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Level of Understanding and Alternative Frameworks in Genetics Fundamental Concepts among Form Four Biology Students in Sabah, Malaysia

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Abstract

This study aimed to identify the understanding of genetics fundamental concepts of Form Four Biology students in Sabah, Malaysia. Quantitative data were collected using a two-tier multiple-choice achievement test instrument called the Genetics Fundamental Concepts Achievement Test (GFCAT), and students had to justify their answer choices. The fundamental concepts of genetics are grouped into four categories, i.e. i. the concept of genes, ii. the concept of chromosomes, iii. the concept of the relationship between genes, chromosomes, and DNA, as well as iv. the concept of the relationship of cell division and inheritance. Findings showed that there were 30 alternative frameworks related to genetic fundamental concepts with a low level of understanding of genetics fundamental concepts, mean score: 2.34 per 13. Students' understanding of genetics fundamental concepts was limited especially in genes and chromosomes. The percentage of students who answered correctly on the first tier of the items in GFCAT was high but the percentage showed a sharp decrease in the second tier. Therefore, interventions should be implemented as early as possible by educators to inculcate students' interest in mastering genetics fundamental concepts and at the same time prevent the alternative frameworks from deeply rooted among students.

Keywords: Genetic Concepts, Alternative Framework, Genes, Chromosomes, Two-Tier Multiple-Choice Achievement Instrument.

Introduction

In recent decades, knowledge in the field of genetics has been applied in the fields of science and technology such as in Human Genomics Project, cloning, genetically modified foods, and gene therapy. Even the recent treatments of various diseases such as cancer, heart disease, and diabetes also apply knowledge in the field of genetics. This phenomenon gives the impression that the field of genetics is one of the most important fields now and in the future.

Nevertheless, studies on students' genetic knowledge, understanding, and literacy of genetics fundamental concepts that have been conducted from the 20th century to the 21st century show that the concept of genetics is one of the biological concepts that are difficult for students to understand and master (Etobro & Banjoko, 2017; Fauzi & Mitalistiani, 2018; Johnstone & Mahmoud, 1980). Several studies have shown that there are many alternative frameworks related to genetics fundamental concepts among students (Akyurek & Afacan, 2012; Aydan & Balim, 2013; Kumandas et al, 2018; Dewi, 2013; Etobro & Banjoko, 2017; Gonzalez & Rossi, 2016; Hadjichambis et al., 2015; Kilic, Taber & Winterbottom, 2016; Rodriguez Gil, Fradkin & Castañeda-Sortibran, 2018; Roini & Sundari, 2018; Rotbain, Marbach-Ad, & Stavvy, 2007; Topcu & Sahin-Pekmez, 2009).

Kumandas et al. (2018) and Yip (1998) have explained that the alternative framework refers to the thoughts and ideas possessed by students that are not in line with actual scientific knowledge. The alternative framework usually emerges due to several factors such as experience, language used in daily communication, teacher knowledge, and even textbooks (King, 2009). The existence of alternative frameworks in science learning reflects students' misunderstandings of the fundamental concepts supported by science facts (Mestre, 2001). The most worrying thing about alternative frameworks is when it has long been entrenched in an individual's understanding, it is difficult to be corrected (Etobro & Banjoko, 2017; Marshall, 2006) without proper instruments (Mbajiorgu et al., 2007). Furthermore, if the implementation of teaching and learning in the classroom is only by lecture (Chi, 2005; Bahar, 2003; Hakim, Liliyasi, Kadarohman & Syah, 2016), it will be more difficult to overcome the alternative frameworks. Tekkaya (2002) has found that educators agree that the emergence of alternative frameworks makes it difficult for students to master biology concepts in future learning. Thus, the existence of alternative frameworks should be constrained so that students' understanding of genetic concepts is always in line with the actual genetic concepts.

Evans & Winslow (2012); Fertherstonhaugh & Treagust (1992) have agreed that alternative frameworks can also be a major barrier and is difficult to control for students to understand a science concept. To overcome the problem of the existence of alternative frameworks, teachers need to first identify the alternative frameworks the students have before starting a lesson (Chi, 2005; DiSessa, 2002; Oztas & Oztas, 2016) and then plan strategies and interventions to correct the alternative frameworks.

Studies of biology education in several fields related to photosynthesis, evolution, circulatory system, reproduction and genetics show a worrying phenomenon when many alternative frameworks are successfully identified (Aydin & Balim, 2013; Bozdog & Ok, 2019; Etobro & Banjoko, 2017; Gonzalez & Rossi, 2016; Gungor, 2017; Kilic, Taber & Winterbottom, 2016; Lewis, Lech & Robinson, 2000; Oztas & Oztas, 2016). Besides, studies related to reproduction have also found that the alternative frameworks in the concept of reproduction stem from the alternative frameworks of students in the concept of mitosis and meiosis (Brown, 1990; Dikmenli, 2010). Furthermore, researchers such as Bozdog and Ok (2019); Etobro and Banjoko (2017) as well as Oztaz, Ozay and Oztas (2003) have pointed out that difficulties in understanding the concept of cell division often occur among students.

Thus, this study was conducted to identify the level of understanding and alternative frameworks among Biology students in Sabah, Malaysia on genetics fundamental concepts which is the basis for the understanding of several other related fields.

Problem Statement

Past studies have found that among the alternative frameworks related to genetic concepts that occur among students include alternative frameworks on chromosomes, genes, division of mitosis and meiosis, mutations and DNA (Akyurek & Afacan, 2012; Aydan & Balim, 2013; Dewi, 2013; Hadjichambis et al., 2015; Kilic et al., 2016; Rodriguez Gil et al., 2018; Topcu & Sahin-Pekmez, 2009). Students were found to have a low understanding of genetics fundamental concepts especially the concept of meiosis when tested by asking them to draw a complete diagram of the meiosis process and found that no one was able to produce a correct complete diagram (Rodriguez Gil et al., 2018). Moreover, similar symptoms are found in fundamental chromosome concepts, chromosome behavior during cell division (Etobro & Banjoko, 2017; Lewis et al., 2000), haploid cells and diploid cells, number of children cells at the end of cell division (Kilic et al., 2016), as well as differences between alleles and homologous chromosomes (Topcu & Sahin-Pekmez, 2009). The findings of Radanovic et al. (2011) also showed that the trend of mastery of genetics fundamental concepts is almost the same when only 33% of students in Croatia able to answer questions related to the gene concept of human body cells correctly.

Alternative frameworks related to genetics fundamental concepts continue among secondary school students (Dewi, 2013; Kilic et al., 2016). Failure to master the concepts of mitosis and meiosis triggers a domino effect on the mastery of the concept of human reproduction and cell life cycle among students (Kurt et al., 2013; Luksa, Radanovic, Garasic & Peric, 2016). They also emphasized that the approach in teaching the concepts of mitosis and meiosis requires change due to the failure of almost 36% of students in understanding the process of mitosis and meiosis and the function of these processes is a matter of concern and should arise concern among teachers. Chattopadhyay's (2012) study in India has also shown similar findings when students were unable to explain the importance of the process of mitosis and meiosis, as well as did not understand the importance of haploid reproductive cell formation.

Several studies have also found that students majoring in Science who take Biology subject do not understand the relationship between cell cycle and cell division (Akyurek and Afacan, 2012; Aydin and Balim, 2013; Dikmenli, 2010; Kilic et al., 2016), cell division in meiosis are associated with the occurrence of chromosome reduction (Kilic et al., 2016; Robinson and Lewis, 2000; Tekkaya, 2002). Flores, Tovar and Gallegos (2003) also found that students had difficulty understanding the role of nucleic acids in meiosis.

As the curriculum formulation in Malaysia is cyclical, fundamental concepts are taught in lower secondary schools and then taught in detail in upper secondary schools. Thus, failure to master the concepts of mitosis and meiosis at the lower level is feared to pose adverse implications at the next level of study. Thus, the study on the level of understanding and alternative frameworks related to genetic fundamental concepts among Form Four students in Sabah is a necessity in secondary school biology education. Studies conducted on the genetics concept only focused on the process of

cell division, i.e. mitosis or meiosis. This study was conducted based on the results of the Sijil Pelajaran Malaysia (SPM) Quality Assurance Report for the subject of Biology in 2017 which found that there were still many Malaysian students who have not mastered the fundamental concepts in Biology. Thus, the panel involved in the 2017 SPM Biology Quality Assurance Report suggested that students should master the concepts of the cell, material movement across the plasma membrane, the chemical composition in cells and the concept of cell division (Malaysian Examination Board, 2018) to facilitate them in mastering the more complex biology concepts such as inheritance. Not to mention, studies on the level of students' understanding of the relationship between a genetic fundamental concept and other genetic fundamental concept in identifying alternative frameworks related to the genetic fundamental concepts of other secondary school students are also not done in the context of Sabah.

Research Objectives

This study was conducted to achieve the following objectives:

- To identify the level of understanding of the genetics fundamental concepts of Form Four Biology students in Sabah.
- To identify the alternative frameworks related to genetics fundamental concepts among Form Four Biology students in Sabah.

Research Questions

- a. What is the level of understanding of the genetics fundamental concepts of Form Four Biology students in Sabah?
- b. What are the alternative frameworks related to genetics fundamental concepts that are common among Form Four Biology students in Sabah?

Methodology

Based on the research objectives and questions, a quantitative study by survey using a two-tier achievement test instrument was implemented to identify the level of understanding and alternative frameworks related to genetics fundamental concepts among Form Four Biology students.

Population and Samples

The population of this study involved the Form Four science stream students who take Biology subject in the state of Sabah. This is due to the Form Four students learn topics related to genetics fundamental concepts, namely cells (Chapter 2 Cell Structure and Organization), nucleic acids (Chapter 4 Chemical Composition in Cells), and Chapter 5 (Cell Division).

To obtain the study sample, clustered random sampling technique, simple random sampling technique, and stratified random sampling technique were used. Clustered random sampling technique was used during the school division stage according to the respective district education offices. In this study, schools in the state of Sabah were grouped into 24 groups of districts according to the number of education offices in the state of Sabah. One area was selected by drawing lots using a simple random sampling technique. Tawau, a district in Sabah, Malaysia has been selected from the ballot. Form Four students who take a Biology subject were selected as samples and this selection

was done using a stratified random sampling technique. A total of 64 respondents consisting of 22 male students and 42 female students were selected in this study.

Data Collection

In this study, an instrument called the Genetics Fundamental Concept Achievement Test (GFCAT) was used in test administration. The instrument is an instrument adapted and modified from The Two-Tier Genetics Concepts Test (Kilic et al., 2016). This instrument was used to identify students' understanding of genetics fundamental concepts. In a nutshell, this GFCAT instrument contains 13 items that test the understanding of Form Four Biology students on the concept of genes, chromosome, relationship between genes, chromosomes and DNA as well as the concept of cell division and inheritance (Table I).

Table I: *GFCAT items according to genetic concepts*

No	Genetic Concept Categories	Item
1	The concept of genes	2, 5, 7
2	The concept of chromosomes	3, 8, 13
3	The concept of the relationship between genes, chromosomes, and DNA	1, 4, 10
4	The concept of the relationship between cell division and inheritance	6, 9, 11, 12

All items in GFCAT require students to justify each of their answer choices. This justification is used to determine the understanding of genetics fundamental concepts of the students involved. All items in GFCAT are in two tiers as shown in Figure 1. The questions in the first-tier are intended to test students' understanding of genetic concepts while the second-tier questions are intended to elicit students' reasons to support their first-tier answers. The questions in the first tier are accompanied by three answer choices while the questions in the second tier are accompanied by five answer choices.

<p>(2) Which cells for an individual, contain genes that determine the traits he inherited?</p> <p>(a) Reproductive cells, gametes (b) Brain cells (c) All cells</p> <p><i>Which of the following is the justification for your answer?</i></p> <p>(a) The chromosomes that make up the genes are found in all cells. (b) Genes are found in reproductive cells because the parent genes are carried by sperm for males and eggs/ova for females. (c) Inherited traits are carried in reproductive cells as they are passed on to children through sex chromosomes. (d) The chromosomes found in all cells contain genes that determine the characteristics we inherit. (e) Everything is controlled by the brain</p>

Figure 1: *GFCAT two tiers items*

GFCAT instruments have been tested to obtain the value of the content validity coefficient and the value of the reliability coefficient. The validity of GFCAT item content was done by four Biology teachers who have been teaching Biology for more than ten years. The content validity coefficient value of the GFCAT item was 0.94, which is good according to Sidek and Jamaludin (2005). Similarly, the reliability of the GFCAT items determined by the value of Cronbach's Alpha coefficient = 0.84 indicated a high-reliability value.

Data Analysis

Data obtained from GFCAT were analyzed using SPSS 23.0 software. For each item, the student response is considered correct only when the student gives the correct response on both tiers of questions with a score range from 0 - 13. The analysis was conducted on the wrong response on the level of understanding and alternative frameworks related to genetics fundamental concepts among students. The response was to meet the criteria of an alternative framework if there are at least 10% of students giving the wrong response to the item (Kilic et al., 2016; Tan, 2000). Student alternative frameworks were grouped according to the genetics fundamental concepts categories.

Findings of the Study and Discussions

The findings of this study were analyzed based on research questions related to students' understanding of genetics fundamental concepts and related to the alternative frameworks that exist among students.

Levels of Understanding and Alternative Frameworks on Genetics Fundamental Concepts

Based on the response of students in GFCAT, it was found that the mean score was 2.34 (very low). The mean value of this score was lower than the scores obtained by Turkish students (4.70) and English students (6.70) who answered the same test questions (Kilic et al., 2016). The most worrying matter found in this study is that none of the students got the maximum score while 2% of the Turkish students and 3% of the English students managed to get it. The weakness of students in mastering these genetics fundamental concepts is also in line with several studies conducted by Kilic et al. (2016) and Duncan & Reiser (2007). The highest percentage of students who gave the correct response for the first tier and both tiers of GFCAT items was the concept of the relationship of cell division and inheritance with conceptual understanding (45.3%) and alternative framework (33.2%) (Table II).

Table II: *Percentage of students based on responses in the first and both tiers of GFCAT items*

Genetics Fundamental Concepts	Item number	The correct response for first-tier (Conceptual Understanding) (%)	The wrong response for first-tier (Conceptual Understanding) (%)	The correct response for both tiers (Alternative Framework) (%)	The wrong response for both tiers (Alternative Framework) (%)
The concept of genes	2	7.8	92.2	4.7	95.3
	5	7.8	92.2	1.6	98.4
	7	17.2	86.8	6.3	93.7
	Mean	10.9	89.1	4.2	95.8
The concept of chromosome s	3	39.1	60.9	3.1	96.4
	8	3.1	96.9	3.1	96.4
	13	17.2	82.8	4.7	95.3
	Mean	19.8	80.2	3.6	96.4
The concept of the relationship between genes, chromosome s and DNA	1	75.0	25.0	60.9	39.1
	4	21.9	78.1	14.1	85.9
	10	7.8	92.2	7.8	92.2
	Mean	34.9	65.1	27.6	72.4
The concept of the relationship of cell division and inheritance	6	51.6	48.4	37.5	62.5
	9	21.9	78.1	15.6	84.7
	11	57.8	42.2	48.4	51.6
	12	50.0	50.0	31.3	68.7
Mean	45.3	54.7	33.2	66.8	

A total of 30 alternative frameworks were found in at least 10% of students, and four of those alternative frameworks existed in over 50% of students. The number of these alternative frameworks was much higher than the alternative frameworks observed among students in Izmir, Turkey (Bozdog & Ok, 2019) and England (Kilic et al., 2016). The alternative frameworks that exist among students were shown in Table III.

Table III: Alternative frameworks that exist among students

	Alternative frameworks	%
<i>The concept of genes</i>		
1	The gene that determines the characteristics inherited by an individual is found in reproductive cells only. (Item 2)	59.4
2	Inherited traits are carried in reproductive cells, so the parent genes are passed on to their offspring through sex chromosomes. (Item 2)	35.9
3	The gene for eye color is located in the sperm because the X and Y chromosomes found in the sperm cell carry all the genes. (Item 5)	37.5
4	The genes for eye color are located in all cells because different parts of the body have their specific genes. (Item 5)	26.6
5	The gene for eye color is located inside the eye because the iris is the part of the eye that is responsible for eye color. (Item 5)	25.0
6	Eye cells and skin cells have the same genetic information. This is because eye and skin cells have n chromosomes, which are the same for both cell types. (Item 7)	15.6
7	Sperm cells and brain cells have the same genetic information. This is because the genetic information in the sperm cells is transferred to the brain cells. (Item 7)	20.3
8	Sperm cells have the same content. This is because the sperm cells of an organism have identical genes. (Item 7)	39.1
9	Sperm cells have the same content. This is because the chromosomes in the reproductive cells are always identical. (Item 7)	18.8
<i>The concept of chromosomes</i>		
10	The number of chromosomes for an organism that has the formula $2n = 30 + XY$ is 16. This is because the number of chromosomes of an organism is n, then if $2n = 32$ then $n = 16$. (Item 3)	45.3
11	The number of chromosomes for an organism that has the formula $2n = 30 + XY$ is 64. This is because $30 + XY$ comes from the father. $30 + XX$ comes from the mother. The total makes it 64 chromosomes. (Item 3)	20.3
12	The number of chromosomes for an organism that has the formula $2n = 30 + XY$ is 64. This is because if $2n = 30 + 2$ then the number of chromosomes for this organism is $32 \times 2 = 64$. (Item 3)	12.5
13	The number of chromosomes for an organism that has the formula $2n = 30 + XY$ is 32. This is because the number of somatic chromosomes is 2 and the number of sex chromosomes is 30. The total number of chromosomes is 32. (Item 3)	18.8
14	A sperm cell can carry X or Y chromosomes, egg cells can carry only X chromosomes. (Item 8)	35.1
15	The chromosomes that determine the sex of an organism are located in sperm cells and egg cells only. This is because sex chromosomes are only found in reproductive cells. (Item 8)	21.9
16	The parent genes are passed on to the child through the sex chromosomes of the father and mother. This is because the inherited traits are carried by sex chromosomes only. (Item 13)	18.8
17	Parental genes are passed on to the child through both sex chromosomes and father and mother somatic chromosomes. This is because the mother's genes are	17.2

	transferred to the zygote by the ovum chromosomes, as the child grows in the mother's body, and the father's genes are transferred by the sperm cells. (Item 13)	
18	The parent genes are passed on to the child through the sex chromosomes of the father and mother. This is because the sex chromosomes of the father and mother are transferred to the child during fertilization. (Item 13)	56.3
<hr/>		
<i>The concept of the relationship between genes, chromosomes, and DNA,</i>		
19	The chromosomes that makeup DNA are found in genes. (Item 1)	26.6
20	Genes are formed when chromosomes merge. (Item 4)	56.3
21	Chromosomes form DNA. (Item 4)	20.3
22	The chromosomes of a somatic cell carry different genes according to the function of a cell. (Item 10)	23.4
23	The genes that makeup DNA are located on chromosomes and differ from each other in every cell of the body. (Item 10)	54.7
<hr/>		
<i>The concept of the relationship between cell division and inheritance</i>		
24	There are 8 chromosomes in the nerve cells of an organism that have 16 chromosomes in the egg cell (ovum). This is because egg cells contain 2n chromosomes and somatic cells contain n chromosomes. (Item 6)	40.1
25	A woman's somatic cell has 22+ X. This is because the X chromosome represents a woman. (Item 9)	32.8
26	The zygote has 22+ X. This is because the zygote contains both somatic chromosomes and sex chromosomes. (Item 9)	12.5
27	A woman's somatic cell has 22 + X. This is because 22 represents the somatic chromosomes, so 22 + X can be found in a woman's somatic cell. (Item 9)	29.7
28	The process responsible for ensuring that the number of chromosomes is the same in all of an individual's somatic cells is the process of meiosis. This is because through meiosis the number of chromosomes for reproductive cells (n) is doubled to form an individual with the 2n chromosome again. (Item 11)	35.9
29	The process responsible for ensuring that the number of chromosomes is the same in all of an individual's somatic cells is the process of meiosis. This is because sperm cells and egg cells that are produced through meiosis, combine to form a single zygote. Then the zygote reduces its chromosome number to half through the process of meiosis. (Item 12)	40.6
30	The process responsible for ensuring that the number of chromosomes is the same in all of an individual's somatic cells is the process of meiosis. This is because sex cells form a zygote through the process of meiosis, and the zygote undergoes mitosis. (Item 12)	14.1

Level of Understanding and Alternative Frameworks on the Concept of Genes

Based on three items related to the concept of genes, it was found that students' understanding of the concept of genes was at a low level. For example, for item 2, only 5% of students can justify that all cells in the individual body contain genes that determine the traits they inherit. Also, the students' response to Item 5 should raise concerns among teachers. This is because only 2% of students understand that the gene for eye color is located in all cells while 98% of students think that the gene for eye color is only in the eye. Students also fail to understand the concept of genes well when in

item 7, only 6% of students can explain that eye cells and skin cells are somatic cells that have identical genetic information.

Three main causes contribute to the occurrence of nine alternative frameworks in the concept of gene. The first reason is that they assume that reproductive cells carry only sex chromosomes. This is seen when 59% of students assume that the genes that determine the characteristics inherited by an individual are found in reproductive cells only (Item 2). This notion is also seen in item 7 when 38% of students thought that the X sex chromosome and Y sex chromosome found in sperm cells carry all genes (Item 5). The second reason is that they fail to understand that every somatic cell in a normal individual has the same genes, but the location of those genes is different. For example, 27% of students think that different parts of the body have their specific genes while 25% of students think that the genes for eye color are only in the eyes. Students' misunderstandings of genetic content in somatic cells were also discovered by Kilic et al. (2016) and Hackling & Treagust (1984) when there were students in their study also assumed that each different somatic cells had different genetic content. As noted by Hackling and Treagust (1984), one of the causes of the occurrence of alternative frameworks is that students do not understand the role of mitosis in growth. Students do not understand that in the process of growth, mitosis plays a role in producing new offspring cells that have the same genes as the genes contained in the original zygote. The third reason is that students fail to understand that the crossover process that occurs during meiosis produces sperm cells with different genetic content. This is the case in 39% of students.

Level of Understanding and Alternative Frameworks on the Concept of Chromosomes

In item 3 which digs into students' understanding of the number of chromosomes of an organism whose chromosome formula is given, only 3% of students can justify correctly on the second tier of item 3, Although in the first tier 39% students who give the correct response, i.e. 32 chromosomes, it turns out that most of the students do not understand that the number of chromosomes is the result of adding the number of sex chromosomes and the number of somatic chromosomes (autosomes). For items 3 and 8, it was found that 3% of the students were able to give the right reasons on both tiers. This gives the impression that many students still do not understand that the chromosomes that determine the sex of an organism (i.e. sex chromosomes) are present in all cells and not just in the ovaries and testicles or in sperm and egg cells as most students understand.

In total, there are nine alternative frameworks for the concept of chromosomes identified in this study (Table III). The existence of this alternative framework is due to students' failure in understanding the four chromosome-related facts. The first fact is that n refers to the haploid which is a set of chromosomes while $2n$ refers to the diploid which is two sets of chromosomes. In the human case, a set of chromosomes consists of 23 chromosomes. Students' failure to understand this fact causes 45% of students to assume that the number of chromosomes for an organism with the formula $2n = 30 + XY$ is 16. A similar finding was obtained by Kilic et al., (2016) when they found that 42% of English students failed to understand the number of chromosomes shown in formula form. The second fact is that in the formula $2n = 30 + XY$, the symbols X and Y refer to the sex chromosome X and the sex chromosome Y. Failure to understand the symbols X and Y cause 19% of students to think that $2n = 30 + XY$ means the number of somatic chromosomes is 2 and the number of sex chromosomes is 30.

The third fact is that somatic cells also have sex chromosomes, which are chromosomes that determine the gender of an organism. 35% of students failed to understand this fact which assumes

that the chromosomes that determine the gender of an organism are located in sperm cells and egg cells only and 18% of students believed that sex chromosomes are only found in reproductive cells. Misunderstanding of chromosomes in these cells was also detected by Lewis et al. (2014) who concluded that there are students who assume that only reproductive cells contain genetic information. These students failed to understand that every cell either reproductive cell or somatic cell found in an individual's body carries two types of chromosomes, namely sex chromosomes, and somatic chromosomes (autosomes). Meanwhile, students' failure to understand the role of mitosis in the production of somatic cells with identical gene content and the role of meiosis in the production of reproductive cells with different gene content also contributed to the emergence of alternative frameworks related to the concept of chromosomes. The fourth fact is that the parent genes are transferred to the child through the sex chromosome as well as the somatic chromosome (autosomes) of the father and mother. As a result of students' misunderstanding of this fact, 56% of students have thought that the parent genes are transferred to the child through the sex chromosomes of father and mother only.

It is undeniable that the alternative frameworks among students are largely due to their weakness in mastering the concept of genes and the concept of chromosomes. This is also discussed by Browning & Lehman (1988); Kilic et al. (2016); Lewis et al. (2000); Aznar & Orcajo (2005); and Stewart (1982) who found that students' failure to link genetics fundamental concepts such as mitosis and the number of chromosomes in cells resulted in the occurrence of alternative frameworks. However, Dewi (2013) has explained that 80% of the students involved in her study understand the concept of chromosomes well because they have understood fundamental facts related to chromosomes such as chromosome molecular structure, size, and variation of chromosome number, gene location on chromosomes and chromosome mutations. This shows that to master genetics fundamental concepts and avoid the occurrence of alternative frameworks, the fundamental facts for each concept need to be understood and mastered first.

Next, alternative frameworks also occur because students assume that chromosomes that determine gender are only found in reproductive cells. In fact, most students think that sex chromosomes are only found in reproductive cells. This was also found by Lewis et al. (2000) who found that many students believe those sex chromosomes are only present in reproductive cells or reproductive organs. In short, several alternative frameworks have been found to occur because students assume that (1) inherited traits are carried by sex chromosomes only, (2) sex chromosomes are only found in reproductive cells, and (3) genes that determine traits are only found in cells reproduction. Such assumptions have also existed among students involved in the study of Kilic et al. (2016); Lewis et al. (2014).

Level of Understanding and Alternative Frameworks on the Concept of Relationship between Genes, Chromosomes, and DNA

Item 1 related to students' understanding of the location of genes, chromosomes, and DNA showed that more than half of the total number of students (60%) have understood that chromosomes are found in the cell nucleus because the chromatin strands that makeup chromosomes are found in the nucleus. However, students' understanding of sex chromosomes and somatic chromosomes (autosomes) was low with only 14% of students understanding that sex chromosomes are not only found in sex cells but also present in all cells. For another item related to the concept of the relationship between genes, chromosomes, and DNA, i.e. item 10, only 8% of students understand

that genes are located on chromosomes, constructed from DNA and all somatic cells have the same gene.

The alternative frameworks in the concept of the relationship between genes, chromosomes and DNA occurs due to students' failure to understand the following three facts well. The first fact is that there is DNA in the structure of chromosomes and the second fact is those sex chromosomes are found in all cell types, and not just in reproductive cells. The third fact is that all somatic cells have the same gene. As a result of these failures, 27% of students thought that DNA-building chromosomes were found in genes, 56% of students thought that genes are formed when chromosomes merge, 55% of students thought that DNA-built genes are located on chromosomes and differ from each other in each body cell (Table III).

Level of Understanding and the Alternative Framework on the Concept of the Relationship of Cell Division and Inheritance

In item 6, 38% of students understood that sex cells have haploid chromosome numbers while somatic cells like nerve cells have diploid chromosome numbers. Regarding item 9 which revolves around cells that have chromosome formulas, in the first tier only 16% of students can provide correct response and justification and the lowest achievement for both tiers for the concept of the relationship of cell division and inheritance. Next, for item 11, students were required to give a reason on the question of why the number of chromosomes in an individual's somatic cells is the same. 48% of students understood that the process of mitosis produces somatic cells that have the same gene content. As for item 12, it was found that 31% of students understand that the formation of sex cells (sperm and egg cells) is through the process of meiosis. Next, the sperm and egg cells coalesce and form a zygote, and then the zygote undergoes a process of mitosis. In short, students' understanding of the concept of the relationship between cell division and inheritance is the highest compared to the other three genetics fundamental concepts.

The alternative framework for the concept of the relationship of cell division and inheritance was largely due to their failure to understand facts n refers to haploids while $2n$ refers to diploids. This is evident when 40% of students think that egg cells contain $2n$ chromosomes and somatic cells contain n chromosomes. Also, students' failure to understand that zygotes and somatic cells are diploid causes students to assume that zygote and somatic cells have 23 chromosomes ($22 + X$) at 13% and 30%, respectively. Besides, alternative frameworks also occur because students do not understand that the mitotic process is responsible for ensuring that the number of chromosomes is the same in all somatic cells. The implication was 36% of students who think that reproductive cells undergo meiosis to double the number of chromosomes. Apart from that, there were 41% of students who think that the zygote undergoes a process of meiosis to reduce its chromosome number.

Due to the misunderstandings and alternative frameworks of students on genetics fundamental concepts, interventions need to be designed and implemented to prevent alternative frameworks from becoming entrenched among students. Among the interventions that have been implemented abroad and can be applied in the context of students in Sabah is the use of diagrams in learning to facilitate students in building and expanding their knowledge of chromosome behavior and chromosome structure during the process of meiosis (Cho et al., 1985; Kindfield, 1994). In addition, the implementation of practical activities such as creating Mitosis and Meiosis Models (Clark & Mathis, 2000) and DNA models using beads (Rotbain, Marbach-Ad, & Stavy, 2006) to increase students' understanding of genetics fundamental concepts, as well as the implementation of

activities such as role-play mitosis (Wyn & Stegink, 2000) to improve students' understanding of the concept of mitosis.

Apart from that, the activity of drawing chromosomes with genes during the process of mitosis and meiosis called Bajema (Mertens & Walker, 1992) is an intervention that has successfully identified students' alternative frameworks for the topic of mitosis and meiosis. Annetta, Minogue, Holmes & Cheng (2009) have found that there is no significant difference in cognitive aspects between students who use video games (video games) in genetic learning with students who do not use video games. Meanwhile, Smith & Wood (2016) have found that clicker question activity combined with group discussion successfully improved students' mastery in solving questions related to genetic concepts. Kalimuthu (2017); Rotbain, Marbach-Ad & Stavy (2007) have found that the use of animation-based instruction can increase students' understanding of the concept of meiosis and their alternative frameworks are decreasing.

Intervention

This study found that Form Four Biology students in Sabah have a low understanding of genetics fundamental concepts. Their response in the GFCAT instrument showed that these students have many alternative frameworks related to genetics fundamental concepts. Misunderstandings and alternative frameworks that occur among these students can also affect their understanding of gene-related chapters in the future. Thus, the teaching of genetics fundamental concepts in the classroom should emphasize students' understanding of fundamental concepts such as gene concepts and chromosome concepts. At the same time, the alternative frameworks found need to be corrected to prevent them from recurring. Alternative frameworks occurred among the students are due to their misunderstanding of the relationship between the genetics fundamental concepts. Several studies have shown that the use of concept maps and drawings can enhance students' understanding of the relationship between genetic concepts (Kibuka-Sebitosi, 2007; Mertens & Walker, 1992; Okebukola, 1990; Rotbain, Marbach-Ad & Stavy, 2005). In addition, Marshall (2008) has also concluded that the use of modules can increase students' understanding of a concept such as the concept of *Drosophila melanogaster* phenotype inheritance. Kalimuthu (2017); Rotbain et al. (2007) have also found that the use of animated videos can increase students' understanding of the concept of meiosis.

It is also showed that in this study, the percentage of students who answered correctly in the first tier of items in GFCAT was high but the percentage showed a sharp decrease in the second tier when students were asked to give reasons for each of their answers in the first tier. This showed that students are learning the concept of genetics but do not really understand it or maybe they are just memorizing the facts they are learning. To achieve meaningful learning, abstract concept visualization techniques may help them in understanding genetic concepts. This is because the use of models, analogies and simulations has been shown to increase students' understanding of abstract concepts (Pashley, 1994; Tan, Taber, Liu et al., 2008; Tsui & Treagust, 2003; Venville & Donovan, 2008).

The existence of variables such as students' ability to justify student learning techniques, and students' attitudes towards genetics cannot be controlled but can affect the understanding of genetic concepts (Kilic & Saglam, 2013; Knight & Smith, 2010). Thus, students in the state of Sabah might have not seen the importance of learning these genetic concepts in their dream career and at the same time influence their interest to master genetic concepts in depth. This is in contrast to students

in England who have realized the importance of the field of genetics in the future (Kilic et al., 2016) and at the same time encourage them to understand and master the concept of genetics.

Ultimately, although alternative frameworks related to genetic concepts are difficult to be reduced to zero with conventional teaching strategies, Tekkaya (2002) has found that the constructivist approach in learning has succeeded in improving students' understanding and further reducing their alternative frameworks regarding cell division. Therefore, it is highly recommended that learning be actively implemented in the learning of genetic concepts.

Conclusion and Implications of the Study

The level of understanding of genetics fundamental concepts of students in Sabah is still low and limited, especially in the concept of genes and chromosomes. This results in them failing to understand the relationship between these concepts and other concepts such as the concept of cell division and inheritance. The implications of the study showed that interventions need to be implemented as early as possible by educators to cultivate students' interest in mastering genetics fundamental concepts and at the same time restrain this alternative framework from continuing to take root.

Theoretical and Contextual Contribution

This study found that alternative frameworks related to genetic concepts exists among students in Sabah, Malaysia. More interestingly, these alternative frameworks are similar to alternative frameworks found by other researchers around the globe such as the alternative frameworks related to chromosomes, genes, mitosis and meiosis (Aydan & Balim, 2013; Hadjichambis, 2015; Kilic et al., 2016; Rodriguez et al., 2018). The alternative frameworks related to the fundamental concepts in genetics is seen as being increasingly critical as it continues among secondary school students (Aziz & Ami Norliyana, 2011; Kilic et al., 2016) and is feared to have disastrous implications at the next level of study. The most worrying is that failure to master the concept of mitosis and meiosis triggered a domino effect on the mastery of human reproductive concept and the cell cycle concept among student (Kurt et al., 2013; Luksa et al., 2016). Clearly, the incomprehension and alternative frameworks related to the fundamental concepts of genetics occur globally and this should be an impetus for future studies especially in Malaysia. The development of teaching aids such as learning modules is seen as an appropriate intervention (Dewi & Primayana, 2019; Juhairiah et al., 2018; Marshall, 2008; Setiyadi, 2017; Sri Wirdani et al., 2016; Susanti et al., 2020)

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