Comprehension of basic genetic concepts by brazilian undergraduate students

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Abstract: Questionnaires were applied in six different Brazilian undergraduate courses (Biology, Medicine, Dentistry, Psychology, Nutrition and Phonology) to analyze students' comprehension of basic genetic concepts. All sampled students together were not able to answer 30% of the questions, while a significant percentage did not adequately answer more than 60% of the questions. The differences in performance between first-year and last-year students of an undergraduate Biology course were evaluated. Interestingly, first year university students, without any formation in genetics at the university level, performed frequently better when compared with their last-year colleagues. Results of the present study revealed that future teachers and other health professionals share distorted understanding of elementary genetics. This finding is of particular interest, reflecting a relationship between acquisition of the genetic knowledge and professional development.

Keywords: teaching of genetics, basic genetic concepts, misconceptions, undergraduate education, health professionals.

Introduction

In many countries bioethical commissions discuss controversial aspects of gene technology, portraying a profound transformation in our understanding of the concept of life and human identity. After publication of the human genome in the year 2000, genetics became a subject present in daily life. Queries about cloning, genetically modified organisms and the use of stem cells have a widespread coverage by the media and therefore promote an intense public debate involving also important political institutions responsible for regulating social and juridical questions. In Brazil, for example, different aspects of gene technology and their ethical consequences were the topic of an intense debate in the National Congress (Izique, 2004).

Growing knowledge in life science, especially in the field of genetics, is considered to provoke revolutionary transformations in agriculture and human medicine (Müller-Hill, 1993; Lubinsky, 1993; Marshall, 1996; Lapham et al., 1996; Rothstein, 1997; Holtzman, 1988 and 1999; Sloan, 2000; Human Genetic Commission, 2002 and 2004). Being concerned about ethical, social and economic problems provoked by this genetic revolution, the participation of a wide range of individuals from all social levels and their representative political organs will be important in future decision processes. Generally it can be assumed that informed societies are also able to make wise decisions. Therefore it is important to understand if basic genetic knowledge, such as the laws of Mendel, that are transmitted to students before reaching the University, are well understood and what happens with this understanding throughout the years of college, a time in which acquisition of scientific concepts has been recognized as fundamental to citizenship, especially among future Biology teachers and future health professionals.

Many authors have described students' misunderstandings regarding established concepts of genetics and diversity of people's ideas about inheritance (Wood-Robinson et. al. 1998; Lewis et al., 2000 a and b; Marbach-Ad and Stavy, 2000; Marbach-Ad, 2001; Richards, 2001; Lewis and Kattmann, 2004; Chattopadhyay, 2005; Santos and Bizzo, 2005; Saka et. al., 2006; Santos, 2006; Duncan and Reiser, 2007). These studies focused on the description of everyday ideas of inheritance and "students' difficulties" to understand concepts such as those ones of genes, alleles, chromosomes, DNA or processes of cell division. Despite the efforts made in the application of alternative strategies to transmit genetic knowledge, these difficulties to teach and to learn genetics are continuously described and remain a problem of students' comprehension (Banet and Ayuso, 1995; Ayuso et. al., 1996; Banet and Ayuso, 2000; Ayuso and Banet, 2002; Orcajo et. al, 2005). According to this situation, research developed since the eighties showed that genetics appears to be one of the most abstract contents to teach (Finley et al., 1982), specifically regarding three topics: mitosis-meiosis, Mendelian genetics and chromosome theory.

In order to evaluate if difficulties to understand basic genetic concepts might be a barrier in professional development, we analysed some answers to a simple questionnaire involving 217 undergraduate students of six different courses of a Brazilian university. Only few studies address the question of differences in the understanding of genetics between students of different courses and the development of genetic knowledge during their time at university. We wanted to know how student's comprehension of genetic concepts develops during the time course, considering that many undergraduate students held everyday ideas of inheritance. Therefore, we evaluated differences in performance between first-year and last-year students of an undergraduate Biology course. How do future health professionals and future Biology teachers understand elementary genetic concepts? What are the variations in their understandings? To participate on debates involving new biotechnologies and to make decisions related to ethical and social issues in genetics, future professionals must understand some basic principles.

Objectives

The present work intends to describe variations in the understanding of some genetic concepts among students of six different health undergraduate courses and to compare performance of first and last year Biology students.

Sample and methods

The descriptive and statistical analysis of undergraduate students' answers was based on a questionnaire to survey elementary concepts of genetics. The questionnaire covered topics of basic Mendelian genetics, which are a part of the curriculum of Biology in high school and undergraduate student courses. The elaboration of this instrument involved three distinct phases: The first phase consisted of a survey of previous knowledge, carried out by a professor of genetics, involving 75 first semester Biology students. Questions were applied about the structure of chromosomes, genes, alleles, their associations with the mitotic and meiotic process and their relations between each other, respectively. The analysis of these data was used to formulate the questionnaire's pilot version, which was applied to a sample of ten students. The questionnaire's final version was composed of 15 questions about basic concepts related to cytology, molecular biology and genetics. The present assay focuses exclusively on genetics.

The questionnaires were delivered to the students, who were requested to return them within one week and to fill them out without consultation of any bibliographical sources. The general objectives of the research, as well as the procedures to answer the questions and responsibility for the accuracy of responses, had been described in an attached letter as an introduction of the questionnaires. In general, about 50% of the first-year and a somewhat lower number of the last-year Biology students participated in the study.

All together the answers of 217 undergraduate students from the University of São Paulo were analyzed. The students belonged to following courses: Biological Sciences or Biology (140 students), 92 first-year and 48 last-year students, Medicine (38), Psychology (26), Nutrition (23), Phonology (12) and Dentistry (32). In the group of Biology students, answers were analyzed before starting with the study of genetic lectures at the University (Bio 1) and just after finishing genetic lectures (Bio 2); third year (Bio 3) and forth year (Bio 4) students were classified as last-year undergraduate students. Information about the curricular structure of these courses is published on the university homepage (http://www4.usp.br/index.php/graduacao).

The questionnaires filled out by students (shown below) were analysed and the results were described considering the following themes

1) Variation in students' understandings of genetics;

2) Performance of students from different courses;

3) Comparison of performance between Bio 1 and Bio 4 students.

Results

Variation in undergraduate students' understanding of genetics

Variations in students' understanding of some basic genetic concepts were verified analyzing the answers given by 217 students of different undergraduate courses. Figure 1 shows how these students represented a pair of homologous chromosomes and the variation in their representations when they were asked to indicate in their figures a chromosome, sister chromatids and a gene. Approximately 15% of the sampled students were not able to identify sister chromatids. Instead of separated chromatids, many students divided both, short and long chromosome arms (generating a break within each chromatid and forming figures shaped like a "v"). From all students tested, only three ones were not able to localize a gene within a chromosome.

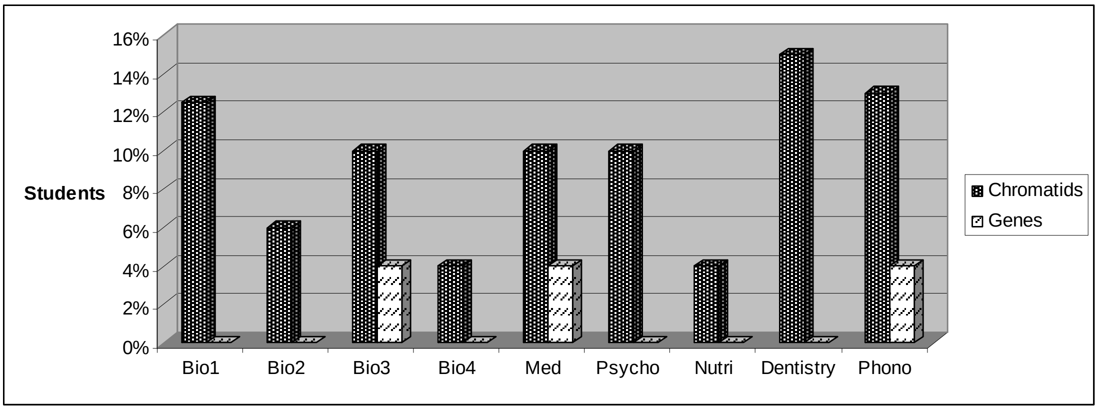

Figure 1.- Percentage of incorrect representations of chromatids and genes drawn by undergraduate students of six different courses. Black columns indicate chromatids, whereas white columns indicate genes.

In the second question, students were asked to represent some phases of mitosis, interphase and meiosis (metaphase of mitosis, G1 phase just before the duplication of DNA, G2 phase just after DNA duplication and metaphase II of meiosis), considering that a cell possesses a pair of chromosomes (2n=2). Figure 2 shows improperly representations, drawn by the students. About 70% of the students represented the processes of mitosis and meiosis inadequately. About 29.5% of the students were not able to represent chromosomes of the G1 and G2 phase of the cell cycle. Metaphase II chromosomes of meiosis were inadequately represented by 21% of the students, while metaphase of mitosis was better understood, since a smaller percentage of students (15%) did represent it incorrectly.

The segregation of chromatids and chromosomes during mitosis and meiosis frequently was represented improperly, resulting in duplicated chromosomes (diploid or tetraploid gametes: "XX"; "XXXX"). Bio 1 students showed better performance when compared with their Bio 3 and Bio 4 colleagues (Figure 2). Some of them, who are future teachers, showed the worst understanding of meiosis.

The third question investigated the students´ understanding of Mendelian inheritance, stating that albinism (incapacity to produce melanin) in humans is genetically conditioned and provokes the albino phenotype in the homozygote condition (aa): A couple, consisting of a man who is albino and a phenotypically normal women, have two children, whereby one child shows the albino phenotype and the other one shows a normal skin pigmentation. With regard to this situation, students were invited to read the following sentences and to complete them with true (T), false (F), or not sure (NS).

a) The allele causing albinism is represented by a.

b) The allele causing albinism is represented by A.

c) The gene causing albinism is represented by A.

d) The woman of the couple possesses one allele causing albinism.

e) The son of the couple, showing the albino phenotype, received the responsible gene only from his father.

f) The affected children received one allele causing albinism from their father and another one from their mother.

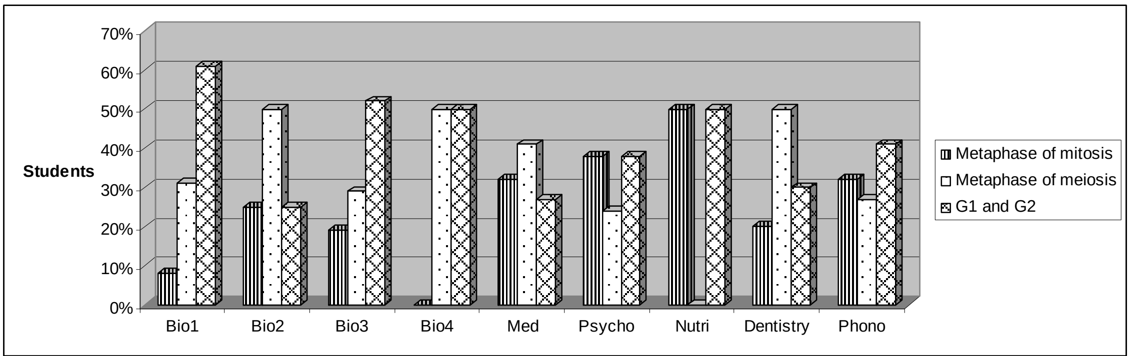

Figure 2.- Percentage of improperly representations of chromosomes during cell cycle and meiosis.

These questions intended to explore the laws of Mendel and ideas related to the concepts of genes and alleles. The majority of students answered these questions correctly. However, 23% of all Dentistry course students indicated that only the father contributed to the inheritance of albinism (Figure 3). These students did not differentiate correctly between the symbols traditionally used to represent different alleles and those ones to distinguish among genes and alleles. Within the Bio 3 students, 22% believed albinism to be transmitted by just one member of the couple, while only 8% of their Bio 1 colleagues answered incorrectly. The Bio 2 group of students, who were interviewed after finishing Genetic lectures, reached higher numbers of correct answers (Figure 3).

The fourth question investigated student's knowledge about the localization of hereditary information, stating that the ear lobule can be adherent or untied: In one specific family, the ear lobule of some individuals was analyzed. A couple, John and Mary, presented adherent lobules. Both have a child with untied lobules. With regard to this case, students were asked where the hereditary information for ear lobule shape is localized. Students had to select between different choices to answer the questions below:

Only in the blood

Only in the ear

Only in the gametes

In all the cells

None of the answers above is correct

a) How does this information pass through the generations?

b) How many genes are involved in the determination of this characteristic?

c) How many alleles are involved in the shaping of the ear? Which is the relation between them?

d) How many genes and alleles are found in a diploid cell at a single gene locus?

e) How many genes and alleles are found in a zygote at a single gene locus?

f) How many genes and alleles are found in a fertilized egg at a single gene locus?

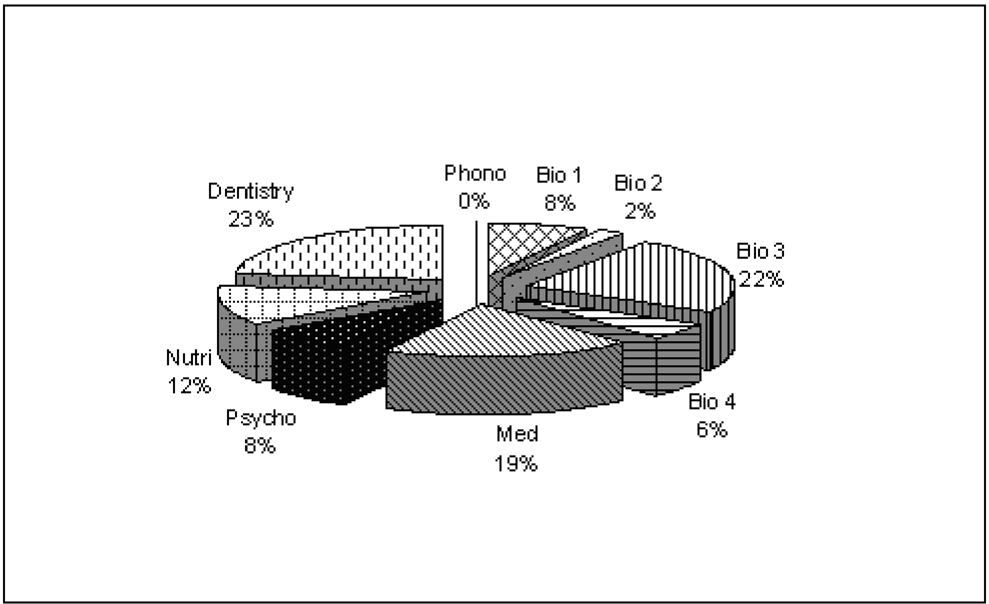

Figure 3.- Percentage of undergraduate students from different courses who suggested that exclusively the father is responsible for transmitting the gene causing albinism.

One student of the dentistry course identified the ear lobule as carrier of heredity information. The idea that genetic information can be found only in gametes was chosen by 8.7% of all the students tested.

Performance of students in different courses

Comparing the answers to all the given questions between different courses, the performance of Biology undergraduate students was significantly better than this one of students from other courses, such as Psychology, Nutrition, Dentistry and Phonology (Table 1). The performance of Biology undergraduate students did not differ from this one of the Medicine course ($p= 0.05$). The latter ones showed a significant higher average note compared to Dentistry and Phonology students ($p\leq 0.05$), but their results did not differ significantly from those ones of Psychology and Nutrition students. Average results among students of Psychology, Nutrition, Dentistry and Phonology also did not differ significantly (p= 0.05).

Students of the Dentistry course showed the highest variability and heterogeneity in their performance (Figure 4). Their performance variation was higher than 30%. All together, they were not able to answer more than 60% of the questions and some students answered only about 35% of the questions correctly. Otherwise, all Biology students were able to answer at least 50% of the questions correctly. Considering all students of the six courses, no one was able to give a correct answer in more than 70% of the questions.

Course	Average	Shunting standard lines	N
Biology	58.4	8.37	85
Medicine	54.5	8.52	38
Psychology	49.3	6.63	26
Nutrition	48.3	7.86	23
Dentistry	46.5	11.49	32
Phonology	43.4	8.28	12

Table 1.- Average values and standard deviations obtained by questionnaires from undergraduate students of six different University courses.

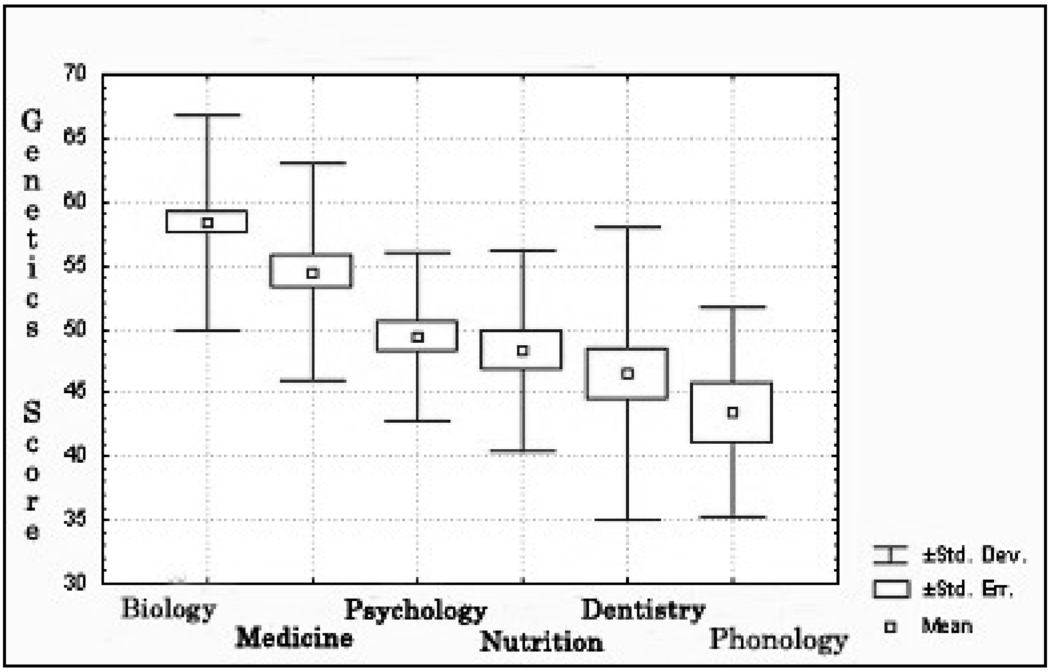

Figure 4.- Diagrams of boxes showing average values and standard deviations of students´ performance from different University courses.

Comparison of performance between first (Bio 1 and Bio 2) and last-year (Bio 3 and Bio 4) biology students

The answers to identical questions were compared between a group of 92 fist-year Biology students (Bio 1 and Bio 2) and 48 last-year Biology students (Bio 3 and BIO 4). This comparison aimed to verify if the understanding of basic genetic concepts was modified throughout the time course of study and to inquire if other disciplines contribute to improve the comprehension of genetics. The results are summarized in Table 2. Interestingly, last-year undergraduate students did not show a better performance compared with their colleagues of the first-year as expected.

<table>
<tr><th colspan="2">Students' performance</th><th>BIO 1 and BIO 2 N= 92</th><th>BIO 3 and BIO 4 N=48</th></tr>
<tr><td colspan="2">In which types of tissues and cells there is DNA? Blood; muscle; skin; spermatozoon; ovule; neuron.</td><td>36%</td><td>42%</td></tr>
<tr><td colspan="2">Representation of chromosomes sister chromatids and localization of genes.</td><td>81%</td><td>75%</td></tr>
<tr><td rowspan="2">Representation of chromosomes</td><td>Metaphase of mitosis</td><td>88%</td><td>81%</td></tr>
<tr><td>Metaphase II of meiosis</td><td>7%</td><td>20%</td></tr>
<tr><td colspan="2">Chromosomes are formed by DNA molecules.</td><td>41%</td><td>31%</td></tr>
<tr><td colspan="2">The genetic condition of albinism is transmitted by both parents</td><td>15%</td><td>37%</td></tr>
<tr><td colspan="2">Hereditary information is found in cells</td><td>18%</td><td>20%</td></tr>
</table>

Table 2.- Comparison of first-year and last-year Biology students' performance. The percentage values of incorrect answers and drawings are shown for both groups.

When students were requested to draw a pair of homologous chromosomes and corresponding chromatids, many were not able to differentiate between both of them. Another unexpected misunderstanding was the idea that chromosomes possess two sister chromatids, containing different genetic information at the same gene loci (Table 2). A high number of Bio 3 and Bio 4 students (67%) did not represent chromosomes adequately in different phases of the cell cycle (G1 and G2), metaphase of mitosis and metaphase II of meiosis. Many of first-year (11%) and last-year (27%) students were not able to describe any phase of mitosis and meiosis. About 23% of Bio 1 and Bio 2 students did not know that alleles are different forms of a gene belonging to the same locus. Another question on this subject stated as follows: "To the scientific community, DNA contains all the genetic information of an individual. Assuming that all cells have DNA, how do you explain that the cells in your body are different?" About 88% of the first-year and 87% of last-year Biology students answered the question above adequately. However, when students were asked regarding a genetic condition like albinism, investigating their understandings of genotype and phenotype, as well as the relationship between genes and alleles, differences were found comparing both groups (Table 2).

Discussion

Literature has pointed out that most students from secondary school, after formal teaching, do not understand genetic concepts and they cannot describe the relationship between some cellular structures like chromosomes, DNA and genes (Shaw et al., 2008; Quinn et al., 2009). Compared to our own results, other studies, involving students of different ages and future science teachers, have shown clearly that many students do not understand elementary Mendelian concepts and terms of mitosis/meiosis like "unreplicated chromosomes", "chromosome/chromatids" or "double stranded chromosome" and "pairs of homologues chromosomes" (Stewart and Dale, 1989; Smith, 1991; Kindfield, 1994; Saka et al., 2006; Quinn et al., 2009).

The nature of students misconception in genetics, the possible sources of these misconceptions and potential ways to improve education in genetics, have been explored in a extensive study, performed by a partnership between researchers of the American Societies of Human Genetics, the National Society of Genetics Counsellors and the Genetic Society of America (Shaw et al., 2008). The analysis of 500 out of 2443 total essays for high school students, collected as a part of the activities during the "National DNA Day", have pointed out the critical influence of individual teachers on students interests, knowledge, comprehension and misconceptions. Shaw and colleagues pointed out that the wrong understanding of genetic concepts is mainly established during students` undergraduate high school courses. This result fits very well with the observation that majority of Biology students in our own study still share distorted understanding of genetics.

Few studies explore the relationship between prior knowledge and conceptual change at the university level. Saka and colleagues (2006) have demonstrated clearly that future teachers possess inadequate understandings of the relation between some basic genetic concepts. Many represented DNA, genes and chromosomes as independent structures in a cell, drawing them inside the nucleus and others in the cytoplasm. In the present study, the students of Biological Sciences who are starting their courses (Bio 1 and Bio 2) showed in many aspects a better performance compared with their colleagues, concluding, or having already concluded their undergraduate studies (Bio 3 and Bio 4).

We propose some alternative hypotheses to explain the differences of performance between first and last-year Biology students. The knowledge learned at the beginning, as undergraduate student, might change and being distorted through time. In this scenario performance varies depending on the temporal distance to the content and time span of graduation. Alternatively, social relevance of Biology has changed over the last few years and therefore students having applied to this career recently could be better prepared, increasing the knowledge of the first-year in relation to last-year students. However, we cannot exclude the possibility of last year students having a lesser willingness to answer the questionnaire, because, in general, they have frequently additional professional activities.

Students from the same course show evident heterogeneity in their understanding of elementary concepts; whereby this situation is more evident in the Dentistry course. This inadequate understanding might influence the learning of more complex genetic contents, such as the concept and social implications of genetic modified organisms (Santos and Martins, 2009). In a comparable study, Professor José Mariano Amabis (personal communication; Instituto de Biociências, Universidade de São Paulo, Brasil) carried out an evaluation asking some first-year Biology students how they understood the expression "a DNA chain." To some students, a chain corresponded only to one of the helices of the DNA molecule, whereas to others a DNA chain was designated as a double helix. This simple example shows how the misunderstanding of a fact can be consensual, reflecting a heterogeneous comprehension among students and might certainly give rise to distorted understandings of more complex ideas. Our results are in consistence with these findings.

The reasons to explain difficulties in the understanding of genetics focus on different aspects of the education and learning process, ranging from such ones as its psychological nature to those ones related to a humanistic perspective (e.g Aikenhead, 2003). The learning of misconceptions has been understood as a result of the simultaneous exposition to an extensive variety of genetic subjects and the inability to reason on ontologically distinct levels of genetic phenomena (Duncan and Reiser, 2007; Shaw et al., 2008). Efforts must be made to analyze the contribution of prior knowledge mediated by secondary education to student's performance and professional development. Students might carry distorted understandings on elementary aspects not directly treated at university level, and such misunderstanding might compromise the learning of other more complex concepts.

Results of the present study indicate the necessity to consider the critical awareness of comprehension of the relationship between acquisition of knowledge and the curricular organization of university courses. If future teachers share a distorted comprehension of elementary genetics, this might influence primary and secondary student's understandings of this content as well as popularization of scientific knowledge carried out by health professionals.

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