# University students' conceptions about the concept of gene: Interest of historical approach

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**Abstract:** Concepts of genetics are often difficult to teach, specifically the central concept of gene. Even the scientists disagree when defining this concept. This paper investigates university students' understanding about the gene and its functions. The results show the dominance of two conceptions of the gene: the Neoclassical model and the Mendelian model. The existence of hybrid conceptions and the lack of the modern model show that students are unable to mobilize the knowledge taught in biology. These results suggest to improve the teaching methods of genetics, for instance, by developing activities that bring students face to face with their conceptions.

**Key words:** gene concept; gene functions; genetic determinism; historical models; students' conceptions

## 1. Introduction

During the second half of the 20th century, genetics progressively became an essential field of biology also feeding controversial ethical, social and economical debates. The multiplicity and availability of products and applications of genetic technology (GMOs, DNA fingerprinting, screening of genetic diseases, gene therapy, cloning, ... ) are more and more daily present, requiring us a high level of scientific literacy and understanding of these issues for a citizenship control (Dawson & Schibeci, 2003; Marbach-Ad, 2001).

Genetics is also one of the most difficult subjects in the biology curricula at the secondary school (Banet & Ayuso, 2003; Bahar, et al., 1999a; Chattopadhyay, 2005; Kindfield, 1994; Lewis & Wood-Robinson, 2000; Lewis, et al., 2000a, 2000b, 2000c; Longden, 1982; Marbach-Ad & Stavy, 2000; Marbach-Ad, 2001; Scriver, 1993; Wood-Robinson, 1994) and university levels (Bahar, 1999b; Johnstone & Mahmoud, 1980; Kindfield, 1994).

The term "gene" was introduced by Wilhelm L. Johannsen in 1909. This central concept in genetics was initially defined as an entity of calculations to account for the transmission of hereditary traits. It became a material entity firstly as a part of chromosome (Morgan, 1911) and then, with the development of molecular biology, as a segment of DNA. More recently, three types of genes were defined related to their functions: genes

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coding for proteins, genes specifying the untranslated RNA (tRNA, RNAs ... ) and the regulatory genes. The more recent conceptions of gene have never totally replaced earlier conceptions: Multiple scientific conceptions of the gene are coexisting (Morange, 2004). Several authors tried to categorize them.

Griffiths distinguished two different conceptions of the gene: The molecular gene is "the molecular process underlying the capacity to express a particular polypeptide product", and the evolutionary gene is "a theoretical entity with a role in a particular, atomistic approach to the selection of phenotypic traits" (Griffiths & Neumann, 1999). Later, Griffiths and Stotz outlined three conceptions of the gene: instrumental, nominal, and postgenomic.

> The instrumental gene has a critical role in the construction and interpretation of experiments in which the relationship between genotype and phenotype is explored. The nominal gene is a critical practical tool, allowing stable communication between bioscientists in a wide range of fields grounded in well-defined sequences of nucleotides, but this concept does not embody major theoretical insights into genome structure or function. The post-genomic gene embodies the continuing project of understanding how genome structure supports genome function, but with a deflationary picture of the gene as a structural unit. (Griffiths & Stotz, 2006)

Gericke and Hagberg (2007) defined five different historical models of gene function: the Mendelian model, the classical model, the biochemical-classical model, the neoclassical model and the modern model.

(1) In the Mendelian model, the gene is a hypothetical construct and its main purpose is to explain genetic transmission, no connection was however made to a material unit in the cell.

(2) In the classical model, the gene is a particle, an indivisible unit of genetic transmission, recombination, mutation and function. The gene determines a characteristic. Definite characteristics were the product of genes, which were located at well-defined loci on the chromosomes.

(3) In the biochemical-classical model, the gene is a particle of transmission, function, mutation and recombination. The gene produces a substance that determines a characteristic. Tatum proposed in 1941 the one-gene-one-enzyme hypothesis for genetic function.

(4) In the neoclassical model, the gene is a materiel unit consisting of a DNA-segment. In this model, structure and function coincide and the gene codes for the production of a polypeptide. The neoclassical view of the gene peaked at about 1970 and stated that the gene (cistron) is a contiguous stretch of DNA that is transcribed as one unit into messenger RNA, coding for a single polypeptide.

(5) The modern model of gene function considers the gene as a hypothetical construct with a diverse material base consisting of DNA segments that take part in a developmental process. The gene is a producer of molecules in a developmental system. There are a number of categories of genes such as enzyme-producing genes, genes producing structural (nonsoluble) proteins, regulatory genes, and genes coding for RNA-molecules. No direct entities representing environmental aspects are present in this model.

In the present work, we will use these five categories.

## 2. Aims of the study

In Morocco, genetics is taught in the 3rd year of upper secondary school: Mendelian genetics, the molecular basis of heredity, human genetics and some basic principles of population genetics. At the university, the teaching of genetics differs from one university to another: Sometimes the genetic is treated in one module at the second year (semester 3), in other cases, it is treated in two modules at the second and third years (semester 3 and semester 5 or 6). Similarly, the main parts of the genetics are treated with more detail than in the upper secondary school: classical genetics, molecular and population genetics. A few research has analysed until now knowledge and understanding of genetics among Moroccan secondary school students (Agorram, et al., 2006; Elaboudi, 1994) and among upper secondary school teachers (Agorram, et al., 2008), but, no study has focused on university students.

The purpose of this study is to identify the university students' conceptions of the gene concept.

## 3. Methodology

### 3.1 Questionnaire design

We use here only a part of the questionnaire containing three open questions: (1) The first related to the definition of gene; (2) The second to its biological functions; and (3) The third aimed to identify the concepts that can associate to the word "gene". We used open questions to capture the various gene conceptions in order to compare them to the five categories of conceptions identified in the literature (Gericke & Hagberg, 2007).

### 3.2 Sample of students

The study was conducted with a sample of 94 university students. They studied several years in the university: 59 obtained the license degree and 35 the Master's degree. A license degree is awarded to students completing educationally broad based post secondary programs requiring at least three years of full-time study. A Master's degree is awarded to students completing two years of university studies full time made following a license degree (license+2 years).

The written questionnaire was administered by the teacher to the students within a class period of 1 hour and was filled out anonymously.

## 4. Results

### 4.1 Definition of gene

The responses of students were categorized (see Table 1).

**Table 1 Students' conceptions of gene**

| Gene conception's categories | | Number of responses | % |
|---|---|---|---|
| The gene is | DNA segment | 75 | 79.8 |
| | DNA segment responsible for the synthesis of a protein (unrelated to any character) | 14 | 14.9 |
| | DNA segment responsible for the synthesis of a protein governing a character | 18 | 19.1 |
| | DNA segment responsible for a character without mentioning how (protein) | 28 | 26.8 |
| | Responsible for a character, functional unit of heredity | 9 | 9.6 |
| | Alleles | 16 | 17.0 |
| | Support of hereditary information | 21 | 22.3 |
| | Responsible of genetic information's transfer | 3 | 3.2 |
| | Carried by a chromosome | 9 | 9.6 |
| | Contained in the nucleus | 2 | 2.1 |
| | No response | 1 | 1.1 |

Note: Analytical categories were not mutually exclusive; each student response may be assigned to one or more categories.

The majority of students knew that genes are parts of DNA (75 students: 79.8%), but only one student (1.3%) mentioned that the genes could also, in some viruses, be parts of RNA.

Among these 75 students, only 18 indicated that DNA is responsible for the synthesis of proteins, which govern hereditary characters (active view of genes), 14 indicated that DNA is responsible for the synthesis of protein but they did not mention a link between these proteins and hereditary traits. 28 students indicated that the DNA is responsible for hereditary characters but they did not mention protein. 15 students (16%) indicated that gene is a DNA segment but they make no reference to their products (proteins via mRNA, others RNA) or the characters they control. 19 students (20.2%) did not make any connection between the gene and its chemical nature (DNA or RNA).

Nine students (9.6%) defined the gene by its relationship to a phenotype regardless of the specific molecular sequence and the whole developmental mechanisms involved. Very few students indicated that the genes are located on chromosomes (9/9.6%) or are located in the nucleus (2/2.1%). 16 students indicated that gene is composed of alleles (17%), one of which indicated that the gene is composed of only two or three alleles. Only one student mentioned that the gene is composed of introns and exons. On the other hand, many students mentioned in the definition of gene, which it carries genetic information (21/22.3%) and responsible for its transfer from one generation to another (3/3.2%).

### 4.2 What is the biological function of a gene?

We identified several categories of conceptions of gene functions cited by students (analytical categories were not mutually exclusive; each student response may be assigned to one or more categories):

(1) Genes are active particles that controls characters (55.3%) (coding for protein synthesis, but only 7 students indicate that gene codes for primary structure of protein);

(2) Genes determine characters (33%);

(3) Genes play a role in transmission of hereditary information (34%);

(4) Genes carry hereditary information (26.6%).

Some students cited other functions of the gene such as: genes are responsible of variation (4.2%), genes play a role in regulation (7.4%) and conservation of hereditary characters (6.4%) or in conservation of species (7.4%), in evolution (2.1%) and conservation of breed and lineage determination (2.1%), and genes are involved in the duplication of DNA (3.2%). Also, some students cited that genes cause diseases (without mentioning by which mechanisms) (8.5%).

Some of these conceptions are not in accordance with the scientific knowledge, for instance, genes are carrier of characters (5.3%).

### 4.3 Gene's related concepts

The aim of this question is to identify all concepts related to "gene" concept spontaneously mobilized by students.

The 94 students cited 915 concepts in total with an average of 9 concepts by student. We have classified it into 7 categories (see Table 2).

The concepts most commonly cited by students are related to genetic information and its transmission (35.4%) and the chemical nature of the gene (nucleotides, DNA ... ) (25.6%).

Only 7.6% of citations concern the cellular environment in which the gene is expressed and only 4.6% of citations are linked to genetic engineering and the applications of genes in different fields (medicine, agriculture ...).

**Table 2 Distribution of concepts related to gene cited by students**

| Categories | Number of citations and % |
|---|---|
| Materiel entity (nucleotides, DNA, chromatin, promoter, ... ) | 234 (25.6%) |
| Information-transmission (translation, transcription, meiosis, codon, ... ) | 324 (35.4%) |
| Products of gene expression (protein, enzyme, ... ) | 64 (7.0%) |
| Cellular environment where the gene is expressed (nucleus, ribosome, cytoplasm, cell, ... ) | 70 (7.6%) |
| Pathological manifestations (colour blindness, down syndrome, ... ) | 67 (7.3%) |
| Applications (GMO, cloning, restriction enzymes, gene therapy, ... ) | 42 (4.6%) |
| Others (biodiversity, genetics, Mendel, Morgan, molecular biology, … ) | 114 (12.4%) |
| Total of citations | 915 (100.0%) |
| No answer | 2/94 (2.1%) |

## 5. Discussion

The Neoclassical model gene concept (A stretch of DNA sequence that codes for a particular protein) (55.3%) was quite popular as was the Mendelian model (unit determining a character) (33%).

But, it is also found that, hybrid models consisting of features from several of the historical models. 26. 8% of students knew the chemical nature of gene (DNA) and defined the gene by its relationship to a phenotype regardless of the specific molecular sequence and the whole developmental mechanisms involved.

Hence, it was noticed that the understanding of gene with modern concept is poor in majority of the students. Only one student mentioned that genes code for products other than proteins and enzyme such as RNA-molecules (RNAs and RNAt). Although the students had a course on molecular genetics, they were unable to mobilize this knowledge to define the gene and its function.

Much of students had difficulties in distinguishing structure of gene and their functions.

Several students indicated that genes are responsible for traits, but could not give any explanation of the mechanisms for this. Even the students have studied the biosynthesis of proteins in the course of Biochemistry and Molecular Genetics, they can not explain with the appropriate biochemical terms the process by which the gene controls a character. Similar results were found by others researchers (Lewis, et al., 2000a).

Few students have cited the location of genes (chromosome, nucleus), this shows that students found it difficult to make connections between the different organizational levels (molecular and cellular levels) and were unable to mobilize knowledge learned in other disciplines (cell biology, ... ) when they faced situations that required it.

Students know and often hear words such as DNA, chromosomes, mRNA, genetic information, genes, ... , but they were unable to link with related gene concepts (chromosomes as organizers of genetic information; the physical entity of the gene; interrelationship between replication of the chromosome and genetic information; distinction between genes and genetic information; regulation of genes, interactions between gene and environment; … ).

These difficulties have been investigated by many researchers who presumed that time gaps between the teaching of related topics is important for understanding genetic relationships, and the compartmentalization between these genetics concepts and processes are the main obstacles to students' understanding and the development of a holistic concept of genetics (Lewis, et al., 2000a, 2000b, 2000c; Marbach-Ad, 2001).

We have also identified several erroneous conceptions such as: "The gene is a sequence of amino acids which is in the form of a chain and is expressed as a phenotype", "DNA is a sequence of several genes=nucleotides", "Codon is responsible for the formation of proteins", "The gene is the whole of hereditary characteristic", "The gene is the unit that constitutes the DNA, each gene contains a genetic character". Similar conceptions were identified in students by other researchers (Johnstone & Mahmoud, 1980; Kindfield, 1994; Bahar, et al., 1999a; Lewis, et al., 2000b).

One out of five of students have difficulties in separating the concept of gene and the concept of alleles, one of these students has indicated that the gene is composed of only 2 or 3 alleles. These difficulties were found by other researchers (Wood-Robinson, 1994; Lewis, et al., 2000a).

No students have referred to the fact that there may be interaction between genes and environment in the expression of different phenotypes. In another side, the 915 citations attached to the term "gene" seem to reflect a latent genetic determinism (linear causality "a gene $\rightarrow$ protein, trait, …") because there is no citation that shows the action of the environment on cellular gene expression. The remarkable absence of the interaction between genes and environment in the responses confirms the anchoring of the deterministic ideology among these students This was also found among upper secondary school students (Agorram, 2006), teachers and future teachers (Castera, et al., 2007; Clement, 2006; Agorram, 2008).

## 6. Conclusion and recommendations

This study shows that, even after receiving instruction in genetics in upper secondary school and university, students (objects of this study) find it difficult to define correctly the word "gene" (one of the fundamental concepts of genetics), to link concepts in genetics and have conceptions about genetics which differ from the current scientific model of heredity. This corroborates other researches conducted in other countries (Clough & Wood-Robinson, 1985). One of the causes of these difficulties is that the teaching of genetics is fragmented and is given on several levels.

For a better understanding of this central concept of genetics by students, teachers must use approaches other than traditional ones such as historical approach. The historical approach does not mean that the teacher cites only the chronological record of various discoveries, but it should insist on the epistemological and methodological obstacles and related them with the science of the time of these discoveries. Thus, students will acquire the competence to take a critical view on scientific concepts and how they were built.

Teachers should encourage students to use concept maps to generate their ideas on the gene concept and to compare it with historical models cited in the literature. Thus, students can identify and characterize the internal and external weaknesses of each model and discover the epistemological and methodological obstacles encountered by researchers when developing these models. Teachers can use the gene models described by Gericke, M. Hagberg (2007) and updated by other researchers (Smith & Adkison, 2008) as a basis for teaching the gene concept. The teachers must also use strategies that will facilitate the connection of concepts about genes and about genetics in general.

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