**"Genetic basis of inheritance and variation"**

Dr. Amjad Mahasneh

Jordan University of Science and Technology

**Segment 1**

Hello and welcome everyone. My name is Amjad Mahasneh. I teach molecular biology at Jordan University of Science and Technology in Irbid, Jordan.

Our today's topic is a very exciting one because it touches all of us as humans.

And before we start, let me ask you a question, are you identical to your parents or to your brothers and sisters or even to your classmates or your friends?

You probably would say although, I share some characteristics with them but we are different.

Have you ever thought why that is why you are different from your parents and from your brothers and sisters?

That's the main focus of our today's topic.

In the first photo, we have a family of a father, a mother and two daughters, and you can easily pick out differences between them if you look at their hair color, their eye color, their freckles, their height, ….etc.

Now, in the 2nd and 3rd Photos, we have an identical twins and its very hard to distinguish between them as they are identical monozygotic or identical twins result from a single fertilized egg that splits a few days after conception. Their DNA originates from a single source, and therefore their genetic material is the same and all of their characteristics that resulted from their genes also would be similar

In the last photo, we have a nonidentical twin and clearly you can distinguish between the boy and the girl because non identical or dizygotic twins result from two eggs that are fertilized by two separate sperms in a single ovulation cycle. They are no more alike than any other sibling set.

The transmission of traits from the parents to their sons and daughters is called inheritance or heredity.

However, sons and daughters are not identical copies of their parents or their brothers and sisters as we saw in the family photo

Along with the inherited similarity, there is also variation. The question is why we are different from our parents and from our brothers and sisters? What are the biological mechanisms leading to the hereditary similarity and variation?

And before we answer these questions, let's move into our first in class activity.

**Activity**

Now, for this activity, I want each one of you to examine the following traits:

First, whether you have an attached or detached earlobe and whether you can roll your tongue or not.

With the help of your teacher, I want you to record your numbers on the black board in a table and I want you to answer the following questions: Do all students share one trait or two traits? Or do they differ in one or two traits? What is your conclusion?

See you after the activity

**Segment 2**

Welcome back

Obviously, you realized that some students share one or the two traits and others differ in one or both of them. We inherit all of our traits from our parents in the form of hereditary units called genes.

Now, let's examine the 2 genetic principles (hypotheses) that account for the passing of traits from parents to offspring?

The "blending" hypothesis is the idea that genetic material from the two parents blends together, it's like blue and yellow paint blend to form the green color, in this case, parents will lose its individual identity. Because the blending hypothesis does not explain many inheritance patterns, it is no longer accepted among scientific community.

The second hypothesis is called the "particulate" hypothesis and its the idea that parents pass on discrete units that we call no genes

Mendel was the first to document a particulate mechanism through his experiments with garden peas

Mendel performed monohybrid crosses, which are mating between plants that are different in one character. From his experiments, Mendel developed the following concepts about inheritance:

The first concept is that alternative versions of genes account for variations in inherited characters. These alternative versions of genes are now called alleles

The second concept is that for each inherited character, an organism has two alleles, one from the father and one from the mother. A homozygous individual has two of the same alleles for a character. A heterozygous individual has different alleles for that character.

The third concept, When only one of two different alleles seems to affect a trait, that allele is called dominant allele (represented by capital letter). The allele that does not appear to affect the trait is called the recessive allele (represented by small letter).

The fourth concept developed by Mendel is that when gametes form, the alleles separate. Each gamete carries one allele for each trait. This is called the principle of segregation or the first law of Mendel.

Mendel also performed dihybrid crosses, crosses of plants with two differing characters. His results led him to develop the principle of independent assortment, which states that the alleles for different genes are sorted into gametes independently.

To elaborate more on these two hypotheses, let's do the following activity.

Activity: Cross a pure tall pea plant with a pure short plant. According to the blending hypothesis, what do you expect the plants to be in the first generation? In a few more generations?

In the above mentioned cross, suppose that in the first generation you obtained only 85 tall plants and in the second generation, you obtained 105 tall plants and 30 short plants.

How can you explain these results? What is your conclusion?

See you after the activity.

**Segment 3**

Welcome back

You probably guessed that according to the blending hypothesis, the plants would be intermediate in length and after few generations we expect to see a homogenous population of similar length plants i.e. the original parental traits disappeared.

On the other hand, and according to the particulate hypothesis, the tall trait is dominant over the short trait. That's why we saw only 85 tall plants in the first generation, and we saw a 3:1 ratio in the second generation (105 tall: 30 short). Mendel's principle of segregation accounts for the 3:1 ratio observed in the $F_2$ generation.

So genes are our genetic link to our parents and they account for family resemblance as well as difference. Our genes program the specific traits that emerge as we develop from fertilized egg into adults.

One would ask how genes can pass from parents to offspring. To answer this question, let's look at types of reproduction:

The first type is asexual where one parent produces genetically identical offspring by mitosis like in lower organisms like hydra for example.

The second type is sexual reproduction where two parents give rise to offspring that have unique combinations of genes inherited from the two parents.

So genes are passed to the next generation through reproductive cells called gametes (sperm and egg) that are similar in chromosome number but vary in genes order.

Therefore, genetic variation is an important consequence of sexual reproduction.

Before we discuss the mechanisms that lead to genetic variation, we have to remember that Mutations are the original sources of genetic variation as

Mutations are changes in an organism's DNA that create different versions of the genes, the alleles.

Once these differences arise, reshuffling of the alleles during sexual reproduction produces the variation that results in each member of a species having its own unique combination of traits.

Lets look the mechanisms that contribute to genetic variation arising from sexual reproduction are:

Before I will introduce the mechanims, I just want to remind you that

Meiosis is preceded by interphase, in which chromosomes are replicated to form sister chromatids. The sister chromatids are genetically identical and joined at the centromere.

Meiosis has two stages I and II. I want to draw your attention to two phases in meiosis I that contribute to genetic variation, namely prophase I in which crossing over takes place between non-sister chromatids, and metaphase I in which independent assortment of chromosomes takes place.

**Mechanisms of genetic variations**

The first mechanism that leads to genetic variations is crossing over.

To understand crossing over, we need to know what do we mean by homologous chromosomes.

Homologous chromosomes are chromosome pairs that are similar in length, centromere location, and gene position. One inherited from each parent, they have corresponding gene sequences and they pair during meiosis.

This diagram shows a pair of homologous chromosomes, one from the father and the other from the mother. They have the same length, the same centromere location and they have the same gene position. For example , this is the locus for the height gene, we have two alleles: one for the tall and one for the short

Crossing over takes place during prophase I of meiosis. This diagram represents a cell with a pair of homologous chromosomes, one from the father (the blue) and one from the mother (the red). These two chromosomes are held together during meiosis by a chiasmata. Through chiasmata crossing over takes place between the non-sister chromtaids.

In anaphase I, the homologous pair separate and each will go to one cell and during anaphase II, the sister chromatids separate producing 4 cells; two resemble their parents and two recombinants.

To better understand crossing over lets look at the following diagram which represents a single crossing over between a two non-sister chromatids.

This represents a homologous pair of chromosomes, each chromosome consists of two sister chromatids and each carries two alleles A capital , B capital (the dominant ones ) and a small , b small (the recessive ones).

If a single crossing over takes place between the A and B, a chiasma will form between the non-sister chromatids, we will end up having two parental chromosomes with A, B and a, b and two new recombinant chromosomes A, b and a, B.

Will take a break, see you after that.

**Segment 4**

Welcome back

The second mechanism that leads to genetic variation is

Independent assortment of homologous chromosomes

To explain the idea of independent assortment, let's do the following activity together. We have 2 pairs of colored pencils, a red one and a blue one, we want to place these two pairs on a straight line, how many combinations we have?

We could arrange them so the red on the left hand side and the blue on the right hand side or we could switch them so the red would be on my right hand and the blue on my left hand side. and the

The answer is 4

To see what happened when a cell undergoes meiosis , let's look at the following diagram

Independent assortment results because each homologous pair of chromosomes is positioned independently of the other pairs in metaphase I of meiosis.

Each daughter cell represents one outcome of all possible combinations of maternal and paternal chromosomes.

Number of combinations possible for daughter cells formed by meiosis of a diploid cell with two homologous pairs of chromosomes is 4

(2 possible arrangements for the first pair X 2 possible arrangements for the second pair).

Only two of the 4 combinations of daughter cells within the figure would result from meiosis of a single diploid cell, because a single parent cell would have one or the other possible chromosomal arrangement at metaphase I but not both. However, the population of daughter cells resulting from meiosis of a large number of diploid cells contains all 4 types in approximately equal numbers.

The last mechanism that contributes to genetic variation results from Random fertilization of gametes

As you saw, each gamete has a unique set of combination of genes as result of crossing over and independent assortment of chromosomes.

So a male gamete can fertilize any of the female gametes. The fertilization between a male gamete and a female gamete occurs randomly.

As a result, each zygote is unique and hence variation occurs due to the <u>different combination of genes</u> from the male and female gametes.

Number of possible combinations from fertilization if a male gamete with 23 chromosomes when it fertilizes a female gamete with 23 chromosomes= $2^{23} \times 2^{23} = 2^{46}$

Before we do the last activity together I want you to calculate the probability that two individuals will have the same genetic makeup knowing that the diploid number of chromosomes in human is 46?

2n= 46 , n= 23

Total number of possible combinations= number resulted from independent assortment in each gamete x number resulted from crossing over in each gamete x number resulted from random fertilization

$= (2^{23} \times 2^{23}) \times (2^{23} \times 2^{23}) = 2^{92}$

This is a huge number

The probability of getting any combination of genes in a given child would be 1/number of possible combinations

In this case it is $1/2^{92}$

I hope you've enjoyed learning about mechanisms of genetic variation and hopefully now you know why you differ from your parents, siblings, friends and classmates.

Thank you so much for your time and for your energy.

**Teacher's Guide**

Hello. This is Amjad again.

Let me first thank you for choosing to do this module.

I hope you and your students enjoyed it as much as I enjoyed making it.

First of all the material we are going to cover deals with genetic basis of variation.

Some of the material we are going to cover is new to the students and some they probably know.

This module doesn't require many prerequisites; it just requires general knowledge of DNA as the genetic material as well as knowledge of meiosis; that's how gametes are produced in the male and female sex organs by gametogenesis.

The purpose of the first pause is to attract student attention to the topic by asking them to identify each photo and recognize few of the similarities and differences between individuals in each photo. The students will try to identify each photo and they will tell you similarities and differences between members in each photo.

Also, you can ask the students whether other living organisms are identical or not for example cats, dogs, elephants, lions, plants.. .etc.

The idea is to make the students recognize that humans as well as other living organisms differ from each other.

Now, while discussing this, I will challenge the students with the question why sons and daughters are different from their parents and from their brothers and sisters. You can extend it to other organisms like animals for example.

For the first class activity, ask each student whether he or she has an attached or detached earlobe and whether he /she can roll his/her tongue. You can write the data in a table.

Students should realize that X number of students share one or two traits while Y number differs in one or both. This variation is due to what they inherit from their parents.

Now in the second segment, the concept of genes will be introduced. Here you should emphasize that the link between parents and children is genes and genes are responsible for all of children's traits.

After introducing genes at the beginning, the two genetic principles (hypotheses) that account for passing of traits from parents to offspring will be reviewed.

The first is the blending hypothesis and the second is the particulate hypothesis. More emphasis is put on particulate hypothesis and Mendel work will be summarized in this segment.

The second activity is a classical monohybrid cross between a tall pea plant and a short pea plant. I guess the new thing is the first part of the activity and that is to predict the phenotype according to the blending hypothesis.

According to the blending hypothesis, we expect to see an intermediate length pea plants after one generation and in a few more generations, the original parental phenotypes will disappear and the while population will be homogenous and has an intermediate length plants.

In this activity, the students should be able to answer the questions and come to a conclusion that genes are discrete units that can pass from parents to offspring and each gene has two alleles.

In the 3$^{rd}$ segment, I started with giving them the answers for the second activity then I start focusing on how genes can pass from parents to offspring through sexual reproduction and at the end of this segment we get to our main topic; the mechanisms leading to genetic variation.

Before I discuss the mechanisms leading to variation, I will draw the student attention to that fact that the original source of genetic variations is mutations which results in creation of alleles and it's the reshuffling of alleles during sexual reproduction that causes variation.

The first mechanism that leads to genetic variation will be discussed and that's crossing over. First, I will explain the idea of homologous chromosomes, sister chromatids, non-sister chromatids, then I will introduce crossing over, when it takes place, chiasma formation, and results of crossing over.

An example of a single crossing over event between two loci will be explained.

The number of possible combinations resulted from crossing over is estimated by scientists to be equivalent to that as a result of independent assortment which is $2^n$

In the $4^{th}$ segment, independent assortment of chromosomes, the second mechanism that leads to variation, will be discussed.

I will remind students with meiosis and show them prophase I and metaphase one as they are important for variation.

To introduce the idea of independent assortment, a simple activity will be demonstrated using two pairs of colored pencils. All possible combinations will be shown.

The idea of homologous chromosome (sister vs. non-sister chromatids) will be clarified further and the possible arrangement of homologous chromosomes during metaphase I of meiosis will be explained with a diagram that shows two pairs of homologous chromosomes.

The formula to calculate possible combination will be introduced; $2^n$ where n is the haploid number of chromosomes (or the number of pairs)

The possible number of combinations in case of 4 chromosomes (n=2) is $2^2=4$

The last mechanism that results in variation is random fertilization in which the possible number of combination resulting form independent assortment of chromosomes and crossing over in each gamete is multiplied upon fertilization

At the end of this segment, I want the students to calculate the possible combinations which result from random assortment, crossing over and random fertilization, and to calculate the probability that two individuals will have the same genetic makeup knowing that the diploid number of chromosomes in human is 46?

I will pause and give the students some time top think and come up with an answer then I will show the solution.

To calculate the probability, we need to find out the possible combinations resulted from the 3 mechanisms we discussed, the crossing over, independent assortment and random fertilization.

$2n= 46$ , $n= 23$

Total number of possible combinations= number resulted from independent assortment in each gamete x number resulted from crossing over in each gamete x number resulted from random fertilization

$= (2^{23} \times 2^{23}) \times (2^{23} \times 2^{23}) = 2^{92}$

The probability of getting any combination of genes in a given child would be 1/number of possible combinations

In this case it is $1/2^{92}$

Hopefully all of the questions of the students have been answered, and hopefully they enjoyed it. I definitely enjoyed teaching this material and I thank you very much for all of your help and all of your attention.

I hope you enjoyed this module and you got the idea why we are different from each other, from our parents and from our siblings

Thank you for your attention and bye for now.