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Express yourself: using modeling clay as a didactic resource for teaching genetics in high school

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Abstract: The Institutional Program for Teaching Initiation Scholarships (PIBID) is a brazilian policy for improving teaching quality. Students and teachers involved experience a form of supervised internship that allows the experience of pedagogical *praxis*. Studying of the

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transmission of hereditary characteristics and relationships of dominance and recessivity between alleles are complex abstract concepts that demand the use of appropriate didactic resources. In this context, PIBID scholarship holders, within the Biology area's scope, were diagnosed through the observation in the third year classes of the public school in Brazil, the need to use an alternative methodology that playfully approached these concepts. In the present study, the aim was to produce a fictitious species made with modeling clay, so that, from the "mating" of this individuals, students would observe the transmission of characteristics and determine the genotypes and phenotypes of the "offspring". The learning was assessed using a a questionnaire that was applied before and after the activity. The questionnaire assessed students' understanding of the concepts of genotype and phenotype, dominance and recessivity, homozygous and heterozygous, parental and filial generation, the understanding of Mendel's experimental methods, and the ability to contextualize the content. In general, the average percentage of students who knew how to define the concept correctly increased, and the percentage of students who did not know how to answer decreased for most questions. The results showed an improvement in the understanding of genetic concepts by students. We also observed an improvement in writing expressing and scientifica experimental method comprehension.

Keywords: biology teaching, molecular biology, active methodologies, pedagogical praxis.

Introduction

The Institutional Program for Teaching Initiation Scholarships (PIBID) aims to improve and enhance the training of teachers who work and will work in primary education in Brazil. The scholarship holders develop didactic-pedagogical activities under the guidance of a teacher linked to a higher education institution and the supervision of another related to the primary school. PIBID encourages teacher training and values teaching by providing teachers in training with a close experience with the school environment and encourages continuing education for teachers in primary education (Coordination for the Improvement of Education - CAPES, 2020).

PIBID program is inserted in the school context as a policy to improve the quality of education. Both the teachers in training and the undergraduate teachers are contemplated by this program. They have the opportunity to experience a different form of a supervised internship, where they can experience the teaching *praxis* with the support of the theoretical foundation and necessary experience (Duarte, 2019) that is not normally explored in the disciplines of teaching practice and conventional internship (Carvalho, 2001), besides providing the approximation between the school and the university (Gatti et al., 2011).

In the school context, the teaching of biology faces difficulties related to the abstraction of complicated concepts that, in some cases, depend on visual resources, infrastructure, and technical training of teachers to carry out practical activities (Silva et al., 2011).

This difficulty is evident during the teaching of genetics, that in despite being a recurring theme in the journalistic media (Reis et al., 2013), it still faces problems with the assimilation of basic concepts, generating the need for practical and playful activities. These actions are necessary to adapt the school practice to the needs of students who are exposed to an intense flow of globalized information, available on digital platforms (Macambira et al., 2013).

The preparation of practical activities at school allows the teacher in training the chance to develop works that place him as the author of teaching practice when experimenting with different educational methodologies and tools (Gatti *et al.*, 2011). The use of modeling clay as a strategy for teaching biology is a tool capable of improving understanding and knowledge retention since it allows the student to build experience while builds an explanatory model for the content that was presented before (Jorge et al., 2017).

This work aimed to explore how concepts involved in the transmission of hereditary characteristics are interpreted, before and after using modeling clay, as an educational tool for the exposure of the content and construction of knowledge. For this purpose, a practical activity was applied to Brazilian students of the 3rd year of high school

Methodology

Diagnosis of previous knowledge and evaluation

First, to measure the activity's effectiveness , a quantitative assessment was made through the application of a questionnaire (figure 1.) before and after the activity was carried out with 56 students from three different classes: 3A, 3B, and 3C. Expository classes on the subjects covered had already been given in the traditional model. The questionnaire assessed students' understanding of the concepts of genotype and phenotype (Q1), dominance and recessivity (Q2), homozygous and heterozygous (Q3), parental and filial generation (Q4), understanding of Mendel's experimental methods (Q5), and the ability to contextualize the content covered (Q6). The analysis of the questionnaire was made by categorizing the responses as correctly delimited the concept (CDC), had difficulty expressing the concept (DEC), did not delimit the concept (NDC), and did not know how to answer (NKA).

QUESTIONNAIRE ON KNOWLEDGE IN GENETICS

PIBID Biology - August 2017

1- What is a genotype? And a phenotype, do you know what that term means?

2- What does it mean to say that one gene is dominant and another is recessive?

3- What do the terms "homozygous" and "heterozygous" mean?

4- Do you know what Mendel did in his experiments on Genetics?

5- When we say that the crossing between two parents leads to an F1 generation, what do you understand about that?

6- What do you learn in Genetics classes that you can apply in your daily life?

Figure 1. Diagnostic questionnaire applied before and after the practical activity “Genetiquinhos”.

Practical activity study guide

The activity “Genetiquinhos” was based on the work of Vilela, 2007 and proposed to the students of the 3rd year classes to create a fictional species made with modeling clay, so that, from the “mating” of individuals of this species, students could analyze the transmission of characters and determine the genotypes and phenotypes expressed in the filial generations. The characteristics analyzed were the body texture: smooth or with lumps, and the type of antenna: long or short. Using a combinations of these characteristics was proposed to students who initially created two individuals from the fictitious species. Then students made “matings” of created individuals mixing the traits in the “offspring”. Finally, students set up explanatory panels pointing out the genotypes assigned to each modeled phenotype. In this practice, Mendel's first law was considered for independent segregation of studied characteristics.

Results and discussion

Students were instructed to create models with modeling clay that represented the “mating” of a parental generation (P) formed by double homozygous recessive individuals (figure 2.A.), that is, individuals with aabb genotype and phenotype characterized by antennae short and smooth body. The second suggestion of “mating” was formed by a double homozygous dominant individual (AABB) that has long antennae and a protruding body and a double recessive homozygous individual. Their respective F1 generations and Punnet’s Board were also used to summarize the “crossings” (figure 2.B).

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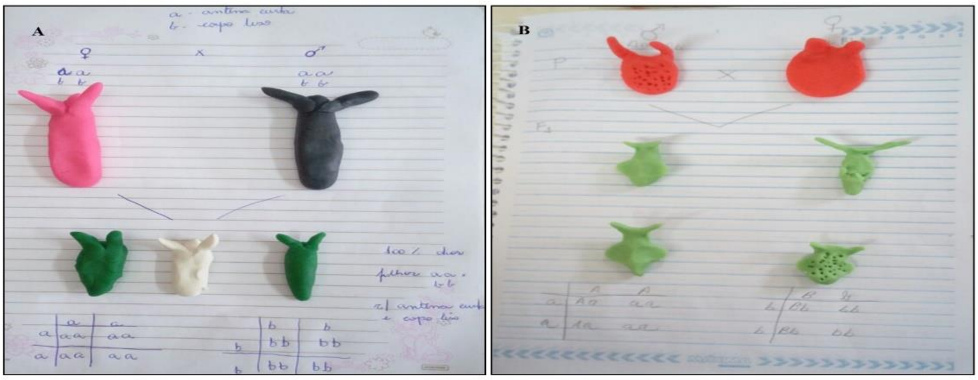

Figure 2. Representative photographs of the “matings” proposed in the practical activity. “Mating” between a homozygous recessive individual with another homozygous recessive individual for antenna size (aa) and body texture (bb) resulting in branch generation with double recessive genotype (A). “Mating” between a dominant homozygous individual for antenna size (AA) and body texture (BB) with another recessive homozygous individual resulting in filial generation with Mendelian pattern genotypes.

When we compared the questionnaire answers applied before the activity it was possible to perceive in general that the percentage of students who knew how to define the concept correctly (CDC) increased in all the questions. Students percentage who had difficulty expressing the concept in writing (DEC) decreased, the percentage of students who did not know how to define the concept (NDC) increased, and the rate of students who did not know how to answer (NKA) decreased to most issues.

In class A (figure 3.), the student’s percentage which could correctly define the genotype-phenotype concepts (Q1) increased (5% to 20%). Besides, there is an increase (0% to 40%) concerning the concepts of homozygote and heterozygous was observed (Q3). Regarding the understanding of Mendel’s methodology (Q4) there is an increase (0% to 10%) and a increase (10% to 20%) about generations P and F1 (Q5). However, there was a reduction in the amount of students that correctly define dominance and recessivity (Q2) from 5% to 0% and a reduction from 35% to 30% concerning the contextualization of the teaching of genetics (Q6). These data demonstrating that there was a misunderstanding of the topics. The percentage of students who had difficulty expressing the concept increased Q1 (20% to 40%) in, Q2 (30% to 70%) and Q5 (5% to 50%). However, there are a decreased in Q3 (30% to 20%), in Q4 (10% to 0%) and did not change in Q6. The percentage of students who did not know how to define the concept in Q4 increased from 5% to 10% and decreased in Q1 (from 25% to 20%), in Q2 (from 25% to 10%), in Q3 (from 35% to 10%), in Q5 (from 20 % to 10%) and Q6 did not change. The percentage of students who did not answer decreased in Q1 (50% to 20%), Q2, (40% to 30%) and Q5 (65% to 30%). In the other hand, it increased in Q3 from 35% to 40%, from 85% to 90% in Q4 and 65% to 80% in Q6.

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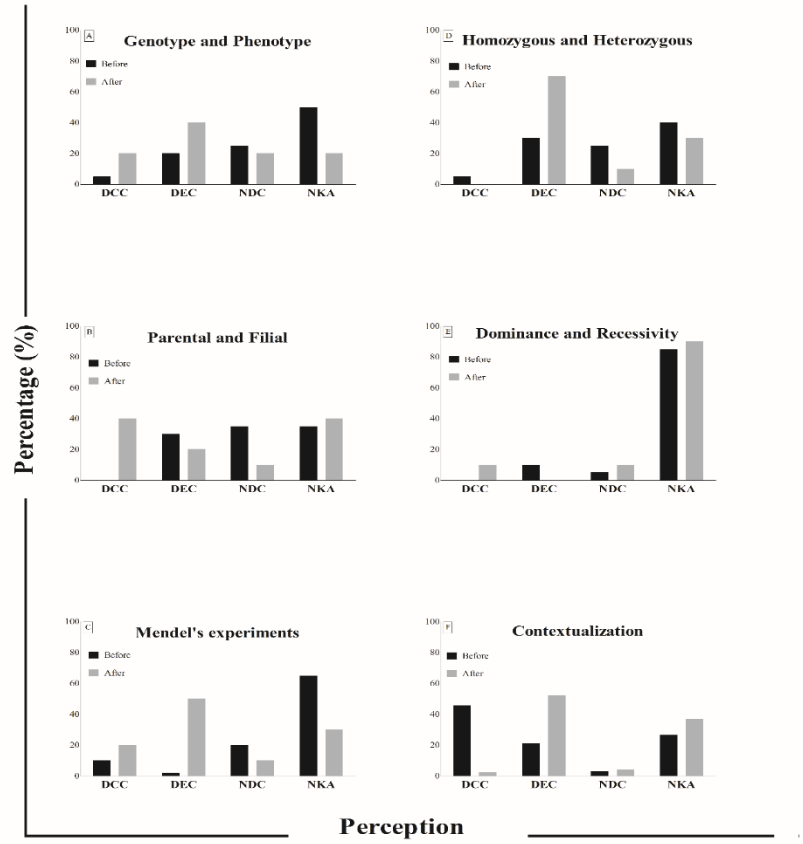

Figure 3. Diagnosis of previous knowledge and the variation in the percentage of students in 3A who demonstrated a change in perception about concepts related to heredity after practical activity: Genotype and phenotype (A); Parental and subsidiary (B); Methods used by Mendel (C); Homozygous and Heterozygous (D); Dominant and recessive (E); Context of teaching genetics (F).

In class B (figure 4.) the percentage of students who knew how to define the concepts of genotype and phenotype correctly decreased from 5.8% to 0%. However, it increased for the concepts of dominant/recessive, heterozygous/homozygous, parental, and filial generations and daily application of knowledge in genetics from 5.8% to 16.6%, from 5.8% to 16.6%, from 5.8% to 33.3%, and from 29.4% to 50% respectively. The percentage of students who had difficulty expressing the concept decreased in Q1 (17.4% to 16.6%), Q2 (17.4% to 16.6%), Q3, (11.6 to 0%), Q4, (11.6% to 0%), and Q5 (5.8% to 0%)and in Q6 did not change. The percentage of students who did not know how to define the concept decreased for Q1 (23.2% to 3.2%) and Q3 (34.6% to 3.2%), increased in Q2 (from 29% to 66.6%), in Q4 (0% to 16.6%) and in Q5 (29% to 50%).There was no difficulty in defining the concept for Q6 either before or after practice and the percentage of students who did not know how to answer decreased in Q1 (52.2% to 50 %), Q2 (46.4 to 0%), in Q4 (87% to 83%), in Q5 (58% to 16%) and Q6 (69.9% to 50%), but increased for Q3 (46.4% to 50%).

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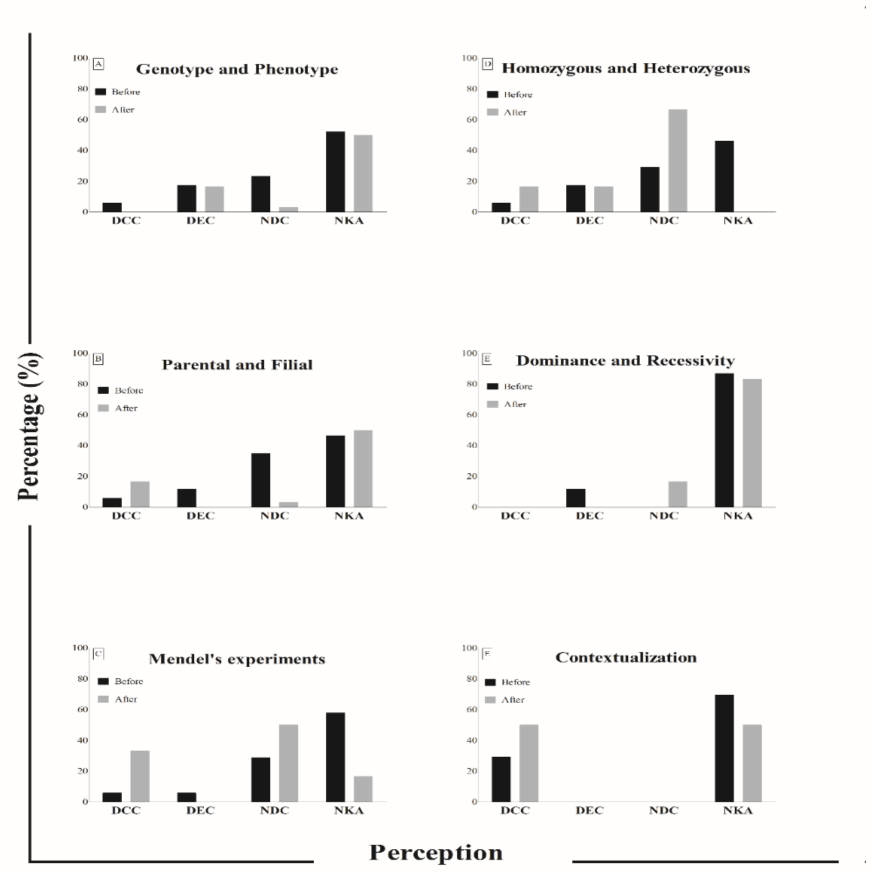

Figure 4. Diagnosis of previous knowledge and the variation in the percentage of students at 3B who demonstrated a change in perception about concepts related to heredity after practical activity: Genotype and phenotype (A); Parental and subsidiary (B); Methods used by Mendel (C); Homozygous and Heterozygous (D); Dominant and recessive (E); Context of teaching genetics (F).

In class C (figure 5.) the percentage of students who knew how to define the concept correctly increased in Q1, Q2, Q3, Q4, Q5, and Q6 (15% to 50%, 5% to 40%, 20% to 40%, 5% to 50%, 10% to 20% and 45% to 70%, respectively). The percentage of students who showed difficulty in expressing the concept increased in Q1 (10% to 30%), in Q2 (20% to 40%), in Q3 (20% to 30%), in Q5 (5% to 40%) but decreased in Q4 (15% to 0%). There were no students with difficulty either before or after practice about Q6. The percentage of students who did not know how to define the concept did not change in Q3, Q4, and Q6. There was a reduction in Q1 (25% to 10%), in Q2 (35% to 20%) and in Q5 (20% to 10%). The percentage of students who did not know how to answer decreased in Q1, Q2, Q3, Q4, Q5, and Q6 (45% to 10%, 35% to 0%, 35% to 10%, 75% to 50%, 60% to 30% and 50% to 30%, respectively).

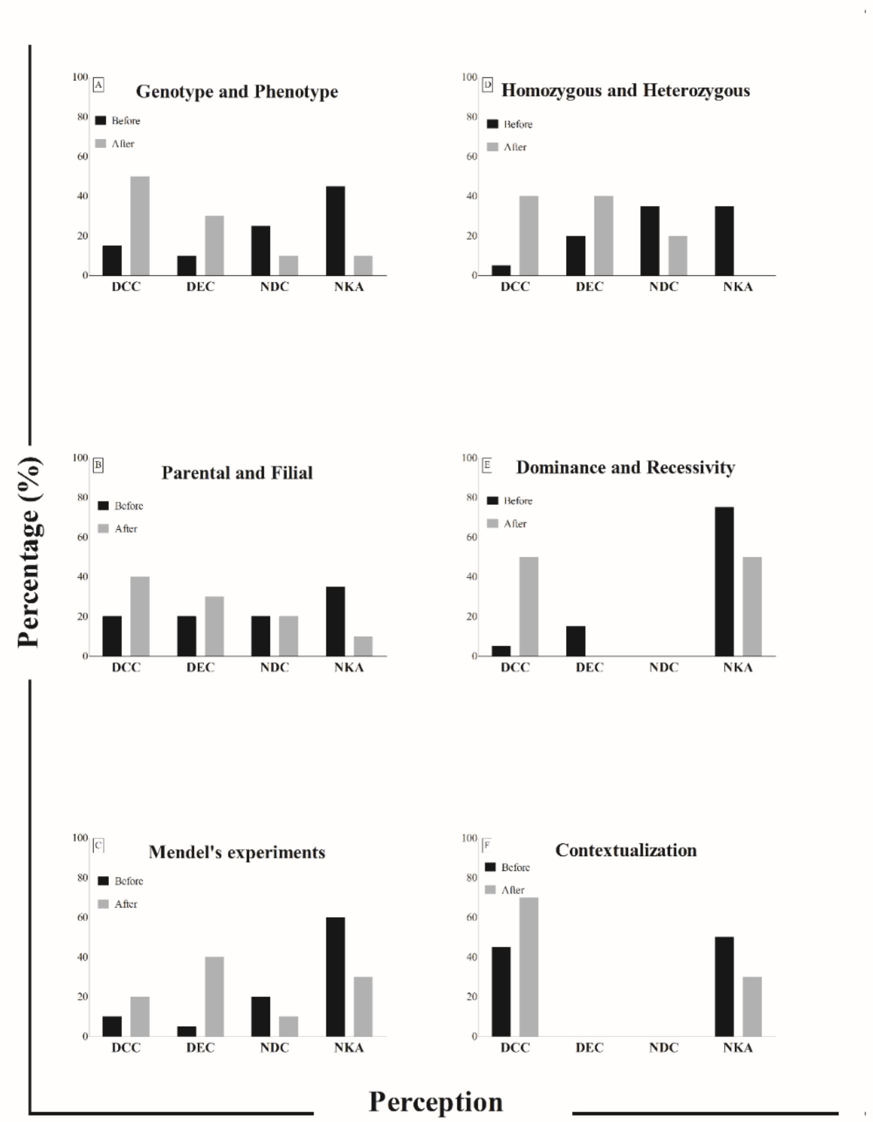

Figure 5. Diagnosis of previous knowledge and the variation in the percentage of 3C students who demonstrated a change in perception about concepts related to heredity after practical activity: Genotype and phenotype (A); Parental and subsidiary (B); Methods used by Mendel (C); Homozygous and Heterozygous (D); Dominant and recessive (E); Context of teaching genetics (F).

Our results demonstrate that the practical activity with modeling clay could generate changes of perception in the students, mainly about the concepts of genotype and phenotype. This improvement can be due to the contextualization of genetic concepts. It became palpable to students when the genotype, which until then only lettered in the notebook, is now expressed as a physical form built with modeling clay, that is, after all, a phenotype. The construction of models for varied phenotypes can be considered an active teaching methodology since the conception of the idea and materialization of it is carried out entirely by the student from his previous concepts (Diesel et al., 2017).

The other concepts covered in this activity require abstraction for learning. Ideas such as the genome' structural organization, the relationship with molecular mechanisms, and applications of this knowledge in everyday life were also worked in parallel during the practice in an expository way. However, since there is no materialization, it is noticed that there is a change in perception, which is not always positive (Pio et al., 2014).

Science education plays a fundamental role in a society in terms of decision making by the public authorities, in addition to assisting students in choosing a university course (Quint and Amaral, 2020). Scientific literacy is essential for the population to be able to critically position themselves both personally and socially, and foster the current productive chain (Zudaire and Fraile, 2020). Students get in contact with an expressive amount of information on the classroom topics in a short period. However, the incorrect content available in the media can create an obstacle to formal education (BOWLING et al., 2008; Donovan and Venville, 2014).

The traditional teaching of genetics are conducted by lecture classes that are usually based on textbooks and the resolution of questions regarding the content explained (Banet and Ayuso, 2000). Literature reports address this strategy' inefficiency for teaching about the transmission of characteristics (Hernández et al., 1995).

High school students are often faced with situations where they absorb isolated knowledge and have difficulty understanding basic concepts in genetics (e.g. the relationship between gene and protein). This approach requires the student to understand and relate different levels of biological organization, which highlights the failure generated by didactic transposition when it comes to the concepts associated to molecular biology (Heemann and Hammann, 2020).

Several factors influence the teaching-learning process. Student's previous knowledge is of fundamental importance for meaningful learning (Gomes, 2010). However, common sense can become an obstacle when formal education is not able to generate a change in the perception of that concept by the student. In this case, the student can confuse concepts even after performing a formal instruction (Lewis and Kattmann, 2004).

Teaching genetics is marked by the diversity of content on the topic available on the most varied media platforms, which opens the opportunity to work on this topic critically and with context to the student's daily life. However, teachers traditionally adopted the teaching methodologies focus mainly on preparing for the selection exams for entry into higher education, which makes the dynamics of the teaching-learning process fastidious, decontextualized, and inefficient (Mascarenhas et al., 2016).

In addition to the competition with journalisticand social media, the primary education biology curriculum presents the contents of genetics in a simplified way. Due this difficult for students understand abstract concepts related to molecular mechanisms (e.g. gene and epigenetic expression), since these are complex concepts. Also, the construction of skills in this field of knowledge is usually associated with contact with technological devices and practical activities that are generally not available in public schools (Dougherty 2009; Schneider et al., 2011; Quint and Amaral 2020).

Practical activities are a tool that helps in the consolidation of concepts considered difficult by students, such as the hereditary transmission of characters. Incorporating of artistic activities and games in the construction of didactic models allows the teaching-learning process to playfully and more efficiently (Martinez et al., 2008).

Modeling clay is a synesthetic tool that improves vocabulary acquisition by students. It provides students with an understanding of microscopic components by stimulating creativity and sensory perception of abstract concepts (Bailey, 2019). This tool was able to promote the active participation of students in the construction of an explanatory model for the subjects covered, generating changes in their perception by combining a dynamic methodology with theoretical knowledge.

Teaching is a form of social practice that involves multiple actors in different times and contexts, being based on pedagogical knowledge. It is a complex practice that consists of the relationship between student-teacher and knowledge. Their actions involve an exchange between theoretical knowledge that serves as a guide for daily actions and receives the student's reactions. The teacher puts theoretical knowledge into practice and observes the results of these practices. Their insights are used as a guide for decision making and planning. The theory itself cannot generate real change in the world, just as mechanistic practice and without conscience is also not enough to generate material changes (Caldeira and Zaidan, 2013). In this sense, teaching activity experiences *praxis* by appropriating a theoretical framework residing in the plane of ideas and applying it in the classroom, intending to provide a change in the students' perception of reality. (Sánchez Vázquez, 1977).

These relationships are due to the social aspect in which the school is located. In the Marxist perspective, *praxis* is configured as a grouping of thoughts and actions that have the purpose of generating some change in the material world. All of these issues must be considered within a social class cutting. It is necessary to reflect on the purpose of teaching as an instrument for generating labor for the market and reproducing class society. (Gruner, 2007).

In this way, pedagogical *praxis* breaks the paradigm that teaching must be based and supported only by formal theoretical knowledge that places the student as a receptacle of knowledge and the teacher as the depositor source. The practice is guided by theoretical knowledge and the theory changes as it is applied to everyday life, to abolish the alienation from ignorance (Freire, 2011).

In this context, the *praxis* process is evident in our work when combining the active methodology applied in the construction of a genotype model expressing phenotype, with the oral exposure of the theoretical concept, generated a change in students' perception. This change in perception was heterogeneous and we observed that the ideas that could be directly addressed with the use of modeling clay succeeded in an improved way. The concepts that depended on the expository approach for reinforcement, on the other hand, were carried out neutrally or even generating inaccuracy in some points. The change in genetic perception on the part of the student causes a difference in the totality of his reality (Caldeira and Zaidan, 2013). Thus we see the direct action of the pedagogical praxis in the cutout of the application of the practical activity.

Final considerations

At the end of the process, it was possible to observe an improvement in the understanding of the content. The practice also made it possible to diagnose a pronounced difficulty in expressing thoughts in writing and the assimilation of the experimental method and its relationship with the studied concepts. There is still an existing barrier when it comes to applying the knowledge addressed in the classroom in everyday life. This active methodology proved to be useful both to facilitate learning and to evaluate the points to be reinforced, in addition to allowing pedagogical *praxis* in the context of a Brazilian public school participating in PIBID.

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