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Evocation of metacognitive thinking to teaching biology with mathematical concepts

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ABSTRACT

The objective of this article is to problematize the conceptions and experiences of high school students at a State school in the municipality of Rubim/MG regarding the development of Biology classes with the application of mathematical concepts and evocation of students' metacognitive thinking. The research was qualitative with principles of Design-Based Research (DBR), combined with the assumptions of phenomenology advocated by Gil (2008). Content Analysis proposed by Bardin (2016) was used to study the written productions in the development of a didactic sequence. Recorded expressions and discursive responses, that is, communications, were considered to describe the content of the messages and indicators (quantitative or not). The results show that mathematical applications in the teaching of Biology with the evocation of metacognitive thinking in high school can provide students with an understanding of the connections between Mathematics and biological phenomena, empowering them to make informed judgments about their studies, promoting creativity, and reflecting on the process of learning to learn.

KEYWORDS: Metacognition; Teaching Biology; Mathematical knowledge.

Evocação do pensamento metacognitivo no ensino de biologia com conceitos matemáticos

RESUMO

O objetivo deste artigo é problematizar as concepções e vivências de estudantes do Ensino Médio de uma escola Estadual do município de Rubim/MG, quanto ao desenvolvimento de aulas de Biologia com aplicação de conceitos matemáticos e evocação do pensamento metacognitivo dos estudantes. A pesquisa foi qualitativa com princípios da *Design-Based Research* (DBR), combinada com os pressupostos da fenomenologia preconizados por Gil (2008). Utilizou-se Análise de Conteúdo proposta por Bardin (2016) para estudo das produções escritas no desenvolvimento de uma sequência didática. Considerou-se as expressões gravadas e as respostas discursivas, ou seja, as comunicações, para descrever o conteúdo das mensagens e indicadores (quantitativos ou não). Os resultados trazem que as aplicações matemáticas no ensino de Biologia com evocação do pensamento metacognitivo no Ensino Médio podem proporcionar aos estudantes uma compreensão das conexões entre a Matemática e os fenômenos biológicos, capacitando-os a fazer julgamentos fundamentados sobre seus estudos, promovendo a criatividade e a reflexão do processo de aprender a aprender.

PALAVRAS-CHAVE: Metacognição; Ensino de Biologia; Conhecimento matemático.

INTRODUCTION

Educational contexts undergo transformations that refer to thinking about educational practices. In this perspective, it is necessary to pay attention to the methodologies that are used in the teaching and learning processes. Within this thought one can highlight the ways of teaching and the ways students learn to learn, which leads to thinking in metacognition or evocation of metacognitive thinking. According to Xavier, Peixoto and Veiga (2021), metacognition can be understood as an educational technology that can be used to act in the stimulation of consciousness and management of cognitive processes, autonomy of the learner for the pursuit of appreciation, both the teaching process and the learning process.

Rosa and Meneses Villagrá (2018) emphasize that metacognition can be beneficial to learning, when it allows students to regulate and control their thinking, because not all subjects can evoke it spontaneously, requiring explicit situations for this. Considering this premise, we perceive the relevance of activities for the study of Biology in High School, with the possibility of provoking students to evoke metacognitive thoughts.

Thus, we sought to answer which aspects of the conceptions and experiences of high school students that may be important when using the evocation of metacognitive thinking to study biology, with application of mathematical concepts. In this bias, this article proposes to report aspects of the conceptions and experiences of high school students from a state school in the city of Rubim/MG, related to the development of part of a didactic sequence (DS) with activities for the teaching of Biology, which require the application of mathematical concepts. In addition, it is intended to present situations that were observed, analyzed and interpreted from the perspective of metacognition.

THEORETICAL FRAMEWORK

Thinking about strategies aimed at the qualification of teaching and learning processes, the use of metacognition, that is, the promotion of possibilities for evocation of metacognitive thinking by students, has been shown to be relevant, according to different studies. According to Santos and Rosa (2021, p. 4),

> operationalization in an educational context, we found that the understanding of metacognition has been marked from two components and their respective metacognitive elements: knowledge of knowledge (metacognitive knowledge), involving the variables person, task and strategy; executive control and self-regulator (metacognitive skills), related to planning, monitoring and evaluation. This understanding, which brings the metacognitive experiences as an aspect that runs through the two components mentioned, has subsidized research aimed at qualifying the learning process in science.

According to Xavier, Peixoto and Veiga (2021), even research pointing out that there is an understanding of the metacognitive phenomenon, and for the expansion of its borders, little progress is still perceived about favoring the work of the teacher in the classroom. In this context, the proposals that problematize this idea are relevant.

It is known that there are several thoughts to conceptualize metacognition. Regarding this, the first records were presented by John Flavell in the 70's and refer to the thoughts and knowledge that individuals have about their own cognitive processes and the ability to control these processes, organizing, monitoring and modifying them to achieve concrete goals (Sousa *et al.*, 2019). As explained by Santos and Rosa (2021), metacognition involves the knowledge that the subject has about his own knowledge and the capacity given to the processes of regulation of executive control.

Certainly, these concepts may seem treated in the same way, however, it is noted that there are differences in understanding the term metacognition. According to Rosa and Schmitz (2020), this comes from the lack of theoretical reference capable of giving sustainability to the definition, especially in the field of Education. For the authors, such differences are due to the approximations made by the authors when using the term. It is in the approach to different areas that the authors end up employing elements that promote various possibilities of definitions to this construct. Therefore, for the work in question, the idea of Rosa (2014) was followed to support the concept from what was collected and analyzed in the intervention. Thus, in general, it refers to the ability to reflect on a specific task such as calculating, thinking, deciding, selecting and using the best method to solve this task.

Considering this, it is observed how important it is to consider in the teaching work the use of activities that bring in themselves the possibility of resorting to metacognition, rather, to metacognitive thoughts. According to Rosa and Meneses Villagrá (2020, p. 62), "it is promising to think of strategies that can be used by teachers and, consequently, activities oriented to students, aiming at a self-knowledge in the way they teach and, respectively, how they learn to learn".

According to Rosa and Meneses Villagrá (2020), metacognition can be associated with the subject's awareness of his own thoughts, that is, it is a thinking about thinking. For Xavier, Peixoto and Veiga (2021, p. 6), "metacognition is a broad term, used to describe the knowledge we build about how we perceive, remember, think and act, under different aspects". These authors also report that it is the ability to know what we know. Thus, it is understood that the strategies used in the classroom need to be rethought. For Cleophas and Francisco (2018), it is important to think of strategies that can be used by teachers with activities for students, to promote self-knowledge and reflection on how to learn. In this idea, the authors bring the perspective that metacognitive strategies should be incorporated by teachers and students at all educational levels.

> For the teacher, this incorporation can be intentional, if he knows the benefits of metacognition, and for the student, it would be the result of the teacher's metacognitive apprehension with a view to the student's self-regulated learning (Cleophas & Francisco, 2018, p. 11).

Xavier, Peixoto and Veiga (2021) emphasize that the use of any strategy in the classroom, needs to start from the principle of the need to transpose a scientific knowledge, to some knowledge to be taught, that is, school knowledge. Thus, it is important to understand the metacognitive processes that, according to Cleophas and Francisco (2018), are those that allow teachers to identify and evaluate the best teaching strategies that promote more lasting learning and produce more effective results in their teaching actions.

Also according to Xavier, Peixoto and Veiga (2021), metacognition in the form of metacognitive strategies can be classified as a learning strategy when the focus of teaching is student-centered. Its role as a teaching tool is designed to facilitate the use, storage and research of information for students. Thus, it promotes in the learner an understanding of the monitoring, regulation and planning of the mind itself. This influences the learning process in a way that stores this knowledge, leading learners to self-knowledge about their own learning process.

Corroborating with this thought, Sousa *et al.* (2019) argue that metacognitive learning strategies are actions and means by which the subject resorts and that influence the acquisition and use of knowledge through activation, control and regulation of cognitive processes. In this bias, it is understood that the role of the teacher is fundamental. Thus, when thinking about organizing activities for the classroom, the teacher needs to seek to plan and develop activities with the possibility of instigating curiosity, motivation, reasoning and interest, linking the contents to their process of knowledge construction. In addition,

> the teacher should stimulate the control and regulation of cognitive processes related to learning, so that students are able to reconstruct knowledge, think, plan, monitor and evaluate their own thoughts, during the processing of information [...](Sousa *et al.*, 2019, p. 203).

Therefore, if there is in the classroom the possibility of students using their metacognitive thoughts, there may be construction or reconstruction of knowledge. It is worth remembering that it is necessary to consider that studies involving the use of metacognition associated with didactic strategies have found problems, because it is necessary to understand their definition, specification of objectives and approximations peculiar to the areas of study, so that by evoking their thoughts students can use them to regulate their learning.

PATHS TRAVELLED

In this article we report the conceptions and experiences of high school students from a state school in the city of Rubim/MG, related to the development of a didactic sequence (DS) that was an educational product developed in the Post-graduate Program Stricto Sensu Graduation in Teaching of Exact Sciences, from an institution in Rio Grande do Sul, in which the first author conducted the research.

The DS to which it refers was organized in accordance with the perspective of Design-Based Research (DBR), considering the elements: teacher, students, material world and scientific knowledge (Kneubil & Pietrocola, 2017). It also considered the epistemic dimension related to the scientific contents of the DS, the problems arising from the material world that based the scientific practice and the historical context. For the pedagogical dimension was considered the aspects related to the role of the teacher, the interactions between teacher-student and student-student. It was also considered the elaboration processes, methods and validation of scientific knowledge and its significance with the real world. It is emphasized that each dimension consisted of one iteration.

The DS was organized into two blocks of activities for teaching Biology. Thus, this text reports on the activities of Unit 2, which was called the Genetic Equilibrium – Hardy-Weinberg principle, in which each class was identified as follows: Class 1 - Conjectural population – Calculating balance; Lesson 2 - If there is panmixis in the population, Hardy-Weinberg to calculate frequencies; Lesson 3 - *Pan miscere* – Crossing of different genotypes. As the research focuses on teaching Biology mediated by mathematical concepts, the activities described here direct to aspects of Biology that require the use of calculations to be studied in high school.

The proposed approach was from the perspective of qualitative research and principles of DBR. To follow the principles of DBR, we sought to develop practical applications and solutions explicitly focused on the practice and innovation of pedagogical praxis (Matta *et al.*, 2014). The development of activities was guided by design principles and methods based on theory to be validated through research and to offer tangible contributions to teaching practice (Nicholson, 2021). In addition, the interventionist character of the DBR was considered, since it makes it possible to intervene in the field of pedagogical praxis to produce an educational product as didactic material; for bringing condition to validate the results of the whole process collaboratively; the iterative character that is based on cycles of study, analysis, projection, application, results to be recycled later, when necessary and possible (Matta *et al.*, 2014 & Amaral, 2019).

As the DBR approach brings the possibility of combining theories, it was also used the perspective of phenomenological qualitative research advocated by Gil (2008). Thus, it was concerned to show and clarify what was observed, that is, the reality was understood, interpreted and communicated by the students participating in the intervention.

For the analysis, we used the approach with the Content Analysis proposed by Bardin (2016). Thus, it was considered the expressions of the students, answers to the discursive questions, that is, their communications to describe the content of the messages, indicators (quantitative or not) that allowed the inference of knowledge related to the conditions of reception/production (inferred variables) of these messages. The communications of the students were recorded and interpreted from the recordings made and the discursive responses presented by them in the activities. The figures and graphs shown in this article were those selected to elucidate the record of the research developed with the said Graduate Program. Thus, this text presents the ideas that were originated from the observations and interpretations performed in the development of the tasks proposed by the teacher to the students.

The work involving the activities occurred with the students organized in groups. In this text, to preserve the anonymity of the students, it is only brought as identification the group of which the mentioned student was part, with the indicative G1, G2, G3, G4 and G5. For the work with the students, it was followed seeking to streamline the classes giving possibility and opportunity of evocation of metacognitive thinking, through questioning and instigating mediation for reflection of the learning process. The students' activities were collected to analyze the development of each class that were recorded and interpreted as reported in this article.

RESULTS AND DISCUSSION

In the development of the activities of the classes in description, a mediation was carried out so that the students could proceed with the previous studies of the DS, which had already occurred. Thus, in Class 1 of Block 2 of the activities of the DS, with the name of Conjectural Population - Calculating balance, we used concept maps (CM) to assist in the discussions and understandings of students about the relationship of Mathematics with Biology in the study of the Hardy-Weinberg Principle.

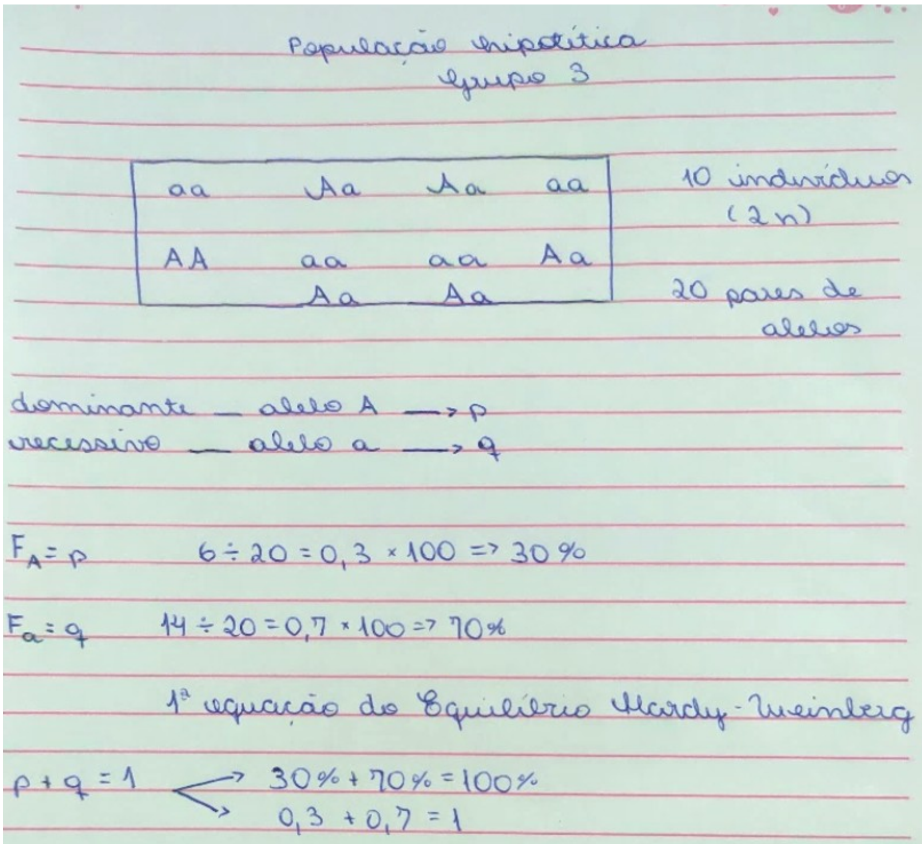
The researchers, Paulo Neto and Macedo (2023), affirm that the use of CM as an evaluative instrument plays a relevant role in the educational process, providing a visual and structured approach to the representation of students' knowledge. Thus, the concept maps used were elaborated to streamline the class. Thus, the maps themselves brought links to access images, formulas and videos, which helped in the discussions.

As the objective of Lesson 1 was to promote the understanding of the central idea of the Hardy-Weinberg Principle and its mathematical applicability, it was proposed the creation of a hypothetical population represented by 10 pairs of alleles, which was performed from the creativity of the students in the groups. The students answered the question of how many alleles there were in the population represented and, to answer the frequency of the alleles, it was suggested that they consider the frequency (gene) of the allele A (p) and a (q), thinking of dominance and recessivity, to demonstrate the 1st equation of the principle cited.

At first, the students asked themselves about how to make the representation. In this context, there was a mediation instigating thinking about mathematics. He directed them to think about frequency and that the average could be calculated. Thus, the students understood and calculated the average frequencies of the alleles of the populations they represented with their respective percentages. Thus, they understood and wrote the 1st equation of the Hardy-Weinberg Principle which is $p + q = 1$, as exemplified in Figure 1.

Figure 1

Demonstration of the 1st equation of the Hardy-Weinberg Principle performed by the students, from a hypothetical population



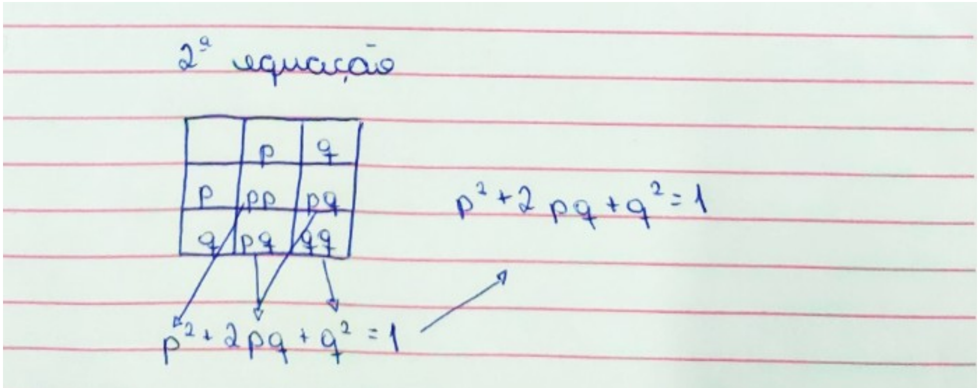
Source: From the author's archive (2022).

In the analysis, the fundamentals of the concept of metacognition presented by Rosa (2014) and the Content Analysis suggested by Bardin (2016) were considered. Therefore, it was interpreted that when students questioned how they could make the representation shown in Figure 1, they were evoking metacognitive thinking. It was also understood that they were reflecting on the task and planning its execution when they argued, "You have to add what we find to p and to q... do you think you need to put the percentage of the alleles? Ah! Let's put... (G3)". In line with the ideas of Rosa (2014), metacognitive questions are considered orientative for reflection in the proposal under study, and motivation is also a significant aspect. In this sense, the oral exhibition can allow colleagues to reflect on the way of thinking of the one who exposes it, pointing out revisions, confrontation of results (Rosa, 2014). This represents the possibility of consolidating a learning qualification process.

Following for the execution of the second part of the task, for the comprehension of the students, in a way that they could use the previous knowledge, it was instigated for them to think about genetic crosses and to use the Punnett Framework. All groups were able to complete the task. It was noticed that they understood how the generation of the 2nd equation of the Hardy-Weinberg Principle occurs, as in Figure 2. However, when asked to think what mathematical application the equation was associated with, none of the groups was able to realize that it is based on the concept of Remarkable Products. However, when explaining and questioning the group with the idea of this concept, some students mentioned aspects about it. It was understood that the students' speeches on the subject favored the conditions to evoke metacognitive thinking.

Figure 2

2nd equation of the Hardy-Weinberg Principle generated by the research students



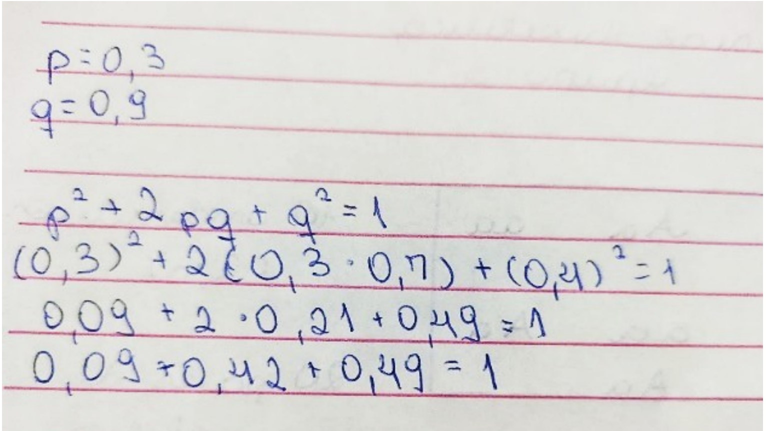
Source: From the author's archive (2022).

According to Rosa and Rosa (2016), when there is the possibility of the insertion of explicit moments of evocation of metacognitive thinking, together with the development of group work, students resort to this way of thinking and develop the ability to self-regulate learning, which manifests itself as an ability to plan mental activities. For Nora; Broietti and Corrêa (2021, p. 71), "from the moment we identify the best cognitive strategies for you, we achieve awareness, which is a metacognitive exercise".

In Lesson 2 of Unit 2, with the title: If there is panmixia in the population, Hardy-Weinberg to calculate frequencies, was a continuity of the activities related to the hypothetical population that the students created and had previously performed a task with the information. To continue with the study, they were asked to calculate the genotypic frequency of the population's alleles, using the mathematical application of the Hardy-Weinberg principle equation (Figure 3).

Figure 3

Mathematical application of the Hardy-Weinberg principle equation performed by students



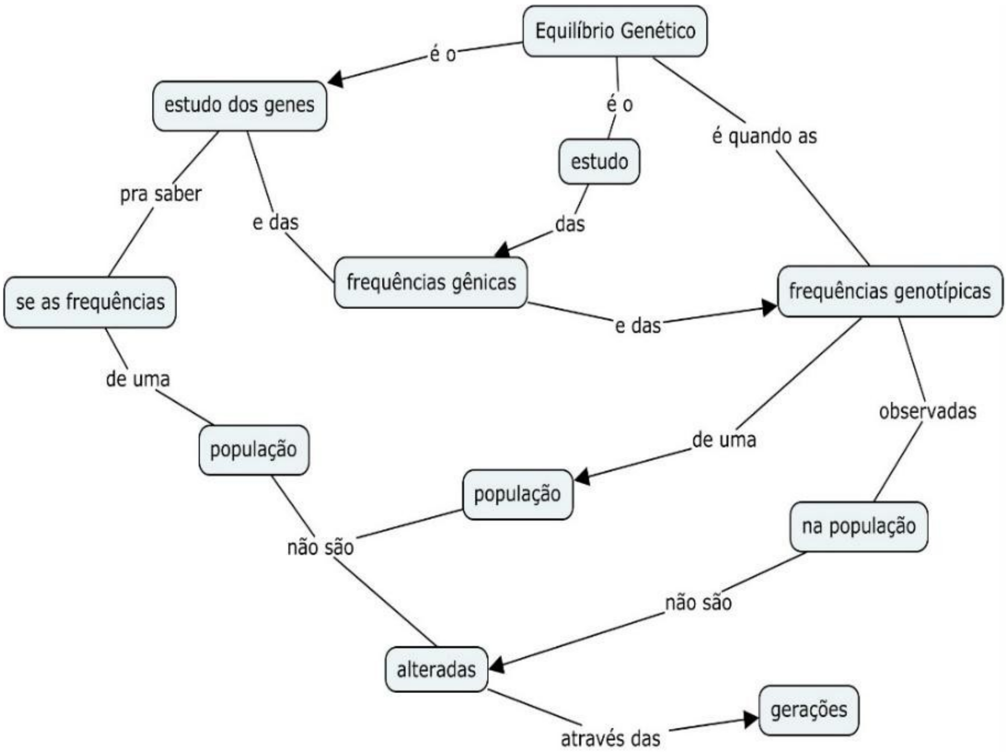
Source: From the author's archive (2022).

In this task pointed out in Figure 3, all groups were able to perform the calculation and complete the activity establishing a relationship with the equation that was elaborated in the previous activity, when they used the Punnett Chart. This led to the belief that they had understood the foundation of this mathematical application. And, seeking to encourage students to express themselves about the study they performed, it was proposed that they elaborate a conceptual map (Figure 4) from the question: "What did I learn about genetic balance using the Hardy-Weinberg Principle?"

It is emphasized that the conceptual map presented to elucidate was transcribed using the Cmap Tools tool for better visualization and understanding.

Figure 4

Concept map prepared by G1 students



Source: From the author's archive (2022).

By representation, the CM highlights how the student architect his knowledge about the content studied (Paulo Neto & Macedo, 2023). It was noted that the students were able to show in the MC the central ideas of the concept of genetic equilibrium related to the Hardy-Weinberg Principle: study of genetic and genotypic frequencies; unchanged genetic and genotypic frequencies in a population; frequencies of unaltered genes across generations. In this bias, it was interpreted that most students knew how to externalize their knowledge satisfactorily, demonstrating a conceptual domain. As stated by Oliveira (2020), the Hardy-Weinberg principle shows that in the absence of evolutionary factors, gene frequencies remain constant in a theoretical population.

It was understood that a simple answer was evident, but that it expressed what was learned. Thus, it seems clear the idea that this tool brings potential to settle the student at the center of the teaching process, with opportunity to act as protagonist of their own learning, that this construction instigates the reflection on their ideas and made it possible to represent them through the conceptual relationship.

After the activity, students were asked to argue about the following question: "Do you feel able to describe what was accomplished and explain the result to others?" In this sense, it was found that a small number of students in the groups did not understand the study to the point of explaining the result they obtained in the activity. In this perspective, it was understood that they placed themselves metacognitive, since they demonstrated that they reflected and performed an evaluation of the learned. In the idea of Nora, Broietti and Corrêa

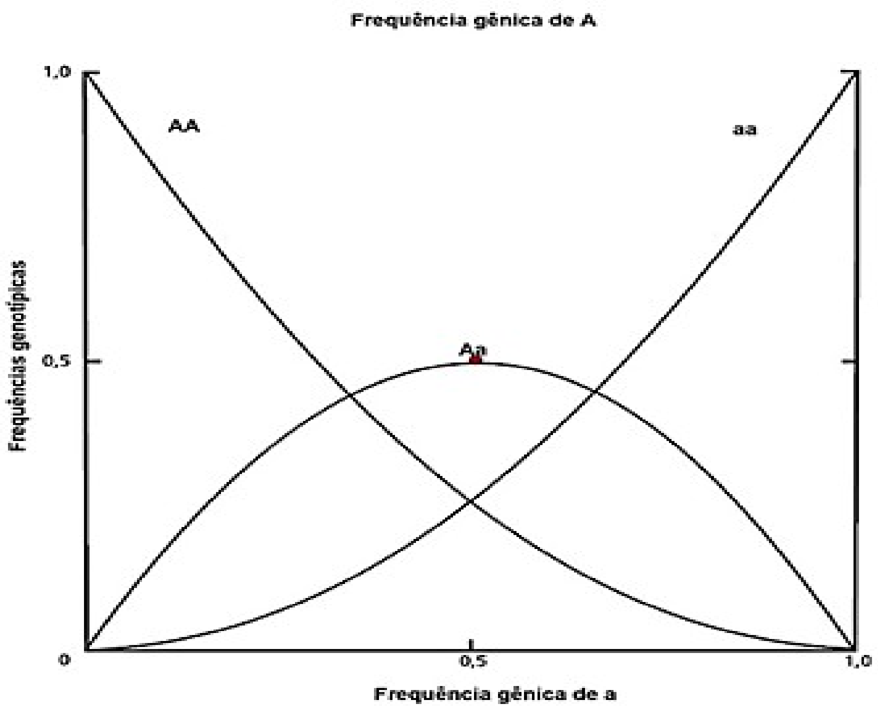
(2021), for a work in the direction of metacognition the teacher needs to mediate and promote self-regulation, enabling students to plan individually, assisting, preparing and monitoring their own activities.

As for Lesson 3, which received the name of *Pan miscere* – Crossing Different Genotypes, the activities followed with the use of mathematical applications with calculations related to the Hardy-Weinberg principle. A priori, the concept of autosomal dominant and recessive genes was discussed. There was a mediation to instigate students to remember that alleles are genes occupying the same locus, that is, the same position in homologous chromosomes, which may be equal or different. It was also sought to mediate for thinking about homozygosis and heterozygosis, associating recessivity and dominance, respectively. The activity consisted of a multiple choice question, but it was necessary to calculate probability and contained the following statement:

The graph (Figure 5) shows the relationships between the frequencies of the alleles A and a, and the genotypic frequencies of AA, Aa and aa of an equilibrium population.

Figure 5

Graphical representation of gene frequency.



Source: From the author's archive (2022).

In an equilibrium population, where crossings occur at random, and the frequency of genes A and a is 50%, for each, the probability of finding individuals AA, Aa and aa is respectively:

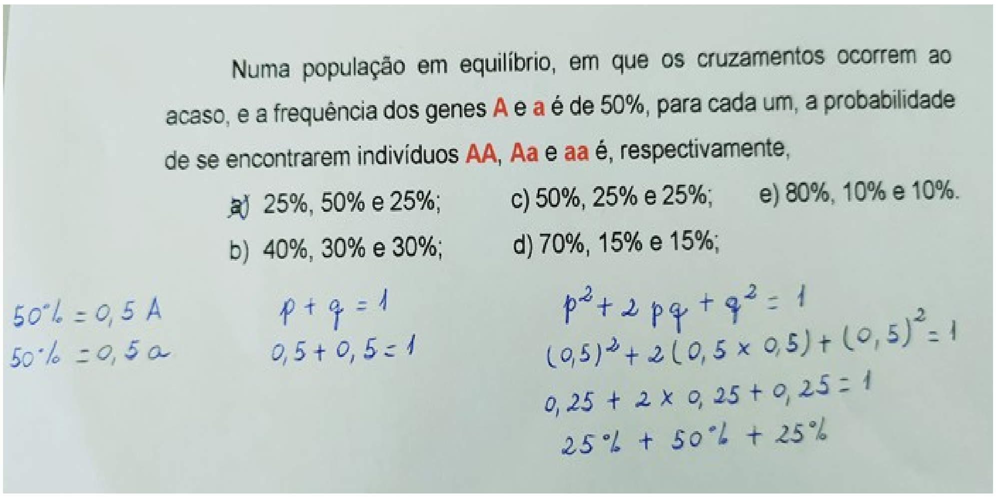
a) 25%, 50% and 25% c) 50%, 25% and 25% e) 80%, 10% and 10%

b) 40%, 30% and 30% d) 70%, 15% and 15%

In this question, the direction was for students to make use of the Hardy-Weinberg equilibrium equation: $p^2 + 2pq + q^2 = 1$. It was observed that the students, at first, were thoughtful and in the group discussions questioned: "Can we? If we use that idea of p + q = 1, will it help to calculate? Let's do... then we see..." By these arguments, it was understood that they were evoking metacognitive thinking. By being instigated, they were able to bring the Hardy-Weinberg principle equation to the solution of the question, as shown in Figure 6.

Figure 6

Application of the equation p2 + 2pq + q2 =1 performed by the student researchers.

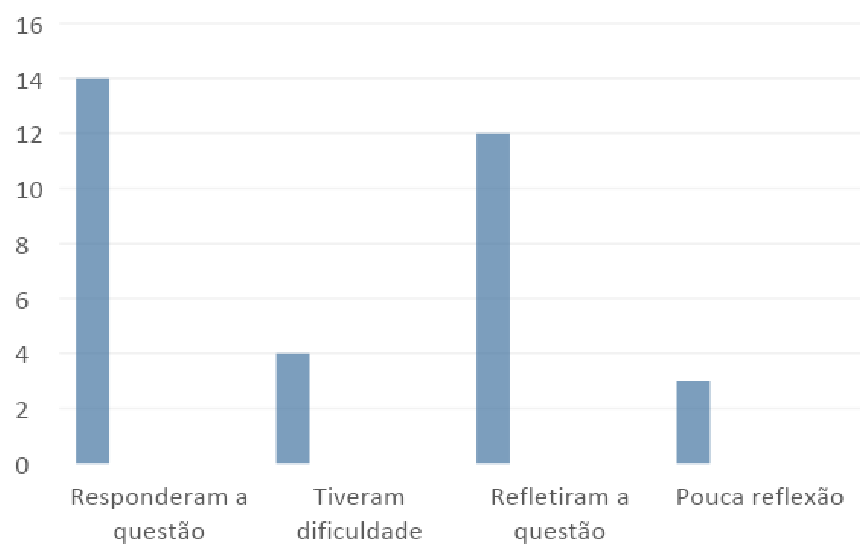


Source: From the author's archive (2022).

For the activity pointed out in Figure 5, only one group was less reflective, according to the observation, however it was found that it was also able to find a solution. It was thus realized that to favor students to succeed, teachers can instigate them to identify their knowledge, as well as control their actions related to a particular task (Gewehr, Stroshchoen & Schuck, 2020). To elucidate, it is demonstrated (Figure 7) how the students were involved in the development of the activity.

Figure 7

Development of the activity with the equation $p^2 + 2pq + q^2 = 1$



Source: From the author (2022).

In the analysis, and as shown in Figure 7, most students were able to perform the calculation and answered the question. It was observed that it was the students who reflected on the question that were able to answer it. However, it was observed that students who reflected little had difficulty completing the calculation. Thus, it was understood that when the student reflects on the task, can raise ideas that help in their learning. When asked whether the graphic and the knowledge they had about the subject favored the development of the activity, most students mentioned that they favored, yes, and explained that the image helped to think to seek the answer to the question. This is in line with the idea of Rosa (2014, p. 18), who says that "metacognitive knowledge can be linked to the student's reflection on their knowledge and their feeling regarding the activity and strategy they should use".

Still in Class 3, a mathematical application was proposed to solve another activity with the statement: "In a certain equilibrium population of Hardy-Weinberg 10,000 children were born; one of these children had a disease, phenylketonuria, determined by an autosomal recessive gene. Calculate the frequency of normal phenotype individuals carrying the phenylketonuria gene in this population".

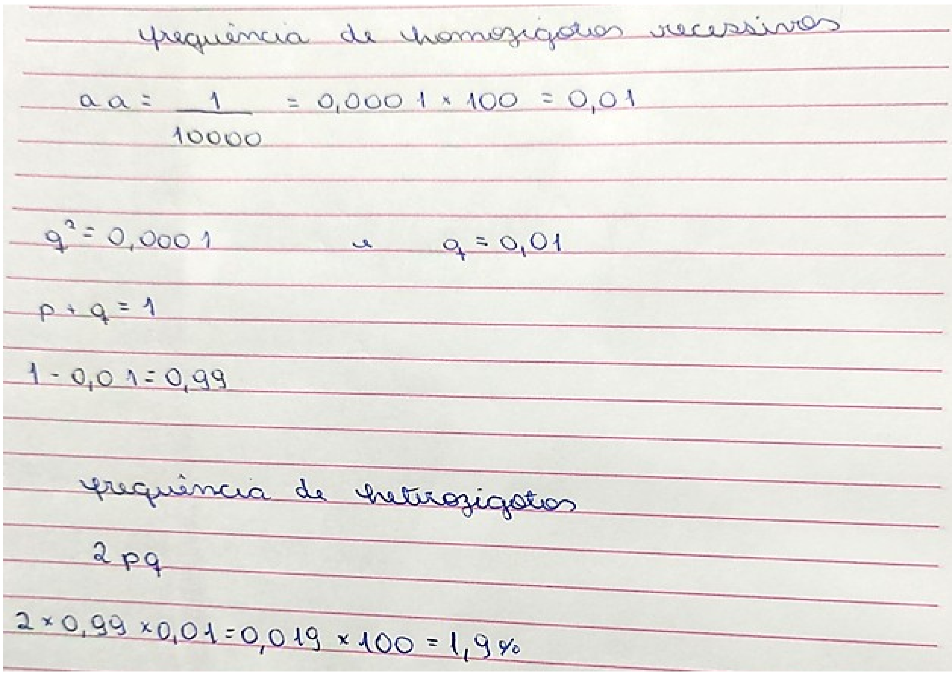
It was observed that, for this activity, the students discussed in the group to decide how they would solve the issue. It was noted that in the arguments brought the idea of probability but did not have a definite notion for the calculation. Thus, to assist the students, an intervention was carried out and it was emphasized to think about the equation $p^2 + 2pq + q^2 = 1$ and to think about proportionality. A G3 student said:

Now you can calculate... It's one child who has the disease among 10,000. I think it's just by dividing one by ten thousand that we'll find the frequency of those who have the disease.

At that moment, the intervention was so that the students could relate the idea of the recessive allele with the q^2 of the equation. The students calculated and were able to associate the idea of p + q = 1. When it was stated that they had found the frequency of homozygotes, but that the frequency of heterozygotes was missing, remembered the activity of the hypothetical population that performed and were able to complete the calculation, as shown in the example in Figure 8.

Figure 8

Calculation of the genotypic frequency performed by the students.



Source: From the author's archive (2022).

From Figure 8, it was observed that the students applied the mathematical concept necessary to answer the question. When asked: "How do you evaluate your knowledge before and after performing the activities," most students, about 65%, said that before did not understand the application of mathematics in the content studied and was not knowing how to use the concepts, but improved from the activities performed. The others, 35%, did not manifest. In the interpretation performed, it was understood, therefore, that the students who manifested themselves were reflective of their learning process and resorted to the metacognitive element of evaluation to infer about their knowledge. According to Rosa (2014), when the student infers that he knows something, or that he thinks he is good at a certain concept or action, this represents an evocation of metacognitive thinking. It should be noted that, a more student-focused teaching, contextualizing the contents and curricula with the universe of student significance, needs to become the central axis of Biology in High School (Duré; Andrade & Abilio, 2021, p. 1).

Finally, it is important to say that how the intervention reported was performed with students, from the perspective of DBR, to structure an educational product, the possibility of replication became clear. This implies recognizing that the transfer of the solution or even part of it, of praxis and actions to other real situations of teaching biology, with attention to feasibility and validation.

FINAL THOUGHTS

With the development of activities that are part of the didactic sequence developed with high school students, it was possible to verify relevant aspects of the conceptions and experiences of students, related to the teaching of Biology with application of mathematical concepts. In addition, it is thought that from the perspective of metacognition it was possible to associate the situations observed, analyzed and interpreted as evocation of metacognitive thinking.

It was understood that with the opportunities and possibilities that were presented to students reflected on their process of learning and thus, it was possible to associate metacognition with the awareness of those students about their own thoughts, what was understood to be in line with the idea of authors who study metacognition in teaching processes.

About mathematical applications in the teaching of Biology with evocation of metacognitive thinking in high school, it was clear that they can provide students with an understanding of the connections between mathematics and biological phenomena, empowering them to make informed judgments about their studies, promoting creativity and reflection of the process of learning to learn.

As the researchers consulted point out, still lacks studies that put the core in the use of metacognition as a didactic-pedagogical methodology, it is suggested new research to add other information to this issue of relevance to the teaching process and consequently, for learning.

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