted, including developing innovative learning media and technology and using integrated learning models to develop interesting teaching materials. In addition to mastery of genetic concepts, several other skills are also developed as outputs in learning genetics, such as literacy, critical thinking, metacognitive, analytical thinking, problem-solving; and so on.

This research is a content analysis of articles in biology education journals published in Indonesia from 2013 to 2024. This research aims to gather information from various research results on genetics learning strategies in Indonesia. In detail, this research was conducted to answer the following questions: (1) How is the trend of genetics learning research over the years? (2) How are there various research designs in genetics learning in Indonesia? (3) What topics are most studied by researchers in genetics learning? (4) What treatments are applied by researchers in genetics learning? (5) What instruments are used by researchers to measure the achievement of genetics learning? (6) What data analysis techniques are used by researchers in genetics learning?

This research differs in several aspects from previous research that focuses on genetic knowledge. First, the articles reviewed were published between 2013 and 2024 and accredited by SINTA. Second, this research focuses on developing learning strategies to improve genetic knowledge. Third, various parameters were used to conduct content analysis.

Table 1. The Aspects and Categories for Content Analysis in the Study

No	Aspects	Categories	
1	Types of research (2a)	A.1-R and D A.2-CAR	A.3-Qualitative Research A.4-Quantitative Research
2	Types of quantitative research (2b)	B.1-Observation Studies (OS) B.2-Correlational Research (CR) B.3-Survey Research (SR) B.4-Pre-Experimental Designs (PED)	B.5-True Experimental Designs (TED) B.6-Quasi-Experimental Designs (QED) B.7-Ex Post Facto Designs (EPFD)
3	Research Subject	C.1-VII Grade JHS students C.2- VIII Grade JHS students C.3-IX Grade JHS students C.4-X Grade SHS students	C.7-Undergraduate students C.8-Postgraduadate students

No	Aspects	Categories	
		C.5-XI Grade SHS students C.6-XII Grade SHS students	C.9-JHS teacher C.10-SHS teacher C.11-lecturer
4	Data Collection Instruments	D.1-questionnaire sheet D.2-observation sheet D.3-test sheet	D.4-interview sheet D.5-unidentified
5	Data Analysis Methods	E.1-mean E.2-percentage E.3-N-gain E.4-t-test E.5-ANOVA	E.6-ANCOVA E.7- Correlation E.8-Unidentified E.9-Others

Data Analysis

The categories of each aspect that appeared in the article were recorded as the raw database in the study. Furthermore, the data was tabulated and converted into percentage form. The percentage of data obtained shows the frequency of categories in each aspect of the number of articles analyzed. Then, the data is presented in the form of a bar chart.

Results and Discussion

Number of Publication

This analysis was conducted to examine the development of research as an effort made to improve genetics learning from time to time. Figure 1 shows the distribution of research results that examine genetics learning found since 2013. Based on the data, research related to genetics learning tends to increase. The peak occurred in 2024, with problems generally based on low student understanding. This trend reflects the increasing interest and attention to research in genetics learning and teaching, especially in recent years. This is evidence that the attention paid by educators is increasingly intense towards learning genetics, which many students have difficulty understanding genetics concepts (Fauzi & Fariantika, 2018; Kılıç Mocan, 2021; Nusantara, 2014) because it contains complex and abstract concepts (Murray-Nseula, 2011; Mustika et al., 2014).

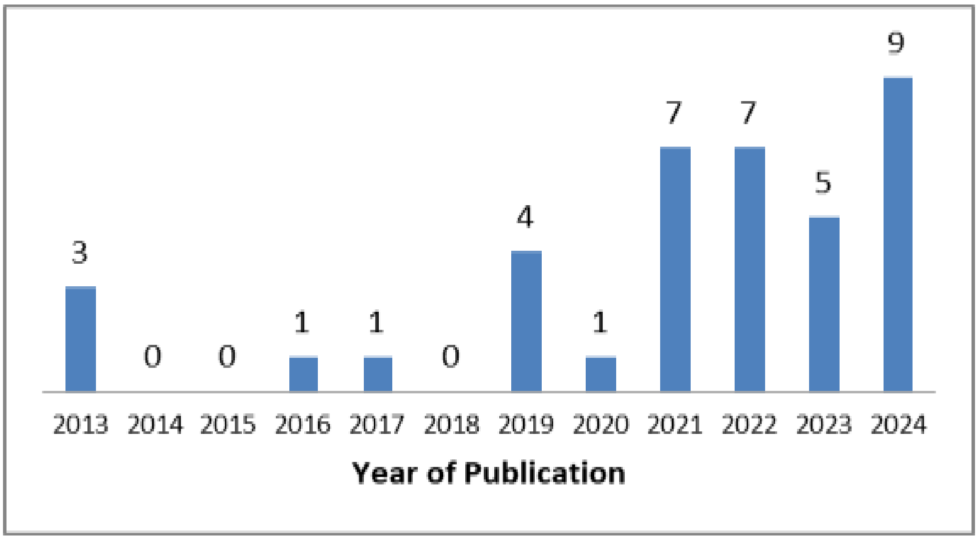

Figure 1: The improvement trend of the number of educational researches with genetic teaching and learning as the main concern in Indonesia in 11 years

Like it or not, the massive use of genetic technology and the COVID-19 pandemic has made us realize the importance of genetics, especially in the development of modern biotechnology. However, genetics is the central core of modern biology (Parish, 1985; Simmons & Snustad, 2006), and the development of biotechnology cannot be separated from genetics. Indirectly, this should be a whip for science education to equip students with sufficient basic knowledge of genetics. However, research on genetics learning is still relatively small; only 38 articles from various SINTA-indexed journals have studied genetics learning in the last 10 years. The recent increase in the number of studies is expected to improve the quality of education, especially in genetics learning. Improving the quality of genetics learning can be a breath of fresh air as an effort to provide the basic foundation of genetic literacy in Indonesia.

Type of Research

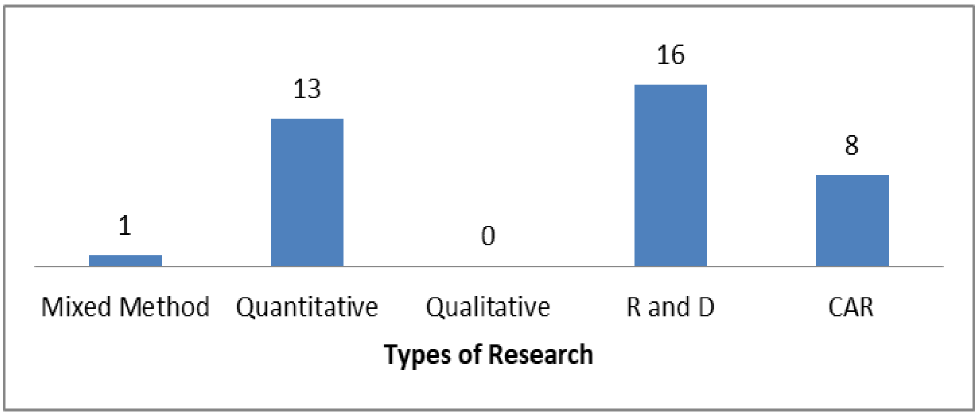

Figure 2: The distribution of researches with genetic teaching and learning as the main concern based on types of research. The chart indicates that R & D is the most popular method, followed by quantitative methods

This analysis was conducted to assess the types of research that are commonly used in genetics learning. Figure 2 shows that R&D is a research design widely used in genetics learning, especially since 2019. In line with the results of research conducted by Fauzi et al. (2018), which claims that R&D was the most chosen research design in 2017, it can be concluded that the trend will continue until 2024. This research generally produces products in the form of books, modules, or learning devices. This trend shows a strong preference for RnD and quantitative methods in genetics research, likely due to the need to develop new models or products.

Subsequent research trends have been dominated by quantitative research. This research design is consistently the most chosen. Previous research also claims that quantitative research designs are more in demand than qualitative research designs, especially for educational research (Göktaş & TellÎ, 2012; Uzunboylu & Aşıksoy, 2014). Based on Figure 3, hypothesis testing is still the most popular quantitative method in research, given that the conclusions are absolute. Research designs with hypothesis testing include quasi-experiment (QED), correlation (CR), and survey (SR)

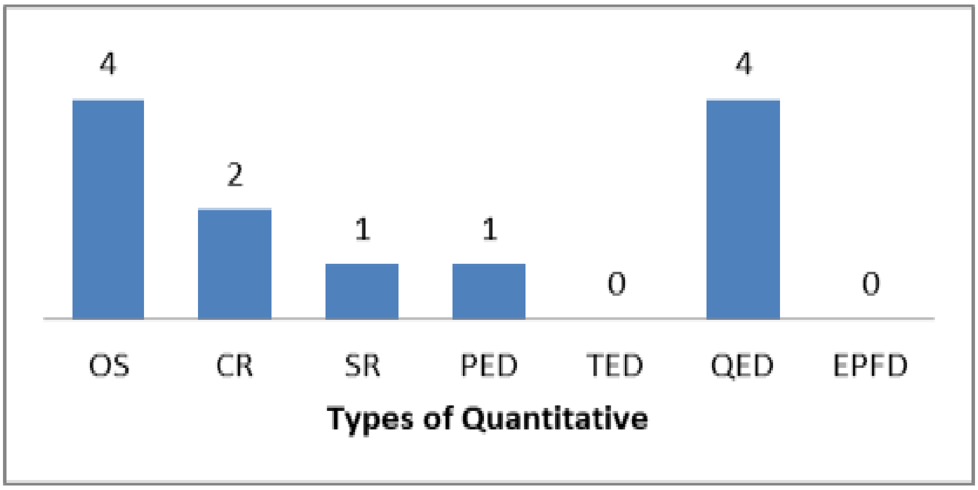

Figure 3: The distribution of quantitative researches with genetic teaching and learning as the main concern in Indonesia. with hypothesis testing type as the most chosen one.

Combining quantitative and qualitative methods can be an option used to complement each other, provide richer insights, and generate new research questions for future studies (Caruth, 2013). The main goal of mixed methods is to utilize the strengths and reduce the weaknesses of both approaches (Creswell & Guetterman, 2019). Unfortunately, qualitative and mixed methods research in genetics learning is still limited. This may be due to the resource-intensive, time-consuming, and complex nature of qualitative analysis if not done well, especially when integrated into mixed methods. Qualitative research can explain phenomena in depth and is compared explicitly to quantitative research, which focuses more on generalizing data. This finding shows an excellent opportunity to conduct further research with qualitative and mixed approaches, especially in further exploring genetic literacy development, which is still relatively new.

Research Subjects

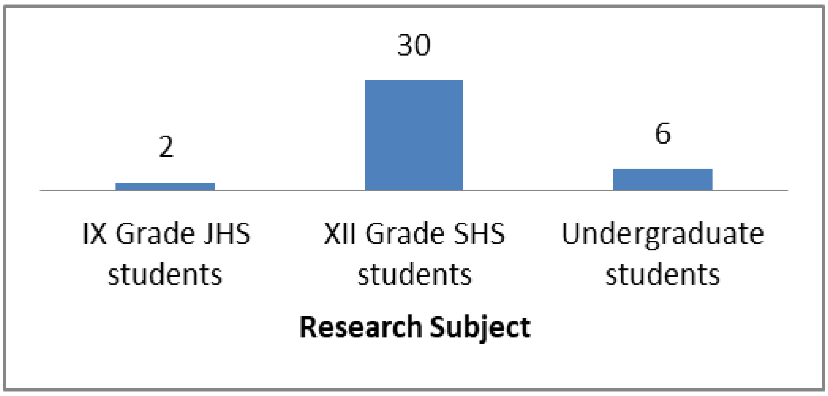

Figure 4: The distribution of research subjects in some educational researches with genetic teaching and learning as the main concern in Indonesia. involving SHS support Chapman's study which formulated instrumentation to asses genetic literacy for public age 18 years old and above

Based on the research designs in the previous explanation, almost all designs involve students as research subjects. Both quantitative, R&D, CAR, mixed method and qualitative research all include students in the research process, which is reflected in the analysis conducted in Figure 4. This means that the focus on increasing genetic knowledge is more aimed at students, especially students at the upper secondary level. This research aligns with the Research results from Watikasari (2023) and Fauzi et al. (2018). In addition, internet searches with the keyword "students" are among the highest search words related to educational research (Choi et al., 2016).

Unsurprisingly, students are still the main target in learning genetics, considering that various aspects of genetics that are now part of public consumption require people to be literate in basic genetic knowledge. This condition encourages scientists to recommend introducing a genetics foundation from the elementary school level (Zudaire et al., 2024). However, learning genetics in students is not easy; many studies show that this topic is difficult to understand because of its complex and abstract nature (Duncan & Reiser, 2007; Lewis & Wood-Robinson, 2000). This difficulty is also caused by the demand to understand phenomena at various levels of biological organization, such as molecules, cells, and organisms (Duncan & Reiser, 2007; van Mil et al., 2013). Therefore, various efforts are made to overcome this challenge and improve the effectiveness of genetics learning in students.

Although it does not directly involve genetic literacy in student learning, the efforts are necessary to provide an essential foundation for students to be literate in genetic issues. Research related to genetic literacy is measured at least in people aged 18 years or equivalent to high school level (Chapman* et al., 2017). This may be based on genetic literacy, which requires a comprehensive understanding of applicable genetic material and involves making attitudes and decisions. Therefore, high school graduates are considered literate with genetic developments and issues, so they need to be equipped through an appropriate learning process.

Topics Selected when Conducting Studies

Genetics is part of biology learning and covers many broad topics. Generally, it is relatively difficult material and needs a special strategy to increase learning effectiveness. Based on the analysis presented in Figure 5, genetic material is the most selected topic in the study, followed by the inheritance of traits or heredity. Genetic material was chosen because it contains basic concepts to understand genetics and biological material (Freidenreich et al., 2011). Genetics is part of biology learning with broad and complex topic coverage, so it is often considered relatively difficult and requires special strategies to improve its effectiveness. However, research still rarely discusses the applicability of genetics technology, such as in the biotechnology field, which is part of modern science. Genetic learning tends to focus on historical aspects, with less attention to the relationship between concepts, so material delivery becomes fragmented and unintegrated (Nusantari, 2014).

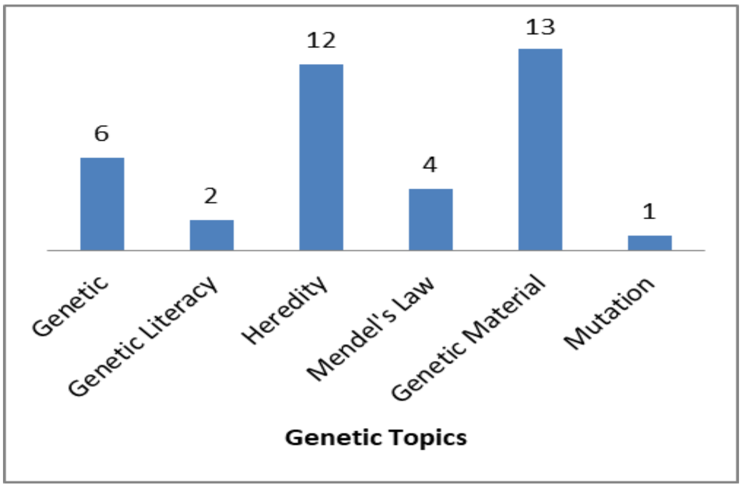

Figure 5: The distribution of genetic topics in some educational researches as the main concern in Indonesia, seem like genetic literacy is not quite popular.

Interestingly, genetic literacy is starting to be considered a topic of genetic learning in Indonesia. Comparative research conducted by Rohmah et al. (2023) compared the genetic literacy of male and female students at the high school level. In addition, Maryuningsih et al. (2022) conducted quasi-experimental research and also examined genetic literacy. However, the research was conducted on university students as research subjects. Research to study genetic literacy is still very limited, considering that genetic literacy is a relatively new form of literacy. The low number of studies on **genetic literacy** indicates the need for further attention. Genetic literacy is crucial because it helps students understand the overall concept of genetics, which is essential in everyday life, especially with the increasing role of genetics in health, biotechnology, and ethics. Further research is needed to improve genetic understanding and literacy among students to be more critically engaged in scientific and genetics-related discussions and understand the ethical implications of evolving genetic technologies.

Treatments

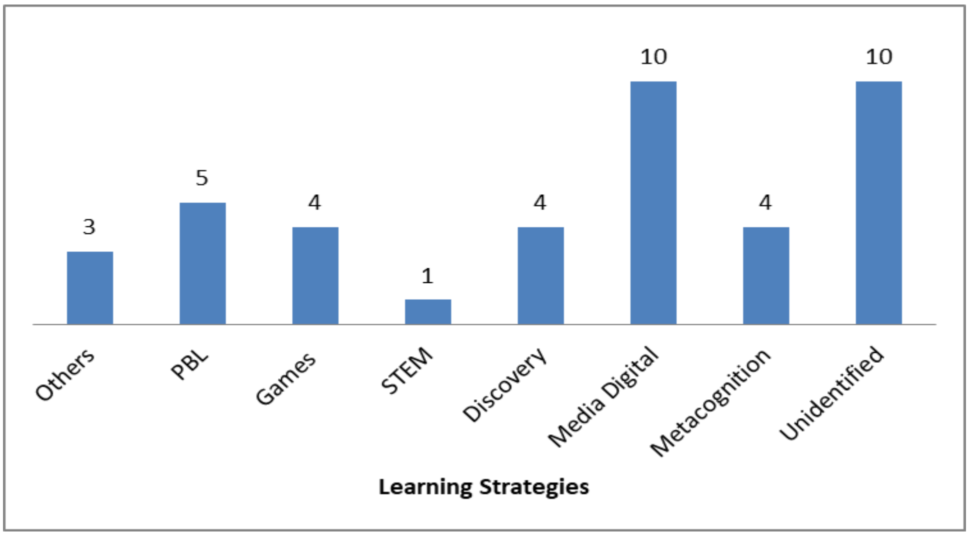

Figure 6: The distribution of learning strategies in some educational researches with genetic teaching and learning as the main concern in Indonesia. Some strategies mostly used to enhance science literacy like PBL, discovery, and STEM.

Practical teaching of genetics is essential to build a basic understanding of biological principles in students. Various strategies have been developed to enhance the learning experience, facilitate understanding, and encourage students to master genetics concepts more easily. One widely applied strategy is digital media, as shown in Figure 6. Digital media is adequate because it can visualize abstract and microscopic genetics concepts, thus helping students understand the material more comprehensively. Smartphone applications, for example, have been used to study microscopic topics, providing easy access to validated learning materials (Nadhiroh et al., 2021). In addition, flexible, open, and interactive digital platforms support online and hybrid learning and are helpful for visual analysis across different education levels and subject areas (Jeffery et al., 2021). Digital media is also considered to improve the quality of biology learning in an interactive and fun way (Muhazaroh, 2023), strengthen student engagement and skills (Permana et al., 2024), and help understand abstract concepts (McMullan, 2017). Furthermore, inclusive teaching strategies through visual tools, interactive simulations, and real-life examples can meet the needs of diverse students. Collaborative approaches and adaptive techniques ensure all students understand genetics concepts, including genetic diversity (Nora Repi & Kolondam, 2023).

Based on Table 2, we can group the selection of learning strategies used into three parts: 1) learning methods, 2) media and learning resources, and 3) learning models and approaches.

Table 2: Types of learning strategies or independent variables frequently selected in educational researches with genetic teaching and learning as the main concern in Indonesia

Learning Strategy		Total	Total
Learning methods	Task Based Learning	1	5
	Games (NHT, STAD, Ice Breaking, Monopoly)	4	
eLearning media	Digital Media	4	4
Learning tools	LKPD	8	12
	Module	4	
Learning Approach.	Contextual	1	1
Learning Model	PBL	5	10
	Discovery	4	
	STEM	1	

Strategies for teaching basic understanding/knowledge of genetics are generally used to facilitate and motivate students in processing concepts and information and learning that involves simple to complex thinking processes. Based on the analysis results in Table 2, many of the strategies developed are related to learning tools and models. Interestingly, the learning models developed are generally used for student-centered learning that trains high-level thinking process skills. These strategies include problem-based learning, STEM, and discovery.

Literacy learning, especially genetic literacy, requires student-centered approaches and higher-order thinking skills. The analysis results in Table 1 show that the student-centered learning model is the leading choice in genetic literacy. This approach involves utilizing students' prior knowledge and alternative understandings to promote deep understanding and active participation. Techniques such as higher-order questioning and open discussion have proven effective in stimulating student interaction (Buma & Nyamupangedengu, 2020). In addition, real problem-based learning is also expected to increase the effectiveness of genetics learning. Effective learning should connect different levels of biology (organism, cell, molecule), explain the relationship between meiosis and inheritance of traits, and encourage active exploration of these relationships. This approach addresses the abstract and complex nature of genetics (Knippels et al., 2005).

Although many developments have been made in learning genetics, effective teaching requires a blend of traditional and innovative strategies (Arends, 2015). Constructivist approaches, active learning models like the PBL, and ludic activities can significantly enhance student engagement and understanding. High-quality pedagogical content knowledge and student-centered methods are essential for addressing misconceptions and promoting deeper learning. Inclusive and adaptive teaching strategies ensure that all students can appreciate the complexity and diversity of genetics. By implementing these varied approaches, educators can create a more effective and motivating learning environment for genetics education.

Further research is needed to explore how contextual issues, such as the ethics of genetics, biotechnology, and its impact on society, can be integrated into learning. These issues are relevant to enhancing students' understanding of the application of genetics in everyday life. They are essential in preparing students for future moral dilemmas and science-based decisions. It is necessary to create cohesive and non-fragmented genetics learning. In addition, the teaching also needs to be adapted to the characteristics/indicators of genetic literacy.

Data Collection Instruments

Instruments are essential in research to assist in data collection. The types of instruments used vary, depending on the type of data collection. Based on Figure 7, test sheets were the most frequently selected instrument, indicating a preference for test instruments in research. Test instruments help assess participants' knowledge, understanding, or skills related to the research topic. They are designed to measure specific variables objectively and systematically, allowing researchers to quantify responses and analyze patterns. Well-designed test instruments guarantee reliability and validity, contributing to the precision and credibility of research findings (Scholtes et al., 2011).

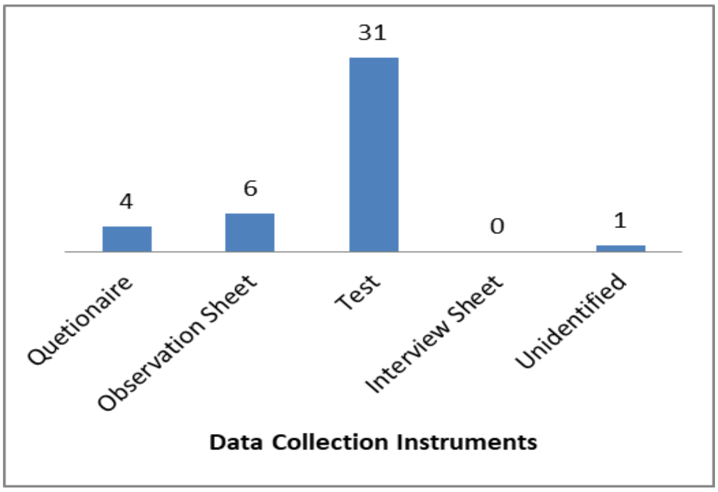

Figure 7: The distribution of data collection instruments in some educational researches with genetic teaching and learning as the main concern in Indonesia

Observation sheets and questionnaires were also used in this study as instruments to collect qualitative and quantitative data. Observation sheets allow researchers to directly observe behaviors, activities, or conditions related to the research subject to obtain objective and factual data. Meanwhile, questionnaires are used to directly get respondents' responses or perceptions, including their opinions, attitudes, or understanding of the research topic. The simultaneous use of observation sheets and questionnaires enriches the data collected, enabling data triangulation to make the research results more accurate, in-depth, and comprehensive.

Test instruments, questionnaires, and observation sheets will be very effective in describing the findings of the research results if these three instruments are used synergistically and adapted to the research objectives. The results obtained will provide a comprehensive and in-depth picture, thus enabling a more thorough analysis and increasing the validity of the research findings. This trend shows that quantitative approaches that measure learning outcomes through tests are preferred, while approaches that explore in-depth understanding through interviews have not been widely applied. Diversifying instruments, such as interviews or questionnaires, can enrich research results by revealing important qualitative aspects, such as conceptual understanding and contextual linkages.

Data Analysis Methods

The accuracy of the data analysis method determines the quality of the findings. Based on Figure 8, descriptive data analysis methods were mainly selected in the study, where researchers processed data in percentages and N-Gain. This choice occurs because quantitative research designs often only use descriptive methods without involving advanced statistical analysis, such as mean difference tests or variance analysis. As a result, data is only presented in basic descriptions without further exploring differences or relationships between variables. This is unfortunate because descriptive analysis alone does not provide sharp and deep insight into the contribution of each variable. To improve the sharpness of the results, applying inferential methods will be more helpful in exploring significant effects or relationships so that the research results can provide more meaningful and reliable information for the development of science.

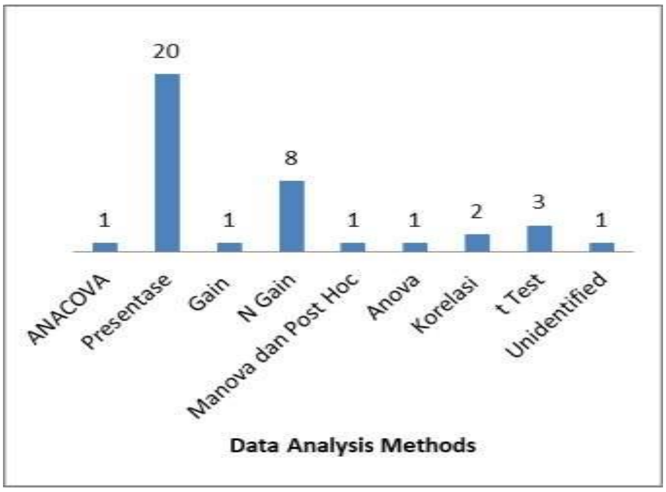

Figure 8: The distribution of data analysis methods in some educational researches with genetic teaching and learning as the main concern in Indonesia

Although not as much as descriptive analysis, some studies have used inferential methods in processing data, which shows an effort to get more in-depth and meaningful analysis results. Inferential methods allow researchers to test hypotheses, analyze relationships between variables, and evaluate the significance of differences between data groups, such as t-tests, correlation, and post hoc tests. This adds value to the research results because this method describes the data descriptively and accurately identifies the influence or relationship of variables. Thus, inferential analysis can potentially increase the external validity of research results, making the findings more generalizable and valuable for theory development and practical applications in related fields.

The widespread use of percentage analysis suggests that research tends to focus on simple data descriptions to illustrate findings in percentage form, effectively providing an overview of research results. However, this technique may lack the ability to explore more complex relationships or show statistically significant differences. Therefore, more research using inferential statistical analysis methods such as ANOVA, correlation, or t-test is needed to provide more in-depth and significantly measurable results. Using descriptive techniques such as presentation is helpful. Still, future research must consider using more comprehensive methods to provide more detailed insights into the effects and relationships between variables in genetics learning.

Conclusion

The content analysis results show that there are efforts to improve genetics learning, especially at the secondary school level. This is reflected in the number of publications each year, which has increased relatively, although there was a decrease in 2017 and 2020. R & D and quantitative are the most widely used designs in research. In addition, the topic of genetic material and students at the high school level is the material and subject most targeted for research. Tests and descriptive analysis (percentage) are the most widely used instruments and data analysis techniques. Meanwhile, the use of digital media is the most popular learning strategy.

This study has several limitations. It is restricted to articles indexed in SINTA, and the data analysis is descriptive, which limits the ability to draw comprehensive generalizations. Therefore, further study, such as a meta-analysis of findings from various related articles, is recommended to obtain more profound and generalizable insights. Based on these limitations, recommendations are provided to guide future research, particularly in enhancing the effectiveness of genetics learning. In-depth studies should employ more appropriate data analysis techniques, and further exploration of statistical findings is necessary through qualitative or mixed-method approaches that allow for more comprehensive data interpretation, especially in the context of genetic literacy research, which remains relatively underexplored.

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Declaration of Interest Statement

The authors declare that they have no conflict of interest.

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