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# BIOLOGY EDUCATION STUDENTS' MENTAL MODELS ON GENETIC CONCEPTS

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**Abstract.** *This research aims to explore the concept of mental model of students about genetic concepts through drawing-writing test. The participants were 85 students of Biology Education at University of Lampung, which has taken genetics course. Mental model of students was categorized into five levels (levels 1-5) based on coding framework which was adapted from Kose (2008) and Saka et al. (2006). The results showed that the most dominant mental models found in each concept through drawing-writing test (D/W) respectively were D3/W3 (drawings with misconceptions/partial understanding with alternative conceptions) on the concept of "genetic materials", D2/W2 (non-representational drawings/alternative conceptions) on the concept of "heredity", D2/W3 (non-representational drawings/partial understanding with alternative conceptions) on the concept of "gene expression", D2/W3 (non-representational drawings/partial understanding with alternative conceptions) on the concept of "gene regulation in metabolic processes", and D1/W2 (no understanding/alternative conception) on the concept of "gene regulation of the growth and development of an organisms". The results indicated that drawing-writing test can be used in probing the learning difficulties and misconseption on genetics.*

**Keywords:** *drawing-writing test, genetic concepts, mental models.*

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## Introduction

Since the mid-20th century, genetics has progressed rapidly and become a big challenge for the young generation in all countries. The development of various products and applications of genetic technologies such as genetic modified organisms (GMOs), DNA fingerprinting technique, genetic disease screening, gene therapy, as well as cloning requires us to have a high scientific literacy. A good understanding of these things is important as social control over the issues circulating in the community through the popular media, such as TV, radio, newspapers, and magazines (Boujemma & Pierre, 2010; Dawson & Schibeci, 2003; Marbach-Ad, 2001). Therefore, it becomes important for the students and university students (especially prospective biology teachers) to have a basic knowledge about the genetics, so that they are able to overcome issues that will occur about genetics, both in political, economic, social, and ethical issues (Boujemma & Pierre, 2010; Marbach-Ad, 2001; Saka *et* al., 2006).

Genetics is one area of study that has been difficult for high school students (Banet & Ayuso, 2003; Chattopadhyay, 2005; Lewis & Wood-Robinson, 2000; Lewis *et al.*, 2000a, 2000b, 2000c; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000) and for university students (Bahar *et* al., 1999b; Saka *et* al., 2006). Several studies have concluded that the use of multiple levels of life organization in the explanation also cause genetics difficult to learn (Duncan & Reiser, 2007; Johnstone and Mahmoud, 1980). Additionally, Knippels (2002) mentioned that one factor contributing to the difficulty of the concept is the immateriality and the complexity of genetic concepts. This complexity arises because genetic concepts are learned through the three levels of thinking, i.e. macro, micro (or sub micro and molecular), and symbolic (representation) (Bahar *et al.*, 1999a; Knippels, 2002). The ability to link the three levels of thinking has a major contribution in the development of students' mental models in formulating the definition and understanding the concepts (Johnstone, 1991). Knippels research results (2002) showed that most student find it difficult to relate the concepts at different systematic level. This indicates that the lack of mental models was the cause of the lack of understanding of the concept in genetics.

The term 'mental model' was first introduced by the Scottish psychologist Kenneth Craik in 1943. Craik explained that the mental model is a dynamic and creative representation of the external world (Chang, 2007). Mental models as a form of mental images is a representation of a mental construction which is needed by a person when learning a new concept (Johnson-Laird, 1983). Mental models reflect the perception of reality and is closely related to the framework of someone's knowledge in describing, explaining and predicting something, so that the mental model has an important influence on the development of scientific knowledge of a person (Brunswik, 1956; Norman, 1983; Rouse & Morris, 1986).

Some researchers analyzed and mapped the students' mental models about the genetic concepts through several techniques. Drawing test is the most widely used technique by researchers to evaluate the students' concept understanding (Ben-Zvi Assaraf and Orion, 2005). Through drawing, the student can represent ideas widely, reflect understanding and conceptualization of ideas and concepts of basic science, reveal the mental models of the students regarding the scientific concept, conceptual changes and misconceptions (Dikmenli, 2010; Gray, 1990; Rennie & Jarvis, 1995; White & Gunstone, 1992). Bahar *et al.* (1999b) analyzed the images of concept association obtained from the word association test to map the cognitive structure on the genetic concepts in the first-year students. Their research results showed that students construct various ideas relating to a given keyword. In general, the images produced did not show any linkage or networking between concepts.

The combination of drawing and writing tests can also be used to evaluate the students' mental models about the concept of genetic materials. Through the writing test, the students reflect on what they have learned in class, so the level of their concept understanding can be measured (Abraham *et al.*,1992; Scherz & Oren, 2006). Saka *et al.* (2006) used the drawing and writing tests to evaluate the students' understanding of the genetic materials in some levels of education. His research results showed that there are differences of understanding among the three groups of respondents. All groups did not show good understanding of the concept of genes and DNA. In addition, it also identified some of the misconceptions on genes and DNA.

In the previous studies, a review of the mental model on the concept of genetics is still limited to the concept of "genetic materials" (genes, DNA and chromosomes). While the research of the mental model of the concept of "heredity", "genetic regulation of the phenotype, metabolism, growth and development of organism" have not been reported. These concepts are important to learn because it will be the basis in studying the higher concepts, such as physiology, development, biotechnology, and molecular biology. Therefore, this research aims to explore the mental model of pre-service teachers of biology in genetic concepts through drawing and writing techniques. The results of this research are expected to be a feedback and a reflection for biology lecturer in improving genetics lectures so that the mental models of students can be developed.

## Methodology of Research

### *General Background*

This research is a qualitative descriptive with cross-sectional design. In this research, researchers collected the data through survey at one time so that it can provide information in a short time about certain attitudes or practices (Creswell, 2012). This research aims to explore the mental model of pre-service biology teachers to the concept of genetic materials, heredity, genetic regulation of the phenotype, metabolism, growth and development. Mental models in genetics concepts were explored by using drawing and writing tests. This research was conducted in May - August 2017 in Biology Education Study Program, Faculty of Teacher Training and Education, University of Lampung.

### *Sample Selection*

A total of 85 students of 4th semester in Biology Education Study Program, Faculty of Teacher Training and Education, University of Lampung were included in this research. The average age of students was 20.1 (range 19-21 years). The majority of students were women (61 of 85). However, gender differences were not evaluated in this research.

### *Instruments and Procedures*

The research data were in the form of mental model students' profile which were obtained through drawing and writing tests about the concept of genetics (Table 1). The students were asked to answer the question by

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describing his imagination related to question (in the form of pictures, concept maps, or other representation) and write an explanation of the genetic concepts on HVS A4 paper. The response of question and mental models of students were compared with the answer key or scientific mental models.

**Table 1. Open-ended questions about genetic concepts.**

| No. | Questions |
|---|---|
| 1 | How is the linkage between genes, DNA and chromosomes look like? |
| 2 | How can hereditary inherit a gene from both parents? |
| 3 | How can genes determine the phenotype of an organism? |
| 4 | How can genes control the metabolic processes? |
| 5 | How can genes control the growth and the development of an organism? |

*Data Analysis*

Data were analyzed independently by researchers and 2 biology lecturers. The results of the analysis were compared and if there were any differences then the discussion was done to decide the final results about the mental model produced. The students' responses in the form of images or other representations were analyzed using a coding framework adapted from Kose (2008). Meanwhile, the students' responses in the form of text or explanation were analyzed using a coding framework prepared by Saka *et al.* (2006). The coding framework of mental model for drawing and writing test results are presented in Table 2. The results of the analysis were presented in the form of frequency distribution table (Table 3). To illustrate the results of our analysis, an image representing the three concepts with the total of highest frequency were presented in Figures 1 – 5. In addition, the students' responses in the form of writing from the three concepts with the highest frequency percentage were presented in Table 4.

**Table 2. Coding framework of mental model for drawing-writing test results.**

| Level | Coding Framework of Drawing (D) | Coding Framework of Writing (W) |
|---|---|---|
| 1 | No Drawing: *Students replied, "I don't know," or no response was given to the statement.* | No Understanding: *Blank, repeats question, irrelevant or unclear response,no explanation given for choice of answer.* |
| 2 | Non-Representational Drawings: *These drawings included identifiable elements of genetic concepts. Also the responses, which included diagrams or formulations instead of the drawings, were evaluated in this category.* | Alternative Conception: *Scientifically incorrect responses.* |
| 3 | Drawings with Misconceptions: *These types of drawings showed some degree of understanding on genetic concepts, but also demonstrated some misconceptions.* | Partial Understanding with Alternative Conception: *Responses that show understanding of the concept, but that also contain alternative conception.* |
| 4 | Partial Drawings: *The drawings in this category demonstrated partial understanding of the concepts.* | Partial Understanding: *Responses that contain a part of the scientifically accepted concept.* |
| 5 | Comprehensive Representation Drawings: *Drawings in this category were the most competent and realistic diagrams of genetic concepts.* | Sound Understanding: *Responses that contain all parts of the scientifically accepted concept.* |

## Results of Research

The analysis results of mental model of students in genetic concepts through drawing-writing test are presented in Tables 3 and 4 and Figure 1 – 5. Table 3 presents the frequency distribution of students' mental models on the concept of genetics. Based on Table 3, it is known that the highest level of mental models through image (D5) is found in the concept of "genetic materials" and "hereditary", while the highest level of mental models through explanation (W5) is found in the concept of "genetic materials", "heredity" "gene expression", and "gene regulation in the growth and development of an organism". The most dominant mental model which was found on each concept through the drawing-writing test (D/W) respectively is D3/W3 (drawings with misconceptions/partial understanding with alternative conception) on the concept of "genetic materials", D2/W2 (non-representational drawings/alternative conception) on the concept of "heredity", D2/W3 (non-representational drawings/partial understanding with alternative conception) on the concept of "gene expression", D2 /W3 (non-representational drawings/partial understanding with alternative conception) the concept of "gene regulation in metabolic processes", and D1/W2 (no understanding/alternative conception) on the concept of "gene regulation in the growth and development of organism". In addition, if it is considered from the total frequency of mental models at level 4 and 5, it is known that students tend to do better in representing the mental models of the concept of genetics through writing or explanation than through image.

**Table 3. Frequency distribution of students' mental models in genetic concepts.**

| Concept | Level | W1 | W2 | W3 | W4 | W5 | Total |
|---|---|---|---|---|---|---|---|
| Genetic materials | D1 | 1 | 1 | 1 | - | - | 3 |
| | D2 | 1 | 2 | 6 | - | - | 9 |
| | D3 | - | 2 | 21 | 8 | 4 | 35 |
| | D4 | - | - | 8 | 10 | 4 | 22 |
| | D5 | - | - | - | - | 16 | 16 |
| | Total | 2 | 5 | 36 | 18 | 24 | 85 |
| Heredity | D1 | 3 | 17 | 2 | 1 | - | 23 |
| | D2 | 4 | 30 | 6 | - | - | 40 |
| | D3 | - | 2 | 7 | 4 | - | 13 |
| | D4 | - | 2 | 1 | 2 | - | 5 |
| | D5 | - | - | - | 3 | 1 | 4 |
| | Total | 7 | 51 | 16 | 10 | 1 | 85 |
| Gene expression | D1 | 1 | 4 | 6 | - | - | 11 |
| | D2 | 1 | 20 | 21 | 6 | - | 48 |
| | D3 | - | 4 | 8 | 5 | 1 | 18 |
| | D4 | - | - | 4 | 2 | 1 | 7 |
| | D5 | - | - | 1 | - | - | 1 |
| | Total | 2 | 28 | 40 | 13 | 2 | 85 |
| Genetic regulation in metabolic | D1 | 11 | 7 | 2 | - | - | 20 |
| | D2 | 2 | 11 | 22 | 7 | 1 | 43 |
| | D3 | - | - | 3 | 3 | - | 6 |
| | D4 | - | - | 1 | 2 | 2 | 5 |
| | D5 | - | - | 1 | 4 | 6 | 11 |
| | Total | 13 | 18 | 29 | 16 | 9 | 85 |
| Genetic regulation in growth and development | D1 | 6 | 24 | 4 | 7 | 4 | 45 |
| | D2 | 3 | 21 | 5 | 5 | - | 34 |
| | D3 | - | - | 5 | - | - | 5 |
| | D4 | - | 1 | - | - | - | 1 |
| | D5 | - | - | - | - | - | - |
| | Total | 9 | 46 | 14 | 12 | 4 | 85 |

*Note: D = drawing; W = writing; n = 85*

Table 4 presents a summary of students' mental models in the form of an explanation of genetic concepts and its comparison with the scientific mental models. Based on Table 4 it showed that the highest dominant level of mental models through the writing explanation test is W3 (partial understanding with alternative conception) which were found in the concept of "genetic materials" and "gene expression", and W2 (alternative conception) which were found in the concept of "heredity", "gene regulation in metabolism", and "gene regulation in the growth and development of organism".

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**Table 4. The comparison of mental model of students on genetic concepts through writing test with scientific mental models.**

| Concept | Examples of Students' Mental Models | Scientific Mental Model |
|---|---|---|
| Genetic materials | • Chromosomes are long strands of genes which are packaged with histone protein; There is DNA in gene as the genetic materials which consists of nitrogen purine bases and pyrimidine; gene is the smallest unit in the DNA **(W3: 42.35%)***.<br>• Genetic materials (chromosomes, DNA and genes) is contained in the nucleus; chromosome is composed by strands of DNA; DNA is prepared by the genes that carry the nature of an individual **(W4: 21.18%)**.<br>• In nucleus cell, there is a chromosome; chromosome is a long DNA strand packaging and histone protein; DNA consists many genes; Genes consist of nucleotide sequence which will be expressed into a structural protein and functional, phenotype determinant of the organisms **(W5: 28.23%)**. | The genetic materials consist of: genes - DNA or RNA - chromosome. DNA (deoxy-ribonucleic acid) is a nucleic acid molecule, helical with a double strand that is a combination of monomers nucleotide which consist of sugar deoxyribose, nitrogenous bases (adenine (A), cytosine (C), guanine (G), and thymine (T)), and phosphate. Genes are units of genetic information which consist of sequences/specific nucleotide sequence contained in the DNA (or RNA in some viruses). One long DNA molecule associated with histone proteins and non-histone then curl up and condense to form chromosomes contained in the nucleus. |
| Heredity | • Heredity can inherit the gene from both parents through the process of DNA replication and for each replication process, there are about 10 nucleotides to be inherited; a child inherits the gene from both parents because DNA replication occurs semi conservatively, meaning one strand from the father and one strand of the mother; inherited chromosomes are chromosomes found in somatic cells which are diploid **(W2: 60%)**.<br>• Spermatogenesis and oogenesis would generate haploid cells in which if combined, will produce diploid descendant, XX or XY, each of which is derived from maternal or paternal genes **(W3: 18.82%)**.<br>• Human body cells have 46 chromosomes that can undergo meiosis which will become haploid; male and female gametes cells, each of which is haploid will undergo fertilization to form the diploid zygote; with fertilization, the genetic materials in zygote has a composition of half from the male parent and half from the female parent **(W4: 11.76%)**. | The process of heredity in living organisms occurs through the process of reproduction, both asexually and sexually. If it is asexually, then the nature of the descendant will be the same with the parents because there is no genetic difference between the parents and the descendant. However, in sexual reproduction there is a combination of a set of chromosomes from the male and female individuals carried by spermatozoa and ovum, called fertilization. Spermatozoa is produced from the process of spermatogenesis in the male genital organs, while the ovum is produced from the oogenesis process in the female genital organs. |
| Gene expression | • Phenotype is determined by genes and can be seen, for example hair color; phenotype is a visible trait which is carried by the genes descended from both parents **(W2: 32.94%)**.<br>• DNA is transcribed into RNA, RNA is translated into proteins; protein determines the phenotype, for example keratin is the constituent of hair **(W3: 47.06%)**.<br>• Genes can determine the phenotype of an organism if expressed at the right place and time; besides genes, the environment also plays a role in determining the phenotype of an organism; phenotypes that appear is not only as the expression of genes, but there are other factors that influence it, such as environmental factors; phenotype is the resultant of genotype and environment; mutations can cause changes in the phenotype **(W4: 15.29%)**. | Proteins are the products of gene expression. Protein synthesized may be structural or functional proteins. One of the functional proteins is an enzyme. The enzyme catalyzes a reaction which directly or indirectly determines the phenotype. In addition, environmental factors also influence the process of gene expression. |
| Genetic regulation in metabolic | • Genes can control metabolism through the stages of initiation, elongation, and the end of the process; genes can control the genes related to metabolism because of chemical processes that take place; genotype and environment determine the physiological characteristics of living things, such as metabolism **(W2: 21.17%)**.<br>• Metabolism requires enzymes produced from protein synthesis processes; metabolism is controlled by the expression of genes which produce enzymes to carry out metabolism according to their environment **(W3: 34.12%)**.<br>• Protein is the result of gene expression, and protein can develop enzymes that control metabolism; insulin is one of the products of gene expression that control blood sugar levels **(W4: 18.82%)**. | Each reaction in the metabolic pathways is catalyzed by an enzyme. To convert the X precursor to an intermediate Y requires an X-ase enzyme, to convert the Y-intermediate into Z-product requires Y-ase enzyme. Each enzyme is encoded by a specific gene, such as X-ase enzyme which is encoded by the X-ase gene locus. If X-ase genes are damaged / mutated then the X-ase enzyme is not formed, so the Z product is not formed, or the metabolic pathway is blocked |
| Genetic regulation in the growth and development | • If the auxin and gibberellins hormones are expressed, the growth of plants will not be disturbed; different water levels will cause PEP hormone to be higher in C4 plants than C3, so C4 plants are more fertile **(W2: 54.11%)**.<br>• Genes can determine the growth and development because genes can encode a specific hormone that plays a role in the growth and development through the process of gene expression **(W3: 16.47%)**.<br>• The genes that exist in the apical meristem will be expressed as leaves; although the leaf-forming genes are in the root, it won't be expressed (genes are "off") **(W4: 14.12%)**. | In the process of growth and development, cells multiply and become more complex. Cells synthesize much more proteins, both structural proteins for cell constituent and functional protein such as a hormone to regulate cell activity. The synthesis of proteins in living organisms is the process of gene expression. Gene expression is regulated spatially and temporally. For example: ABC Theory at flower organogenesis. A gene encodes sepals, A + B genes encode petal, B + C genes encode stamen, and C gene encodes carpel. |

*Note: * writing level followed by frequency (in percentage)*

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Mental model of students which is the most dominant on the concept of "genetic materials" through the image test is level D3 (41.17%), which means drawings with misconceptions. Most students are able to describe the hierarchy of genetic materials of genes, DNA, chromosomes, and nucleus and able to explain the linkage between genes, DNA, chromosome and its location in the cell well. From the analysis result to the students' answers, it is found that there are some errors in the drawings and explanations made by students. Errors in drawings include: the incompleteness of genetic materials, the exchange between arrows indicating genes and DNA, not describing the presence of histone proteins, and not showing the gene location in DNA correctly. The examples of students' mental model on the concept of "genetic materials" through a drawing test are presented in Figure 1.

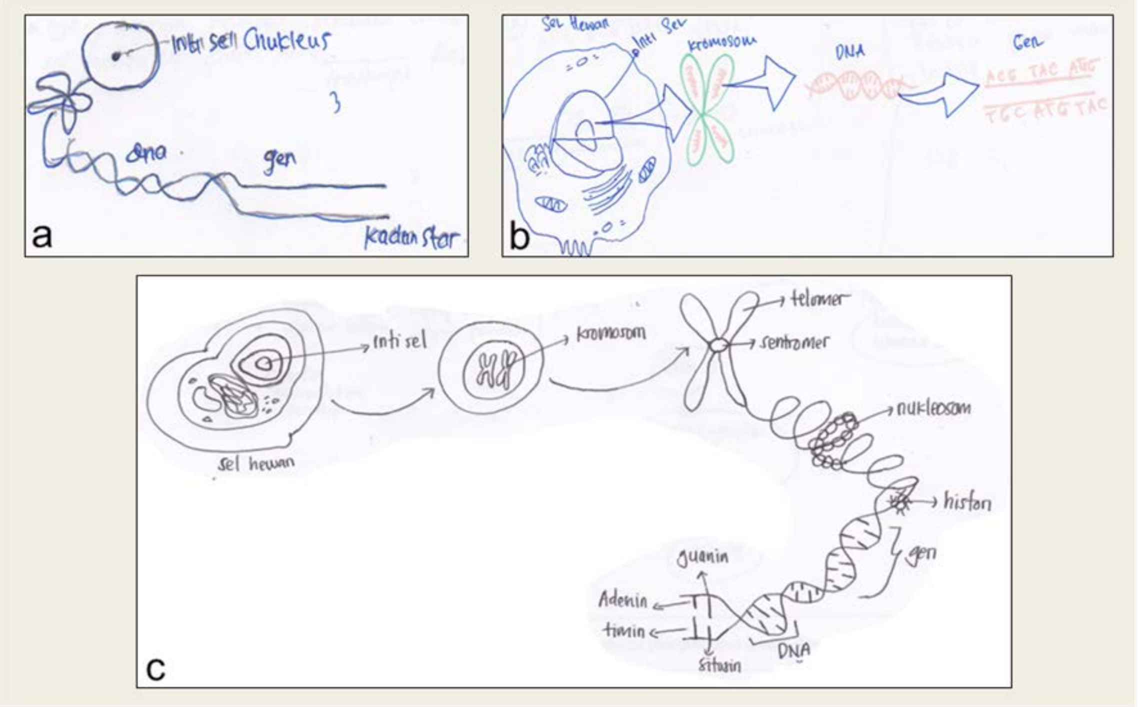


**Figure 1: Example of student's mental model on the concept of "genetic materials".**

(a) drawings with misconceptions (D3), (b) partial drawings (D4), and (c) comprehensive representation drawings (D5).

The most dominant mental models of students on the concept of "heredity" through the image test is level D2 (47.06%), which means non-representational drawings. There are several types of representations used by students to complete the explanation of the concept, such as cross diagram, cross charts, family tree diagrams, and images of gametogenesis and fertilization. However, many of these representations are not relevant to the explanation, such as not being able to make symbols that represent genetic abnormalities on the genealogical chart, incorrectly making the order of gametogenesis and incorrectly making a cross diagram. The following are examples of mental models of students at several levels (Figure 2).

The most dominant mental model of students on the concept of "gene expression" through image tests is D2 level (56.47%), which means non-representational drawings. All students use representations such as mind mapping, starting from the simple one (linear with some interconnected links between concepts) to the complex one (branched forms, multiple interconnected links between concepts). However, there are many mind mapping, which are not relevant because of incorrect linking of the existing concepts, such as: the concept of the genotype (genes, DNA, RNA), the process of protein synthesis or the central dogma of molecular biology (transcription and translation), and phenotype (characteristic morphological, physiological, and behavioral). The following are examples of mental models of students at several levels (Figure 3).

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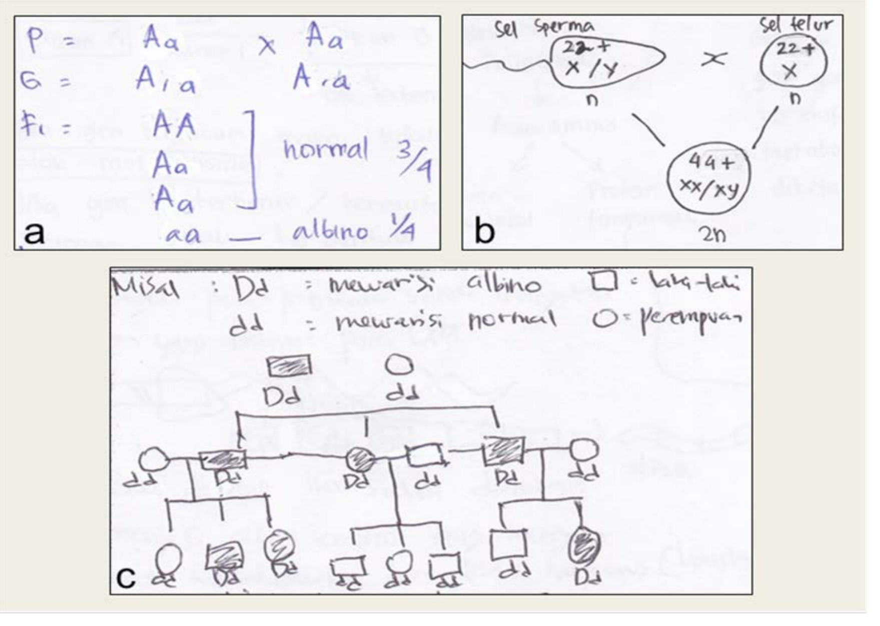


**Figure 2: Example of a student's mental model on the concept of "heredity".**

(a) non-representational drawings (D2), (b) drawings with misconceptions (D3), and (c) partial drawings (D4).

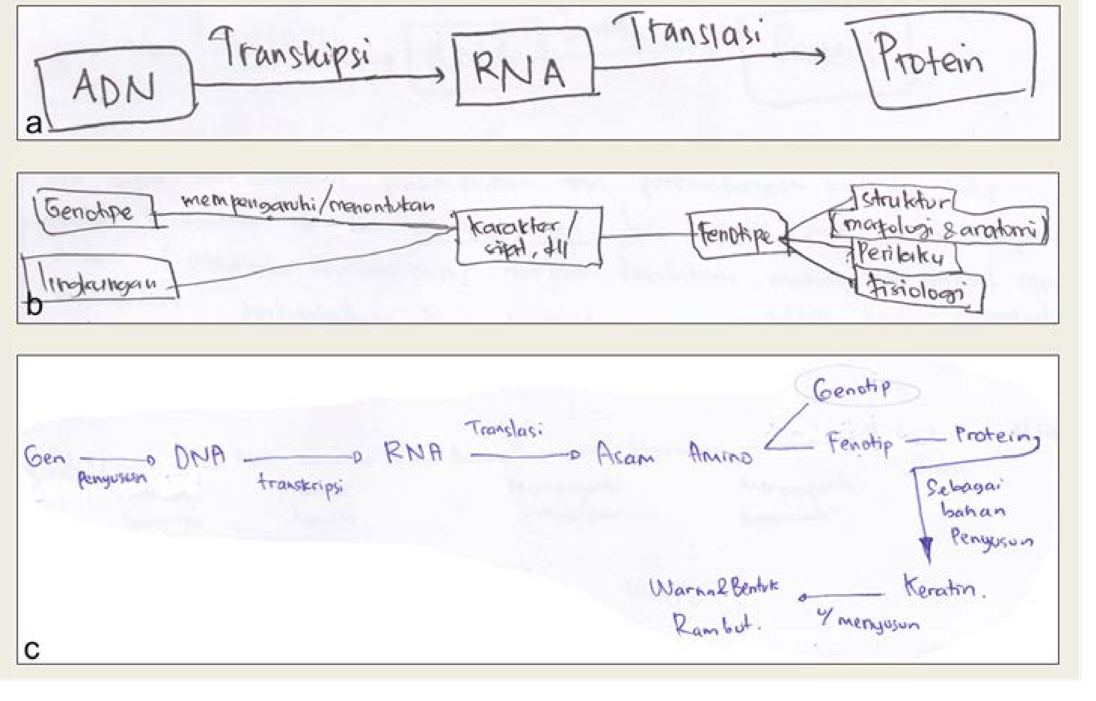


**Figure 3: Example of a student's mental model on the concept of "gene expression".**

(a) non-representational drawings (D2), (b) drawings with misconceptions (D3), and (c) partial drawings (D4).

The most dominant mental model of students on the concept of "gene regulation in metabolic processes" through the image test is level D2 (50.59%), which means non-representational drawings. There are several kinds of representations used by students to complete the explanation of the concept, including drawings, mind mapping, and charts. Most students illustrated that one of the gene expression products is the functional protein in the form of enzyme that plays a role in catalyzing reactions in the metabolic processes. Only a small number of students said that mutation in enzyme-coding genes will cause metabolic disorder in an individual. The following are examples of mental models of students at several levels (Figure 4).

The most dominant mental model of students on the concept of "gene regulation in the growth and development of an organism" through the image test is level D1 (52.94%), which is no drawings meaning that students are generally unable to describe the concept in any form of representation. Most of the students have difficulty in describing examples of gene regulation of the growth and the development of an organism. Only a small number of students described the gene expression in a butterfly metamorphosis regulated by juvenile hormone (JH), the development of young women who are affected by estrogen and progesterone, and mutations in the gene that will lead into abnormalities in a person's growth and development. The following are examples of mental models of students at several levels (Figure 5).

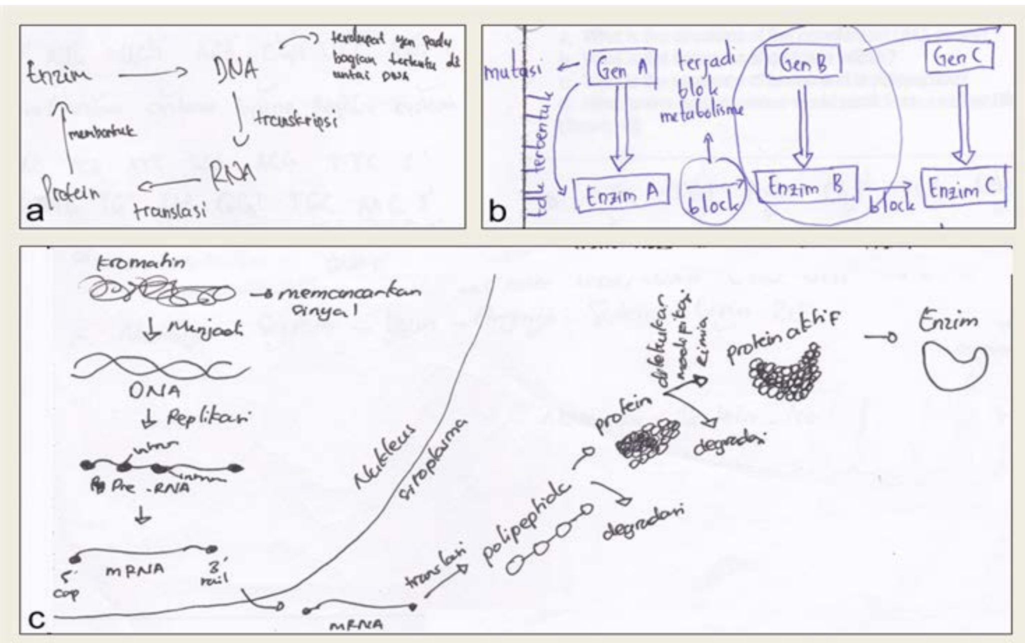


**Figure 4: Example of a student's mental model on the concept of "gene regulation in metabolic process".**
(a) non-representational drawings (D2), (b) partial drawings (D4), and (c) comprehensive representation drawings (D5).

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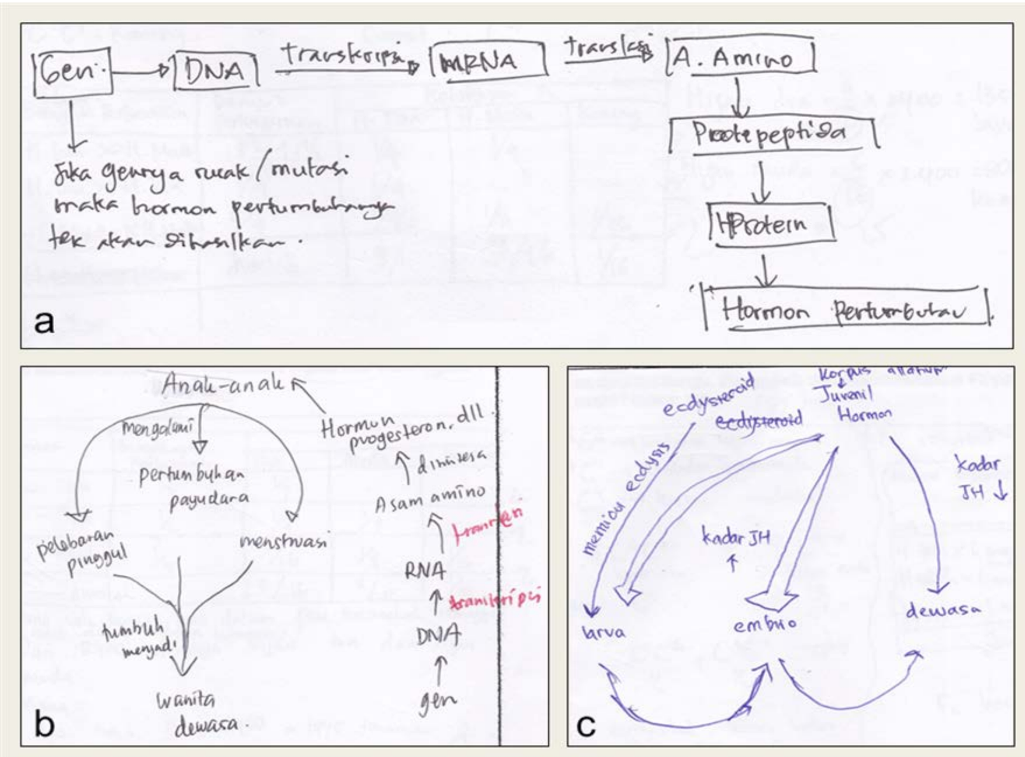


**Figure 5: Example of mental models of the students on the concept of "gene regulation in the growth and development of an organism".**

(a) non-representational drawings (D2), (b) drawings with misconceptions (D3), and (c) partial drawings (D4)

Generally, the level of students' mental model of genetic concepts obtained through drawing and writing test were varied. The results showed that the students' mental model of the concept of genetics is low. In addition, through this research, it is shown that students' images and explanations about a concept can reveal their concept understanding, misconceptions, and learning difficulties.

**Discussion**

In this research, the mental model of students on the five genetic concepts that include "genetic materials", "heredity", "gene expression", "genetic regulation in metabolic process" and "genetic regulation in the growth and development" were evaluated by analyzing the image and the explanation of the concept. The results showed that the mental model of students through writing test (W) shows a higher level than drawing test (D) in the five genetics concepts being studied. It shows that students can easily express their ideas through writing rather than representations such as drawings and concept maps. It occurred because students are rarely trained in spatial abilities through the assignment to make a representation. Ishikawa & Kastens (2005) explains that representational skills are determined by a person's spatial abilities. This spatial ability has low correlation with verbal ability. Students who have high verbal skills do not always have high spatial ability, and vice versa.

The results of student writing responses analysis indicated that almost half of the students (42.35%) have mental model at level 3 (partial understanding with alternative conception) on the concept of "genetic materials". The students write an explanation of "genetic materials" concept as follows: *"Chromosomes are long strands of genes which are packaged with histone protein; There is DNA in gene as the genetic material which consists of nitrogen purine bases and pyrimidine; gene is the smallest unit in the DNA."* Based on the data, it was found that students had difficulty in determining the relationship between genetic materials and its packaging in the cell. The students' drawings also support their explanations. From the analysis result of the images, it is known that most of the students (41.17%) had mental model at level 3 (drawings with misconceptions). Some errors which were found from the students' drawing are: the incompleteness of genetic materials, the exchange between arrows indicating genes and DNA, not describing the presence of histone proteins, and not showing the gene location in DNA correctly. The results of this research supported the results of Lewis & Wood-Robinson (2000b) research which concluded that students' understanding about the process of genetic information transfer, and basic knowledge about the gene between genes, chromosomes and cells is low. In addition, from the students' responses, it is identified that there are misconceptions, uncertainty and confusion in answering questions. This result is also supported by the results of research conducted by Saka *et al.* (2006) which used drawing and writing tests to identify the understanding of the three genetics concepts on students across ages. The research concluded that students have an alternative concept (misconceptions) of "genetic materials", all groups of the students did not show a good understanding of the concept of genes and DNA. In addition, it also identified successfully several misconceptions about genes and DNA.

The result of student's writing response analysis shows that most of the students (60%) have mental models at level 2 (alternative conception) on the concept of heredity. Students write an explanation about "heredity" as follows: *"Heredity can inherit the gene from both parents through the process of DNA replication and for each replication process, there are about 10 nucleotides to be inherited; a child inherits the gene from both parents because of DNA replication occurs semi conservatively, meaning that one strand from the father and one strand of the mother; inherited chromosomes are chromosomes found in somatic cells which are diploid"*. The students' drawings also support their explanations. From the analysis result of the images, it is known that most of the students (47.06%) have mental model at level 2 (non-representational drawings). Several types of representation used by the student are not relevant to an explanation of the concept. To our knowledge, information about student mental model on the concept of heredity is still limited. However, Bahar *et al.* (1999) investigated the cognitive structure of students by using word association test. The results of the research indicated that students made a wide range of ideas associated with a given keyword but did not show a strong link or network between the keywords, especially between chromosomes and genes, gametes and cell division, hemophilia and pedigree, phenotype and backcross. Moreover, Bahar *et al.* (1999) and Kempa & Nicholls (1983) explained that the more branches or connections between concepts which have been successfully made by the students, the higher the level of students' knowledge and understanding. In addition, the more easily a connection between concepts is made, the more effectively it will be used as a non-routine problem solving. Therefore, a good cognitive problem-solver structure is seen from the complexity and the closeness of the relationship between concept which have been made.

The results of student writing responses analysis indicated that almost half of the students have mental model at level 3 (partial understanding with alternative conception) on the concept of "gene expression" and "gene regulation in metabolic processes", respectively 47.06% and 34.12%. Students write an explanation of concepts of "gene expression" and "gene regulation in metabolic processes" as follows: *"DNA is transcribed into RNA, RNA is translated into proteins; protein determines the phenotype, for example keratin is the constituent of hair. Metabolism requires enzymes produced from protein synthesis processes; metabolism is controlled by the expression of genes which produce enzymes to carry out metabolism according to their environment."* The students' drawings also support their explanation, but from the analysis result of the images, it is known that more than half of the students have a mental model at level 2 (non-representational drawings), respectively 56.47% and 50.59%. Students use a representation in the form of mind mapping, but mostly irrelevant because it was not right in linking the existing concepts, such as: the concept of the genotype (gene, DNA, RNA), the protein synthesis process (transcription and translation), and phenotype (morphological characteristic, physiological, and behavioral). Based on the analysis and evaluation, it is known that the students have difficulty in describing this concept, such as difficulty in connecting between genotype and phenotype, linking the environmental contribution to the formation of the phenotype, and the linkages between proteins, enzymes, and the phenotype of an organism. The results of this research are consistent with the results of research by Marbach-Ad (2001) which showed that the concept maps and open-ended questions can identify the patterns of comprehensive thoughts and understanding of the genetics concept. In addition, the results showed that the majority of pre-service teachers are able to create concept maps with strong linkage between the concepts. However, especially for the linkage between enzyme and DNA or RNA, the students give response associated with the direct causal relationship and ignore the coding relationship. The statement of coding relationship shows a good understanding of genetics concepts such as "a gene (or DNA) 'codes for' or 'is translated into' a protein, enzyme, or trait". However, half of the students just stated that "enzymes catalyse reactions that involve DNA and genes ".

The results of student writing response analysis showed that more than half of the students (54.11%) have mental model at level 2 (alternative conception) on the concept of "genetic regulation in the growth and development of organisms". Students write an explanation of the concept of gene regulation in the growth and develop-

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ment of organisms as follows: *"If the auxin and gibberellins hormones are expressed, the growth of plants will not be disturbed; different water levels will cause PEP hormone to be higher in C4 plants than C3, so C4 plants are more fertile"*. In this concept, the majority of students (52.94%) did not describe a representation in any form. Only a small number of students described the regulation of gene expression in the metamorphosis of a butterfly, female adolescent development, as well as abnormalities in a person's growth and development as a result of mutation. It can be assumed that the students' understanding is limited to the sequences of genetic transmission material which is based on the central dogma of molecular biology "from gene to protein' and not able to apply it in the context of daily life. Just like one of the results of research conducted by Lewis & Wood-Robinson (2000a) which indicated that only a few respondents (4%), have mentioned the importance of genes as the regulator of growth and development of the body. In addition, the students seem to work easier on problems of genetics-based Punnet squares than the concept of sex-linked inheritance.

This research showed that through images and explanations about a concept, it can reveal what is known and understood by students. The interpretation of the images and explanations can be an effective method in identifying the aspects of students' learning difficulties to the concept of genetics. It is also stated by Dikmenli (2010) that drawings can be an effective method of probing some aspects of their learning difficulties. Based on the explanation above, it is known that the students' mental model on the concept of genetics is low. These results indicated that it needs to improve the quality of the lectures, especially on the aspects which are difficult for the students in order to improve the students' mental models of the concepts of genetics. Therefore, it is a challenge for educators both in secondary education and higher education to train and develop students' mental model, so that a thorough and meaningful understanding of the concept can be achieved.

## Conclusions

The results showed that the students tend to be better at representing the mental model of the concept of genetics through writing or explanation than through images. The mental model of students through writing test (W) showed a higher level than the drawing test (D) on the five genetic concepts. The highest level of mental model through image (D5) was found in the concepts of "genetic materials" and "heredity", while the highest level of mental model through explanation (W5) was found in the concept of "genetic materials," "heredity," "gene expression", and "gene regulation of the growth and development of an organisms". The most dominant mental models found in each concept through drawing-writing test (D/W) respectively were D3/W3 (drawings with misconceptions/partial understanding with alternative conceptions) on the concept of "genetic materials", D2/W2 (non-representational drawings/alternative conceptions) on the concept of "heredity", D2/W3 (non-representational drawings/partial understanding with alternative conceptions) on the concept of "gene expression", D2/W3 (non-representational drawings/partial understanding with alternative conceptions) on the concept of "gene regulation in metabolic processes", and D1/W2 (no understanding/alternative conception) on the concept of "gene regulation of the growth and development of organisms".

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