Barrier in Mastering Knowledge of Genetic Concepts in College Students

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Abstract. Genetics is the essence of biology because it underlies various other fields of life sciences, so studying genetics is essential, especially for undergraduate students. However, undergraduate students often need help understanding several concepts in genetics. Thus, this study aimed to track the most difficult concepts in genetics from undergraduate students. This study used a survey research design involving 212 biology undergraduate students taking the Genetics course at Malang State University, Indonesia. The instrument used in this study was essay questions about several concepts in genetics learning, with descriptive analysis as a research data analysis technique. The results showed that undergraduate students experience difficulties in some genetic concepts, as evidenced by their low acquisition of conceptual knowledge. The average value of students' concept knowledge in some genetics concepts that are considered problematic, namely 1) translation (m=20), 2) post-transcriptional modification and genetic code (m=21), 3) DNA replication (m=22), 4) the rate of mutation in living things, the principle of detecting mutations in living things, the process by which DNA repair occurs (m=29), 5) the structure of DNA and RNA as genetic material (m=36), and 6) transcription in living things (m=39). This study concluded that improving students' conceptual knowledge of genetics is necessary for these complex concepts. Therefore, future research should develop effective learning strategies, engaging learning media, and more relevant teaching materials.

Keywords: Genetic Concepts, Knowledge, Difficulties, Descriptive Analysis

1 Introduction

In the current genomics era, genetics is the core of biology that underlies various other fields of life sciences. Knowledge of concepts in genetics can encourage progress in multiple aspects of life[1], both related to technological advancement and community welfare [2]. In general, conceptual knowledge can be interpreted as "awareness" and "understanding" of certain aspects of "reality" [3]. Knowledge is a collection of experiences, appropriate information, and skilled insights that offer a structure for estimating and integrating new experiences and information [4]. Several experts noted that general knowledge of genetic concepts could be interpreted as students' awareness of connecting various information related to heredity units and regulatory changes of different physiological functions, which will later form new information associated with the character of organisms relevant to various genetic phenomena. In studying

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genetics, [5] groups genetic concepts into several topics, which include: 1) structure of genetic material, including genes, chromosomes, DNA, RNA, plasmids, episomes, and transposable elements, 2) reproduction of genetic material, including cycle cells, DNA replication, reverse transcription, rolling circle replication, cytoplasmic inheritance, and mendelian inheritance, 3) genetic material, including the genetic material, transcription, post-transcriptional modification, genetic code, translation, the concept of one gene-one enzyme, interaction gene, control of gene in prokaryotes, control of gene in eukaryotes, genetic control of immune responses, genetic control of cell division, sex expression, changes in genetic material, 4) changes in genetic material, including mutation and recombination, 5) genetics in the population, and 6) genetic material engineering. Some of these genetic concepts play a role in producing a solution to address the genetic phenomena currently occurring in the broader community [1].

Understanding genetic concepts will create a more prosperous society [6]. In the biotechnology field, for example, genetics concepts are needed in genetic engineering, starting from manipulating genetic material, gene therapy, exon changes, and gene editing [7]. Apart from that, genetics concepts are also fundamental in the cloning process, DNA testing, Genetically Modified Organisms (GMOs), and identification of certain diseases [8]. These various genetic concepts have been taught from high school [9] to university [10].

The teaching of genetic material at various levels of education has shown the need for students to understand genetics in-depth, especially among 21st-century science students [11] [12]. It is essential for students not to see genetic information as just a "black box" but to understand the basic principles of genetics to make life choices [13]. The need for mastery of the concept of genetics is believed to significantly influence the development of science and technology in a country [14]. However, despite the importance of genetics in the field of Biology and life, students still perceive genetics as a subject that is difficult to understand [6], [7], [11], [15], [16], [17], [18]. In one of the studies, it has been revealed that several topics in genetics, especially those related to genetic material (chromosomes, DNA, and genes), cell division, and protein synthesis are the three genetic materials that are considered the most difficult by students [18]. The other study also showed that inheritance patterns, gene deterministic, and genetic information are included in concepts that are difficult to study in genetics [11]. Further explained that many students have difficulty understanding the concept of genetics because genetics contains a lot of vocabulary and terminology, so students have difficulty choosing the right word [19]. Genetics is also considered difficult because it includes many abstract concepts as well as the existence of concepts in genetics at various levels of representation, and also the existence of various ontologically distinct genetic entities [17]. Besides that, difficulties in understanding concepts in genetics are also triggered by the inability of students to relate concepts in genetics [14]. The other student's difficulties are the inability of students to provide details in the description of terms in genetics, difficulties in giving explanations of genetic processes in an unsequential manner, failure to define test crosses correctly, unable to explain the process of crossing in general and having a poor response to questions about complex genetic traits [7]. Based on the analysis of these various reports, it can be seen that many students need help understanding some of the concepts of genetics [15].

In general, students' difficulties in understanding the concept of genetics can contribute to evaluating and finding solutions for teaching genetics topics to make them more easily understood by students [19]. Since the 1980s, various studies have revealed that learning genetics can encourage the creation of a good enough education for future students [14]. Cesarini & Visscher (2017) explained that most students already have basic skills in explaining the nature of genetic information, but students still have difficulty synthesizing knowledge of genetic concepts. Another challenge in learning genetics is the inability of students to understand the complex interactions between the environment and genetic mechanisms in the development of individual traits [13]. Understanding that phenotypes result from the development of interactions between genes and the environment is crucial for scientists and scientific investigations, but it also plays a role in determining individual attitudes toward various genetic issues. Understanding of gene expression is an essential part of genetics education which is increasingly focused on the basic concepts for "omics" research (e.g., metabolomics, proteomics) [8].

The difficulty of students achieving a deep understanding of genetics is also one of the effects of learning that is less meaningful. The lack of teacher knowledge in implementing learning strategies that encourage conceptual change [11][12], as well as the application of conventional learning [20], is an actual condition that causes topics in genetics to be challenging to study, not only at the high school level, but also at the university level [19]. In addition, some researchers state that textbooks are the main parameter that can cause difficulties in understanding the concept of genetics in students [21], [22], [23]. Some researchers associate the inability of students to understand genetic processes and concepts with the low quality of genetic learning books which lack coherence, include inaccurate vocabulary, unclear pictures, and contain unnecessary concepts and details that will hinder students' understanding [6], [21], [24]. In other findings, it was also revealed that genetic textbooks do not contain coherence between inheritance, DNA function, and the role of trait development at various levels of biological organization in both the national curriculum and textbooks [23]. In addition, many studies have stated similar statements, that students' difficulties in understanding genetic concepts are also caused by the national curriculum that is less relevant to the conditions and developments that are taking place [11], textbooks and conventional teaching methods [3] or even media used in learning that are still inadequate [14].

The challenge to understanding genetics is a serious problem because even though it may not be difficult to identify and improve. It will be challenging to forget concepts that are misinterpreted, for example, in the inheritance of traits that only refer to the role of genetics without considering the part of the environment, which can later lead to negative stigmas such as genetics determinism and genetic essentialism [25], [26]. Based on these conditions, it is necessary to conduct research that provides an overview of the level of learning difficulty in understanding genetics. Through a survey of students' level of conceptual knowledge, this study aimed to trace material in the genetics course that students consider difficult. Henceforth, it is hoped that there will be solutions to provide meaningful genetics learning for students through learning models, teaching materials, and relevant learning media.

2 Methods

This study used a survey research design, with a quantitative approach as a research method in determining the topics that were considered the most difficult by students. This research was conducted at Universitas Negeri Malang, East Java, Indonesia, with 212 students participating. Participants in this study consisted of 38 male students and 174 female students. The age range of the participants ranged from 18 to 22 years. 110 were undergraduate students from the biology education program, while 102 were undergraduates from the biology study program. This research was conducted from late March to early May 2023.

The instrument used in this study was an essay test of conceptual knowledge on 18 topics of learning genetics. Retrieval of conceptual knowledge data through these 18 topics is based on the overall scope of genetic concept knowledge, starting from basic genetic concepts to applied genetic concepts that students need to master while taking genetics courses at the university level. The topics referred to in more detail include:

1. The structure of DNA and RNA as genetic material
2. Plasmids, episomes, transposable elements, extrachromosomal inheritance as genetic material
3. DNA replication
4. Transcription in living things
5. Post-transcriptional modification and genetic code
6. Translation
7. Regarding mutations, the causes of mutations and types of mutations in the genetic material of living things
8. The rate of mutation in living things, the principle of detecting mutations in living things, the process by which DNA repair occurs, and the relationship between mutation and adaptation
9. Practical application of mutations in everyday life, various changes in the structure of chromosomes, and abnormalities related to changes in the number of chromosomes
10. Regulation of gene expression in prokaryotic organisms
11. Regulation of gene expression in eukaryotic organisms
12. Genetic control of immune response
13. Genetic control of cell division
14. The sex of living creatures
15. Understanding enzymes and specific elements related to recombination
16. Transformation, transduction, conjugation, and recombination in bacterial phages
17. The genetic material in the population
18. Genetic engineering as a form of application of genetics in modern biotechnology

Measurement of students' conceptual knowledge in terms of the extent to which students' answers are correct in answering questions on the test. The data in this study were obtained from the average value of student answers on each learning topic. Furthermore, the average data will be analyzed descriptively and presented in graphical form.

3 Results and Discussion

In this study, the students' conceptual knowledge level was known for 18 genetic topics, as shown in Figure 1. Based on Figure 1, it can be seen that of the 18 genetic topics tested, students had diverse understandings of each topic. Participants get the lowest average score of 20 out of the range of 0-100 on translation material, followed by post-transcriptional modification and genetic code (m=21); DNA replication (m=222); the rate of mutation in living things, the principle of detecting mutations in living things, the process by which DNA repair occurs, and the relationship between mutation and adaptation (m=29); the structure of DNA and RNA as genetic material (m=36); transcription in living things (m=39); plasmids, episomes, transposable elements, extrachromosomal inheritance as genetic material (m=40); the genetic material in the population (m=48), genetic engineering as a form of application of genetics in modern biotechnology (m=48); regarding mutations, the causes of mutations and types of mutations in the genetic material of living things (m=51), regulation of gene expression in eukaryotic organisms (m=51); practical application of mutations in everyday life, various changes in the structure of chromosomes, and abnormalities related to changes in the number of chromosomes (m=53); understanding enzymes and specific elements related to recombination (m=54); regulation of gene expression in prokaryotic organisms (m=55); genetic control of cell division (m=65); the sex of living creatures (m=66); genetic control of immune response (m=71); and for the highest average value of 75 achieved in material transformation, transduction, conjugation and recombination in bacterial phages.

The lower the average value of students' conceptual knowledge, it can be said the material is more challenging to master, and the higher the average student score, the easier the genetic material is to master. Based on the acquisition of the average score on these 18 materials, six materials with the lowest average score were taken as the genetic topics that were the most difficult for students to master. The six materials that received the lowest average score in this test can be seen in Figure 2. Figure 2 showed the six materials with the highest difficulty, namely: 1) translation (m=20), 2) post-transcriptional modification and genetic code (m=21), 3) DNA replication (m=22), 4) the rate of mutation in living things, the principle of detecting mutations in living things, the process by which DNA repair occurs (m=29), 5) the structure of DNA and RNA as genetic material (m=36), and 6) transcription in living things (m=39).

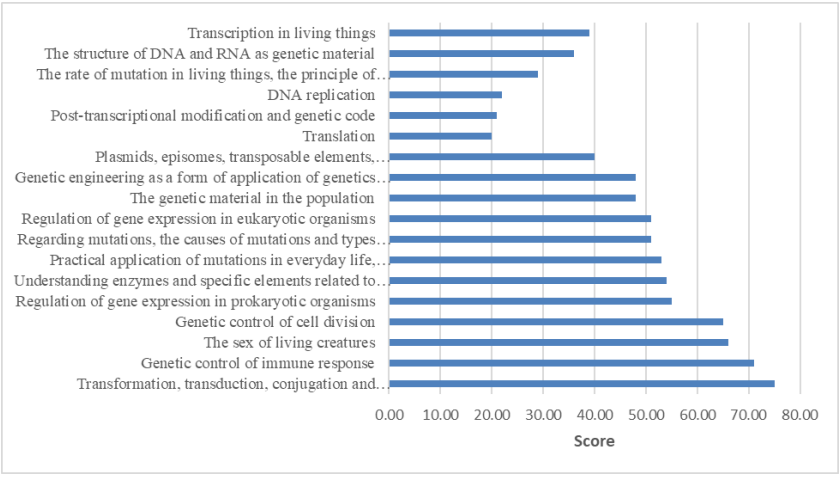

Fig. 1. Student's scores on the genetic test.

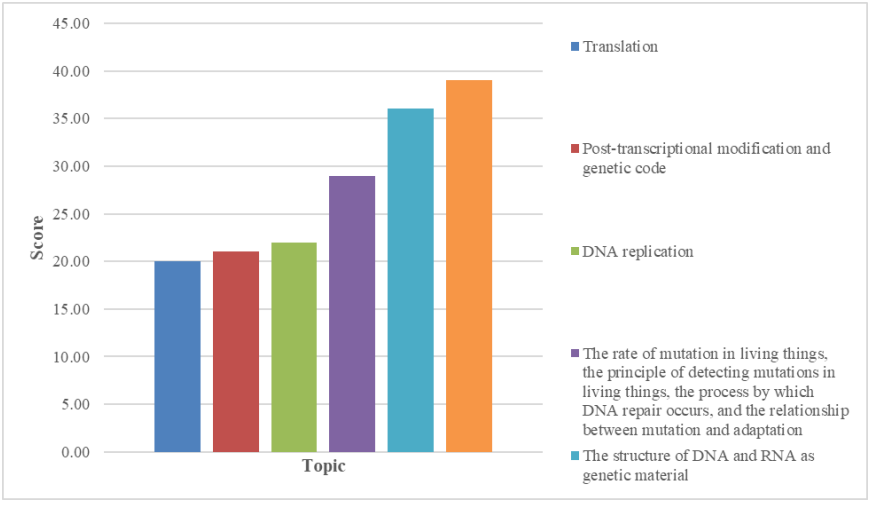

Fig. 2. The most difficult genetic topic in undergraduate students.

Some of the difficulties in understanding concepts of genetics can be explained by looking at the various barriers to it. There are barriers to understanding genetic concepts, including the many concepts that must be mastered and challenging for students to understand [2]. Various genetic events cannot be seen with the naked eye, some concepts are too abstract, and many foreign terms exist [17]. Furthermore, to understand some of the more complex genetic concepts, for example, those related to genetic engineering, it is necessary to have a good mastery of certain prerequisite concepts such as the components of genetic material, the process of protein synthesis, to several methods in mutation. If the prerequisite concepts are well mastered, students

can understand the following more complex concepts [7]. Other research results stated that many core entities and processes in genetics, especially molecular genetics, were unknown to high school and university students[6], [15], [19]. Genetic phenomena that cover various levels of life organization and reasoning about these various levels provide challenges for students [8], [13], [23], [27]. Futhermore, the challenge aspect of genetic phenomena that has yet to receive much attention in genetic education research is related to the complex interaction between the environment and genetic mechanisms in developing traits that still need to be visible [13]. Neglect of this interaction and over-simplification of inheritance by focusing on monogenic traits [21], [24], [28] led to a deterministic view of genetic traits being determined mainly by genes rather than modulated by genes and environment [16], [29].

Several studies stated that to provide an in-depth understanding of genetics, it is necessary to state explicit relationships between traits, proteins, and DNA [13] at all levels of biological organization [23], [30], [31], but neither current genetics curricula nor textbooks accommodate this [14], [24], [28]. Although most of the basics of genetics have been taught at the junior secondary level, the characteristics of proteins are often introduced in more detail in chemistry textbooks aimed at a higher level [13]. Because of that, students do not know the properties of proteins and how they affect these properties, students cannot fully understand genetics [13], [17]. In other findings, it was also revealed that textbooks play a role in the success of learning and function as an obstacle to learning. Therefore careful consideration must be given to using textbooks during learning [31].

In this study, six genetic topics that were difficult for students to master, four of them were primary material regarding central dogma (translation, post-transcriptional modification, genetic code, DNA replication, and transcription in living things). The central dogma in molecular biology is challenging to understand [8]. Nevertheless, the concepts related to this central dogma are fundamental in genetics, especially in interacting with genetic data. Some obstacles often encountered in understanding the central concept of dogma include distinguishing between molecules produced from a particular process, understanding some genetic techniques, and a genetic vocabulary still foreign to students [8]. Students often find errors related to the application of codon terms to a process of inheritance or need to understand how the structure of a gene affects the expression of that gene [14]. It was further argued that when students have completed genetic learning, students only retain most of the low-level factual information; for example, the names of the bases or monomers that make up the polymer. When students focus on more than low-level knowledge of the central topic of dogma, this is generally at odds with educational reforms focusing on practice and conceptual understanding [32]. Thus, to provide instruction regarding this material, educators at all levels must be aware of the level of cognitive development of their learners and also the preconceptions they may already hold [18]. Many students form their understanding of genetics even before the topic is taught, so teachers must actively explore students' previous ideas during lessons and reconstruct the connections between basic genetic concepts [1], [12]. It is also important to note that all processes in genetics need to be understood at all levels of biological organization [17], starting at the organismal, cellular, and molecular levels and their interconnections in further material.

Recommendations to provide in-depth learning related to protein synthesis material, which must be taught simply at the junior secondary level. All components in this material must be introduced concisely, clearly, and easily understood by students. The general character development process must be supported by teaching about proteins and their functions naturally together with the basics of genetics [13], not as knowledge of organic chemistry [21]. Through the teacher's assistance, students should understand the process of DNA inheritance and DNA as a protein code, visualize the general function of proteins in the body, and be aware of how proteins affect physical properties [33], [34].

Once students fully understand the concept of heredity, DNA as a significant part of the reproductive process, and can describe the relationships between DNA and particular traits, they can move to more complex genetic concepts such as the Mendelian laws of heredity [7]. Protein synthesis should also be used as a simple way to explain the impact of mutations, hereditary diseases, and genetic engineering, which are now widely used so that students will fully understand the use of genetics in real life [35]. These social science applications and issues related to genetics should be taught as assignments that enable active learning [36]. Using their understanding of protein synthesis as a mediator of trait development, students should assign parts of the process to specific levels of biological organization and explain how certain changes at one level affect other levels [4]. Students should also be allowed to conclude, for example, how changes in gene expression can affect the growth of selected genetically engineered organisms and the possible threats and benefits of this process when applied in specific fields such as agriculture [37].

Students can fully understand the various processes of heredity and DNA transformation into visible characteristics (such as hair color or blood type) only if the learning process runs coherently, not learning that only focuses on one unit. Based on the results of studies that have been conducted, it is argued that if appropriately introduced, the perceived difficulties with genetic material no longer occur even at the junior high school level [3], [11], [28] as well as at the school level upper secondary [13], [18], [38]. A sensible simplification and appropriate connection of all parts of the genetics curriculum at all biological organization levels will help students develop a coherent understanding of a given topic and develop better systems thinking skills, enabling them to navigate more effectively on real-life problems [23].

One way to provide accessible genetics learning for students is by developing effective learning strategies [19], engaging learning media [39], and more relevant teaching materials [40]. The use of several appropriate learning models, such as cooperative script and reciprocal teaching, can be an alternative to implementing genetics learning [18], [19]. In addition to the learning model, and educators must also pay attention to the use of textbooks used. Educators must monitor whether textbooks contain the national curriculum and use the correct sequence of topics that promote meaningful understanding and learning ([7], [13], [24], [28]). The basics of cell biology, reproduction, and human genetics cannot be separated but are closely related to learning [8]. Therefore, teachers should also be motivated to use different topic sequences to connect topics more efficiently than is contained in current textbooks. In addition, students also need to be facilitated by learning media that can help make the

abstract concept of genetics more concrete to learn and assimilate it effectively. Utilization of this learning media is a form of dissemination and use of appropriate technology in supporting teacher pedagogic activities. This finding is in line with the results of publications by [3], [16], [19], [21], [24], [37], [38]

4 Conclusion

Genetics is an exciting science, but several factors, such as material characteristics, teaching methods, or less relevant learning resources, make genetic topics difficult to study. There were six topics in genetics with the most challenging level of mastery of concepts for undergraduate students, which include: 1) translation, 2) post-transcriptional modification and genetic code, 3) DNA replication, 4) the rate of mutation in living things, the principle of detecting mutations in living things, the process by which DNA repair occurs, 5) the structure of DNA and RNA as genetic material, and 6) transcription in living things. Furthermore, the information obtained in this study can address similar problems, particularly in studying genetics at the tertiary level. Through this research, lecturers can find out which topics are still complex for students to master during lectures, so lecturers can find solutions through learning models, teaching materials, and appropriate learning media before teaching these topics.

One of the limitations of this study is that the data collection technique only used essay tests to measure the level of students' conceptual knowledge on 18 topics in genetics so that an explanation of the characteristics of these topics in the opinion of students cannot be known. Therefore, it is suggested that researchers use other instruments, such as questionnaires, in future research to collect more information.

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