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Fluxo da informação gênica: recurso didático para o ensino de genética com foco na inclusão de estudantes com deficiência visual e auditiva

Larissa Aparecida Santos SILVA[1]
Anna Cláudia Guimarães FREIRE[2]
Fernanda de Oliveira BUSTAMANTE[3]

Resumo
Dentre os temas de biologia, o fluxo da informação gênica é considerado um assunto abstrato por envolver processos bastante complexos. Além disso, há poucas estratégias de ensino destinadas a estudantes com deficiência visual, auditiva e surdos. Assim, o objetivo do presente trabalho foi desenvolver um modelo didático tridimensional sobre o fluxo da informação gênica, bem como promover a inclusão de alunos com deficiência visual, auditiva e surdos. Além disso, foram desenvolvidos vídeos autoexplicativos com legenda em português. Para a confecção e montagem dos recursos didáticos foram utilizados materiais de baixo custo. Com a utilização do material didático o estudante poderá aprender sobre os três processos do fluxo da informação gênica: replicação, transcrição e a tradução. Para os estudantes com deficiência visual, os educadores poderão auxiliá-los a apalpar e manusear o recurso didático, facilitando a compreensão do ensino e aprendizagem da informação gênica de forma inclusiva.

Palavras-chave: Biologia. Surdos. Vídeos.

[1] Biologist from the State University of Minas Gerais, Divinópolis Campus. ORCID: https://orcid.org/.0000-0001-6580-1093
E-mail: ls9947499@gmail.com
[2] Ph.D. in Biochemistry and Immunology. Manager of the Ninho Center - Health and Early Childhood Education Services. ORCID: https://orcid.org/0000-0002-0641-6694
E-mail: annaclaudia.bio@gmail.com
[3] Ph.D. in Genetics and Plant Breeding. Professor at the State University of Minas Gerais, Divinópolis campus. ORCID: https://orcid.org/0000-0002-2826-5217
E-mail: fernanda.bustamante@uemg.br

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Gene information flow: didactic resource for the teaching of genetics with a focus on the inclusion of students with visual and hearing impairment

Larissa Aparecida Santos SILVA
Anna Cláudia Guimarães FREIRE
Fernanda de oliveira BUSTAMANTE

Abstract
Among the themes of biology, the flow of gene information is considered an abstract subject because it involves very complex processes. In addition, there are few teaching strategies aimed at visually impaired, hearing impaired and deaf students. Thus, the objective of this work was to develop a three-dimensional didactic model on the flow of gene information, as well as to promote the inclusion of visually impaired, hearing impaired and deaf students. In addition, self-explanatory videos with Portuguese subtitles were developed. Low-cost materials were used for the preparation and assembly of didactic resources. With the use of the didactic material the student will be able to learn about the three processes of the flow of gene information: replication, transcription, and translation. For students with visual impairment, educators can help them feel and handle the didactic resource, facilitating the understanding of the teaching and learning of gene information.

Keywords: Biology. Deaf. Videos.

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Flujo de información genética: recurso didáctico para la enseñanza de la genética con enfoque en la inclusión de estudiantes con deficiencia visual y auditiva

Larissa Aparecida Santos SILVA
Anna Cláudia Guimarães FREIRE
Fernanda de oliveira BUSTAMANTE

Resumen

Entre los temas de biología, el flujo de información genética se considera un tema abstracto porque involucra procesos muy complejos. Además, hay pocas estrategias de enseñanza dirigidas a estudiantes con discapacidad visual, auditiva y sordos. Así, el objetivo del presente trabajo fue desarrollar un modelo didáctico tridimensional sobre el flujo de la información genética, así como promover la inclusión de estudiantes con discapacidad visual, auditiva y sordos. Además, se desarrollaron videos autoexplicativos con subtítulos en portugués. Para la confección y montaje de los recursos didácticos se utilizaron materiales de bajo coste. Con el uso del material didáctico el estudiante podrá aprender sobre los tres procesos del flujo de la información genética: replicación, transcripción y traducción. Para los estudiantes con discapacidad visual, los educadores podrán ayudar a palpar y manejar el recurso didáctico, facilitando la comprensión de la enseñanza y el aprendizaje de la información génica de forma inclusiva.

Palabras clave: Biología. Sordos. Los Vídeos.

Introduction

Teaching molecular biology and genetics often presents significant challenges due to their abstract and complex nature (SILVA; ANTUNES, 2017). According to Campos et al. (2003), these subjects are typically taught in a theoretical and traditional manner, which complicates students' understanding. The heavy reliance on expository and dialogic lectures in the learning process may not address various skills and intelligences, potentially hindering learning (FILHO; ALLE; LEME, 2018). This approach can lead to decreased student interest, as they may find the content too complex and monotonous.

Genetics as a science began to develop in the mid-19th century with Mendel's studies, which were independently confirmed by Hugo De Vries, Carl Correns, and Erich Tschermak-Seyssenegg. Molecular biology gained prominence following Watson and Crick’s 1953 publication on the DNA structure in *Nature* (GRIFFITHS et al., 2016), significantly advancing its scientific impact (FRANCISCO, 2005). Among the various topics in genetics and molecular biology, the flow of genetic information is particularly complex and abstract (AQUINO; SANTOS, 2018).

The flow of genetic information consists of replication, transcription, and translation (GRIFFITHS et al., 2016), and is crucial for living organisms (DORNELLES, 2020). DNA stores and transmits genetic information, leading to the synthesis of different types of RNA, which are involved in protein synthesis (ALBERTS et al., 2017) and gene silencing (ZOTTI et al., 2018). Proteins are essential for cellular growth, maintenance, and function (WATSON et al., 2015). The complexity of the flow of genetic information arises from the simultaneous involvement of multiple molecules (FREITAS et al., 2020). Therefore, teaching this topic requires considerable effort from educators to engage students, especially those with visual, auditory, or hearing impairments, who may face even greater challenges in understanding abstract concepts.

According to the 2019 School Census data released by the National Institute for Educational Studies and Research Anísio Teixeira (INEP), there was a 34.4% increase in the number of students with disabilities compared to 2015, totaling 1.3 million students regularly enrolled with some form of disability. Despite a significant portion of the school-age population having a disability, strategies for special education are minimal or non-existent. According to the National Guidelines for Education, educational systems must enroll all students, and it is up to schools to organize themselves to meet the needs of students with special requirements (BRASIL, 2001). "Educational inclusion is a student’s right and requires changes in the conception and practices of management, classroom instruction, and teacher training to ensure that everyone has the right to schooling" (PAPA et al., 2015, p. 1). Thus, school inclusion aims for students with disabilities to share the same educational social space as other students (SILVA et al., 2017). Moreover, Carneiro (2007) emphasizes that special education must ensure that all students with disabilities have access to school by removing obstacles that prevent these students from assimilating knowledge.

Therefore, teachers can make adaptations to the environment in which the student is placed, re-evaluating their teaching methods and strategies to develop each student's individual skills, positively contributing to their school life. The teacher is the facilitator in the classroom and partially assumes the responsibility of seeking mechanisms, strategies, and alternative conditions for a suitable and inclusive teaching and learning environment. Additionally, educators should develop methods to engage and interest students (NOBRE; SILVA, 2014). According to Rocha et al. (2017), students are the subjects of their learning processes, with teachers acting as mediators in the students' interaction with knowledge objects.

One way to reduce teaching and learning difficulties for students, including those with disabilities, is through the use of teaching resources (SOUZA, 2007). According to Souza (2007, p.111), "Teaching resources are any materials used to aid in the teaching and learning of the content proposed to be applied by the teacher to their students," and these resources can be produced from low-cost materials (CERQUEIRA; FERREIRA, 2017), such as modeling clay, recyclable waste, and plaster (CECCANTINI, 2006). The application of teaching resources in the teaching and learning process is important for helping students understand the content, develop their creativity, motor coordination, and ability to handle various objects used by the teacher (SOUZA, 2007). Furthermore, teaching resources can be adapted by the educator according to the student's needs, facilitating the student's integration with the topics covered in the classes (NASCIMENTO; CAMPOS, 2018). According to Krasilchik (2008), the use of teaching resources in lessons can fill gaps left by traditional methods. Therefore, didactic models can offer students a more dynamic learning experience, leading to better learning outcomes. Additionally, teaching resources can lead to a restructuring of practices, thereby moving away from traditional methods that may negatively impact student learning (PAVAN et al, 1998).

In order to facilitate the understanding of the mechanisms involved in the flow of genetic information, this study aimed to develop teaching resources to enhance the teaching and learning of this topic in genetics education, with a focus on including students with visual, auditory, and hearing impairments. A three-dimensional teaching material and four self-explanatory videos on the subject were created. The produced videos were published on the YouTube platform to assist in the creation of the teaching model and improve the understanding of the processes involved in the flow of genetic information by both students and educators. All the videos include Portuguese subtitles to support comprehension for students with hearing impairments.

Methodology

Creation of Materials

For the creation and assembly of the teaching resources, low-cost and easily obtainable materials were used, including modeling clay, tempera paint, brushes, hot glue, magnets, metal scraps, small artificial pearl spheres, navette-shaped stones used in embroidery, popsicle sticks, and thin wire. These materials were selected to ensure easy reproduction.

The teaching model developed in this study features a three-dimensional structure to facilitate the understanding of the processes of replication, transcription, and translation by students, including those with visual, auditory, and hearing impairments. This model provides tactile interaction with the components. According to Landinho (2019), the use of tactile resources significantly aids in the comprehension of new knowledge, especially for students with visual impairments. Additionally, all pieces are labeled to assist in identification.

Cell Nucleus

The cell nucleus is responsible for various cellular functions, including the control of cellular activities and the storage of genetic information. This structure is present in all eukaryotic cells and absent in prokaryotic cells (GRIFFITHS et al., 2016). It was represented by a piece of cardboard cut into a rounded shape with a diameter of 20 cm and painted with blue tempera paint. The piece was exposed to a ventilated environment for one hour to dry (Figure 1).

Cytoplasm

The cytoplasm is the intracellular space where the cell nucleus and various organelles are found, and it also performs several functions, such as storing chemical substances essential for maintaining life. This structure is present in both eukaryotic and prokaryotic cells and corresponds to the internal region of the cell (GRIFFITHS et al., 2016). The cytoplasm was represented by a piece of rounded styrofoam cut in half and painted green, with an approximate diameter of 70 cm. The piece was exposed to a ventilated environment for thirty minutes to allow the paint to dry (Figure 2).

Nitrogenous Bases and Nucleotides

Nitrogenous bases are chemical compounds and are represented by adenine, guanine, cytosine, thymine, and uracil (ALBERTS et al., 2017). Each of the nitrogenous bases was constructed using biscuit, with specific shapes and colors (Table 1). Adenine was initially modeled in the shape of a rectangle, which was then cut with a spatula to create a triangular shape, and painted light pink. To achieve the light pink color, pink and white gouache paints were mixed. Thymine and uracil were represented by isosceles triangles painted with yellow and blue gouache paints, respectively. To further differentiate thymine and uracil, the uracil piece underwent texturization by adding sand to the blue gouache paint, which can be felt by touch.

For cytosine and guanine, two scalene triangles were made and painted with light green and purple gouache paints, respectively. To further differentiate guanine and cytosine, hot glue was added to the guanine piece to modify its texture, which can also be felt by touch. All pieces (Table 1) were exposed to a ventilated environment for approximately two days to dry. The labels for the uracil and guanine pieces were painted white due to the dark colors of the blue and purple paints.

Nucleotides consist of one of the previously mentioned nitrogenous bases, a pentose sugar, and a phosphate group. DNA nucleotides contain a nitrogenous base, which may be adenine, thymine, guanine, or cytosine, deoxyribose sugar, and phosphate (Figure 3A). RNA nucleotides contain one of the nitrogenous bases adenine, guanine, cytosine, or uracil, ribose sugar, and a phosphate (Figure 3B) (ALBERTS et al., 2017). The phosphate was made in the shape of a sphere and painted white using biscuit. The deoxyribose and ribose sugars were made in the shape of a pentagon and painted with black and light green gouache paints, respectively. To further differentiate deoxyribose from ribose, the ribose piece underwent texturization by adding sand to the light green gouache paint. This differentiation is perceptible by touch. The nitrogenous bases followed the same colors and shapes shown in Table 1. The three types of pieces phosphate, sugar, and nitrogenous base were assembled using toothpicks, resulting in the final nucleotide shape (Figure 3). After modeling all the nucleotides, they were exposed to a ventilated environment for approximately two days to dry.

DNA Strands

Deoxyribonucleic acid (DNA) is an organic compound present in the nucleus of eukaryotic cells, consisting of two antiparallel and complementary strands. Its function is to carry the genetic information of organisms (GRIFFITHS et al., 2016). The DNA strands were made using biscuit dough and painted light pink with gouache paint. To create the strands, two strips of dough, each 12 cm in length, were first prepared. Their ends were then joined, and the structure was rotated to form a helical shape (Figure 4A).

For DNA replication to occur, replication forks are formed along the entire DNA strand (GRIFFITHS et al., 2016). To construct the replication fork, the ends of the two strands were only glued at the extremities, leaving an opening in the center of the molecule for the nitrogenous bases to be attached with hot glue (Figure 4B). To represent the final product of the replication process, two DNA strands were developed: one representing the new strand in blue and the other representing the old strand in light pink. Their ends were joined to create a helical shape (Figure 4C). The DNA strands were left in a ventilated environment for two days to dry.

DNA Polymerase, Helicase, and Primase

During DNA replication, various enzymes play crucial roles. The enzyme helicase facilitates the breaking of hydrogen bonds that hold the nitrogenous bases of the double-stranded DNA together. This process results in the opening and unwinding of the DNA double helix. The enzyme primase synthesizes primers, which are short RNA sequences containing few nitrogenous bases. These primers precede the initiation of DNA synthesis by DNA polymerase, which is responsible for adding nucleotides to the new DNA strand in the 5' to 3' direction (ALBERTS et al., 2017). The DNA polymerase, helicase, and primase were crafted using biscuit dough. DNA polymerase was represented in a circular shape with a small opening on its side and painted blue with gouache paint. The helicase was made in a rounded shape and painted black with gouache paint. The primase was represented in a rectangular shape in the color of the biscuit dough (Figure 5). All three pieces were left to dry for approximately one day

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Introns e exons

Different types of RNA are transcribed from specific regions of DNA. In prokaryotes, RNA corresponds exactly to the transcribed DNA segment. In eukaryotes, however, there are additional steps before the RNA is fully matured. Initially, during transcription, there are two types of regions: coding regions known as exons and non-coding regions known as introns. Introns are removed, and exons are joined together in a process called splicing or remodeling (ALBERTS et al., 2017). For this project, seven rectangular pieces were developed, with four painted blue to represent exons and three painted red to represent introns. The exons were also subjected to texturization by adding sand to the gouache paint to facilitate tactile differentiation (Figure 6A). To keep the pieces together, small aluminum pieces and magnets were glued to the ends of the exons and introns (Figure 6B). Small wire loops were attached to the ends of the pieces to connect them with other structures (Figure 6C).

Cap and Poly-A Tail

In the final stage of RNA maturation, the cap and the poly-A tail are observed, which serve to protect the mRNA and increase the stability of the molecule (ALBERTS et al., 2017). The cap was made using a navette-shaped stone (Figure 7A), and the poly-A tail was represented by small pearl-like beads threaded onto a toothpick (Figure 7B).

Messenger RNA (mRNA)

mRNA is responsible for carrying all the information from the DNA, which is in the nucleus, to the cytoplasm, facilitating protein production (WATSON et al., 2015). The mRNA was represented using spaced codons (triplets of nucleotides). The codons were depicted by nitrogenous bases made from biscuit dough (Table 1) and glued with hot glue onto a piece also made of biscuit dough, painted with gray watercolor to represent the mRNA (Figure 8A). The spaces between the codons were highlighted so that students with visual impairments can feel, through touch, that the nucleotides are read in triplets (Figure 8B).

Ribosomal RNA (rRNA): subunits

rRNA has two subunits, a larger one and a smaller one (GRIFFITHS et al., 2016). These were made from biscuit dough and painted with light pink watercolor (Figure 9). The pieces were allowed to dry for approximately three days.

Ribosomal RNA (rRNA): sites

In the larger subunit of rRNA, there are three sites: the A site, which refers to the entry of aminoacyl-tRNA; the P site, which refers to the binding of peptidyl-tRNA; and the E site, which refers to the exit (GRIFFITHS et al., 2016). The sites were represented in oval shapes using biscuit dough painted with yellow watercolor. Different sizes were used to distinguish the sites, with the P site being the largest, the A site intermediate, and the E site the smallest (Figure 10).

Transfer RNA (tRNA)

The tRNA functions to transport amino acids that will be used in protein synthesis and is composed of four distinct arms and the acceptor stem (GRIFFITHS et al., 2016), represented by biscuit dough. First, a single strip of biscuit dough approximately 10 cm in length was made. Then, the acceptor stem and the arms were shaped. To represent the nucleotides in the tRNA, small pearl-like spheres were glued inside, highlighting the anticodon arm, which contains nitrogenous bases with their specific shapes (Table 1). The tRNA has an amino acid attached to the 3’ end (GRIFFITHS et al., 2016), which was fixed to the acceptor stem of the tRNA by a small wire loop (Figure 11).

Amino acids

Amino acids are the fundamental units for protein formation, with 20 different types existing (WATSON et al., 2015). Some amino acids were represented in distinct shapes and colors (Table 2). The amino acids will be joined together with a small wire loop, forming the polypeptide chain. The peptide bond, which links amino acids together, is formed by the removal of a water molecule and always features an amino group (NH2) and a carboxyl group (COOH) (GRIFFITHS et al., 2016). The pieces were shaped from biscuit dough in specific shapes and colors and were left in a ventilated area to dry for 24 hours. To facilitate the identification of amino acids resulting from nucleotide triplets, the genetic code (Table 1) and the names and abbreviations of the amino acids (Table 2) were also represented.

Termination Factor

The end of the translation process occurs when release factors recognize the stop signals (GRIFFITHS et al., 2016). This was represented by the termination factor, which was shaped from biscuit dough into a rectangular form with a width of 3 cm and rounded edges. The piece was painted with purple gouache paint and left in a ventilated area to dry for two days (Figure 12).

Explanatory Video

To facilitate the creation of the pieces and the teaching and learning process, four videos were produced. The first video explains and demonstrates the creation of all the pieces used in the teaching resource. The second video illustrates the DNA replication process. The third video demonstrates the transcription process, and the fourth video shows the translation process. The videos are available on the *Genética.recursodidático* channe*l* on YouTube and can be accessed via the following link: https://www.youtube.com/channel/UCAH04o2yyEZWDZkb0952HBg by clicking on "Playlists.".

Results

Teaching Resource and Gene Information Flow

The flow of genetic information is a topic considered complex by many students due to the numerous processes involved, which can lead to difficulties in understanding. Therefore, students often require additional information and materials to grasp the content (FREITAS et al., 2020), such as didactic materials.

The use of the didactic resource developed in this work can be supported by an educator throughout the simulation of the studied processes. Initially, the educator should explain and present each piece to the students. For students with visual impairments, the educator can assist them in feeling and handling all the pieces, helping with their initial identification and providing supervision and assistance during the entire simulation of the gene information flow process. For students with hearing impairments and deaf students, the educator and/or a sign language interpreter should assist, and students can also watch the videos with Portuguese subtitles.

The processes involved in the flow of genetic information occur in specific locations within the cell. In eukaryotes, DNA replication takes place in the nucleus (JUNQUEIRA; CARNEIRO, 2012), while RNA formation begins in the nucleus and concludes in the cytoplasm. Other stages of the gene information flow, including the formation of final products such as non-coding RNAs and proteins, also occur in the cytoplasm (GRIFFITHS et al., 2016). In this study, the nucleus was represented by a blue sphere (Figure 1), and the cytoplasm was represented in green (Figure 2). The pieces are arranged such that the nucleus is positioned beneath the cytoplasm (Figure 13).

While most organisms have DNA as their genetic material, some viruses, including the novel coronavirus, possess RNA as their genetic material (UZUNIAN, 2020). Both DNA and RNA are composed of nucleotides and play various roles in cellular metabolism. Nucleotides consist of a nitrogenous base, a sugar (ribose in RNA and deoxyribose in DNA), and a phosphate group (Figure 3). Nitrogenous bases are classified into two types: purines and pyrimidines. Purines include adenine and guanine, while pyrimidines include cytosine, thymine, and uracil (Table 1). DNA contains adenine, thymine, cytosine, and guanine as bases, whereas RNA has uracil instead of thymine (ALBERTS et al., 2017).

To demonstrate the specific pairing between nitrogenous bases, they were molded into shapes that facilitate their matching, such that adenine pairs with thymine or uracil, and cytosine pairs with guanine (Figure 14). Additionally, thymine can be distinguished from uracil and cytosine from guanine by the texture added to the uracil base using sand in the paint and the guanine base using hot glue (Table 1).

DNA consists of two antiparallel strands (Figure 4A), with one strand called the coding strand, oriented 5’-3’, and the other called the template strand, oriented 3’-5’. The strands are described as complementary due to the base pairing (adenine pairs with thymine, and guanine pairs with cytosine) (Figure 4B), which are joined by hydrogen bonds.

Replication

The first step in the flow of genetic information is DNA replication, which involves duplicating all the genetic information contained within the cell (GRIFFITHS et al., 2016). To facilitate understanding, only a segment of the DNA molecule was represented. The initial stage of replication involves the unwinding of the DNA strand by the enzyme helicase (Figure 5), which binds to the DNA molecule and breaks the hydrogen bonds. This process leads to the separation of the bases, resulting in the formation of the replication fork (Figure 15). Multiple replication forks form along the DNA molecule in eukaryotes.

Next, primase (Figure 5) synthesizes primers, short RNA sequences that precede the start of DNA synthesis by DNA polymerase (Figure 5). DNA polymerase adds new nucleotides to the strand being replicated based on base complementarity. The synthesis of the new strand occurs in the 5’ to 3’ direction. Considering the synthesis direction from left to right, replication occurs discontinuously on the coding strand (from right to left) through the action of multiple primers. In contrast, on the template strand, synthesis occurs continuously (from left to right) with the action of a single primer (Figure 16). Primers are removed, and DNA ligase joins the adjacent DNA fragments (Figure 17), completing the replication process and resulting in two DNA molecules: one strand from the original molecule, represented in light pink, and one newly synthesized strand, represented in blue, illustrating the semiconservative nature of replication (ALBERTS et al., 2017) (Figure 18).

Transcription

The process of transcription begins in the nucleus, where an RNA strand is produced from a specific sequence of DNA. The primary enzyme involved in this process is RNA polymerase, which uses only one of the DNA strands, the template strand, to synthesize the complementary RNA strand. RNA polymerase synthesizes the RNA strand in the 5’ to 3’ direction, adding new nucleotides to the 3' end of the growing strand. It is important to note that in RNA, base pairing occurs between cytosine and guanine, and adenine and uracil, with thymine not being present (GRIFFITHS et al., 2016) (Figure 19).

In eukaryotes, RNA maturation involves three events. First, a cap is added to the 5’ end of the RNA (Figure 20). Next, splicing occurs, which involves the removal of non-coding regions, known as introns, and the joining of coding regions, known as exons. The third event is the addition of a poly-A tail to the 3’ end of the RNA molecule (GRIFFITHS et al., 2016) (Figure 21). In the educational model, the addition of the cap and poly-A tail is represented by a small piece of wire attached to the exon (Figure 5).

After RNA maturation, the mRNA is transported to the cytoplasm, where it participates in the translation process. This process requires the involvement of three types of RNA: mRNA, which carries genetic information from the nucleus to the cytoplasm; tRNA, which transports amino acids used in protein synthesis; and rRNA, which forms ribosomes, organelles that, together with mRNA and tRNA, ensure that protein synthesis occurs correctly (WATSON et al, 2015).

Translation

In eukaryotes, the translation process begins with the initiation complex, which consists of the small ribosomal subunit and the initiator tRNA carrying the amino acid methionine (Table 2). The initiation complex scans the mRNA sequence in the 5'-3' direction until it finds the start codon AUG (Figure 22). Subsequently, the large ribosomal subunit joins, and translation begins (GRIFFITHS et al., 2016). The space where the mRNA binds to the ribosome is represented by an opening in the small subunit of the educational model (Figure 22). The initiation codon AUG on the mRNA pairs with the UAC anticodon on the tRNA due to base complementarity. Only the tRNA carrying methionine (Met) (Table 2) will enter the P site, while other tRNAs will enter the A site (Figure 23). It is important to note that the binding of the amino acid to the site is determined by the nucleotide sequence on the mRNA, and reading occurs every three nucleotides, or every codon (GRIFFITHS et al., 2016).

The next codon on the mRNA in the model is UUU. Thus, the tRNA carrying the amino acid phenylalanine (Phe) (Table 2) with the anticodon AAA, complementary to the codon UUU, will enter the A site (Figure 24). The tRNA in the P site will then move to the E site, where it will be released. The tRNA in the A site will move to the P site, leaving the A site vacant to receive the next tRNA. At this point, a peptide bond forms between the amino acids, with methionine binding to phenylalanine in the P site. As the next mRNA codon in the model is GGA, the tRNA that will enter the A site has the anticodon CCU and carries the amino acid glycine (Gly) (Table 2) (Figure 25).

As the correct amino acids are incorporated, the ribosome moves along the mRNA strand in the 5' to 3' direction, promoting the elongation of the protein being formed (WATSON et al., 2015). In the example illustrated in this work, this process will repeat two more times, represented by the binding of a fourth tRNA to the ribosome, carrying the amino acid histidine (His) (Table 2) with the anticodon GUA, which pairs with the codon CAU on the mRNA (Figure 26). Then, a fifth tRNA carrying the amino acid arginine (Arg) (Table 2) with the anticodon GCA will bind to the codon CGU on the mRNA (Figure 27).

Translation termination occurs when one of the three stop codons UAA, UAG, or UGA (Table 2) is in the A site, for which there is no tRNA with complementary anticodons but rather release factors that recognize them as stop signals (GRIFFITHS et al., 2016). In the example illustrated in this work, the codon UAA is present, for which there is no corresponding tRNA, but rather a termination factor (Figure 28). The translation process is then completed, with the polypeptide chain being released from the tRNA, forming the final product consisting of the following amino acids: methionine, glycine, phenylalanine, histidine, and arginine (Figure 29A). The mRNA is released from the ribosome (Figure 29B), and the two ribosomal subunits separate (Figure 29C) (GRIFFITHS et al, 2016).

All the processes can be viewed through the videos, which are divided into four parts, available on the Genética.recursodidático channel on YouTube, accessible via the link: https://www.youtube.com/channel/UCAH04o2yyEZWDZkb0952HBg.

Final considerations

The biology content taught in high school addresses both the macroscopic and microscopic aspects of living organisms and their structures, often considered challenging for students to grasp. Teaching genetics is particularly challenging for educators due to its constantly evolving nature and its interdisciplinary aspects, which complicate student learning (CARBONI; SOARES, 2010). Therefore, it is necessary for teachers to review their teaching practices and incorporate tools that aid in better comprehension of the content (OLIVEIRA & TRIVELATO, 2006).

The use of didactic resources is one way to assist in the learning process (QUIRINO, 2011), as these tools can expand structures, allowing for tactile exploration (STELLA & MASSABDI, 2019). According to Nicolas and Paniz (2016), didactic resources are important for developing students' ability to handle objects, improving their motor coordination, and engaging them with the content, which aids in understanding. Additionally, Nascimento and Campos (2018) emphasize that didactic resources are crucial for promoting active student participation in their knowledge construction. Therefore, students can handle the educational material and assist in creating the pieces that make up the didactic resource.

Thus, the didactic model on the flow of genetic information developed in this work will facilitate the teaching and learning of molecular biology content and can be reproduced by schools or even students. All the materials used are easily accessible and can be found in stationery stores, craft supply shops, and other places, and they are inexpensive. Furthermore, the educational material is constructed using biscuit dough, making it durable and long-lasting, suitable for storage by schools. Another advantage is that the model can also be constructed by high school students themselves, contributing to their active participation in lessons.

The didactic resource aims to promote the inclusion of students with visual and hearing impairments. It provides a three-dimensional model that enhances tactile contact for visually impaired students and includes specific colors and captions to aid understanding for students with hearing impairments and deaf students. To further facilitate the demonstrative process of the flow of genetic information, explanatory videos on obtaining the structures used and the entire process were recorded and are available for students and educators. Thus, the developed didactic model offers students a more engaging and understandable approach to the abstract topic of genetic information flow.

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