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INTERACTIVE LEARNING IN BIOLOGY: AN EDUCATIONAL GAME FOR TEACHING THE CLASSIFICATION OF LIVING BEINGS

APRENDIZAGEM INTERATIVA EM BIOLOGIA: UM JOGO EDUCACIONAL PARA O ENSINO DA CLASSIFICAÇÃO DOS SERES VIVOS

APRENDIZAJE INTERACTIVO EN BIOLOGÍA: UN JUEGO EDUCATIVO PARA ENSEÑAR LA CLASIFICACIÓN DE LOS SERES VIVOS

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Abstract: This study presents the development and implementation of a digital educational game, created using programming logic in C++, to support high school students in understanding the classification of living beings. The game simulates a question-and-answer system based on biological characteristics, allowing students to correctly identify different organisms through randomly drawn cards. The activity was applied to students aged 15 to 16, and the results indicated increased engagement, better understanding of taxonomic concepts, and development of logical reasoning. The use of active methodologies, combined with the integration of technology and biology content, proved effective in promoting playful and meaningful learning.

Keywords: Biological classification; Biology teaching; Educational game; Programming logic; Active methodologies.

Resumo: Este estudo apresenta o desenvolvimento e aplicação de um jogo educacional digital, criado com lógica de programação em linguagem C++, para auxiliar estudantes do ensino médio na compreensão da classificação dos seres vivos. O jogo simula um sistema de perguntas

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e respostas com base em características biológicas, permitindo que os alunos identifiquem corretamente diferentes organismos a partir de fichas sorteadas. A proposta foi aplicada com estudantes entre 15 e 16 anos, e os resultados indicaram aumento no engajamento, maior compreensão dos conceitos taxonômicos e desenvolvimento do raciocínio lógico. A utilização de metodologias ativas, aliada à integração de tecnologia e conteúdos de biologia, demonstrou ser eficaz na construção do conhecimento de forma lúdica e significativa.

Palavras-chave: Classificação biológica; Ensino de biologia; Jogo educacional; Lógica de programação; Metodologias ativas.

Resumen: Este estudio presenta el desarrollo y la implementación de un juego educativo digital, creado con lógica de programación en lenguaje C++, para apoyar a estudiantes de secundaria en la comprensión de la clasificación de los seres vivos. El juego simula un sistema de preguntas y respuestas basado en características biológicas, permitiendo que los alumnos identifiquen correctamente distintos organismos a partir de tarjetas sorteadas. La propuesta fue aplicada con estudiantes de entre 15 y 16 años, y los resultados indicaron un mayor compromiso, mejor comprensión de los conceptos taxonómicos y desarrollo del razonamiento lógico. El uso de metodologías activas, junto con la integración de la tecnología y los contenidos de biología, demostró ser eficaz en la construcción del conocimiento de forma lúdica y significativa.

Palabras clave: Clasificación biológica; enseñanza de la biología; juego educativo; lógica de programación; metodologías activas.

INTRODUCTION

The diversity of life forms on Earth has, throughout history, motivated the creation of biological classification systems capable of organizing organisms based on their common characteristics. The systematization of this knowledge dates back to Carl von Linné, who in 1735 proposed, in the work Systema Naturae, a hierarchical structure for grouping living beings, later refined into categories such as kingdom, phylum, class, order, family, genus, and species (AMABIS; MARTHO, 2006).

With scientific advances, especially since the contributions of Charles Darwin in the 19th century, taxonomy also began to consider the phylogenetic relationships between organisms, establishing evolutionary links based on anatomical, genetic, and molecular evidence (FUTUYMA, 2002). Currently, understanding these classifications is fundamental to learning biology and is a central theme of the high school curriculum, as outlined in the National Common Curricular Base (BRASIL, 2018).

However, studies indicate that students have difficulty understanding concepts related to the classification of living beings, especially due to the terminological complexity and abstraction required to relate morphological and functional characteristics of organisms

(SOUZA, 2021; COSTA; AVELAR, 2018). This difficulty highlights the need for teaching methodologies that favor the active construction of knowledge, bringing school content closer to students' realities.

In this context, the adoption of playful and interactive pedagogical strategies, such as educational games, has demonstrated potential to increase engagement, facilitate learning, and develop cognitive and socio-emotional skills (KISHIMOTO, 2011). Furthermore, the inclusion of technological resources in the school environment, such as programming logic, can contribute to the development of skills related to computational thinking, problem-solving, and student autonomy (PAPERT, 2008; DELGADO et al., 2019).

Programming logic consists of a set of rules and structures used to build algorithms and solve computational problems. When applied to the educational context, this logic can be incorporated in an interdisciplinary manner, promoting the development of logical-mathematical reasoning and creativity (VALENTE, 1999). Thus, integrating biology and programming content into an innovative teaching approach can foster meaningful teaching and active learning.

Furthermore, teaching biological classification in high school is a recurring challenge for science and biology teachers. Students' difficulty in understanding is often associated with technical nomenclature, abstract concepts, and a disconnect between the content and students' daily experiences (SOUZA, 2021). Therefore, it is essential to seek pedagogical strategies that foster meaningful knowledge construction and spark students' interest.

According to Costa and Avelar (2018), the use of alternative teaching materials and active methodologies, such as games and recreational activities, can promote engagement and improve student performance. Educational games, in particular, contribute to the development of cognitive, social, and affective skills, in addition to stimulating critical thinking and problem-solving (KISHIMOTO, 2011).

In the contemporary context, marked by the constant presence of digital technologies, the use of programming and computational thinking as teaching resources has gained prominence. Papert (2008) already advocated the use of computing environments to develop students' autonomy and creativity. Programming logic, in this sense, can be explored for educational purposes, fostering integration between areas of knowledge and enabling students to act as creators of solutions rather than just consumers of content.

According to Delgado et al. (2019), incorporating programming logic into the teaching-learning process helps develop logical reasoning, abstraction, and problem-solving skills. When combined with school subjects, such as biology, this approach can enhance learning through interdisciplinarity and the use of interactive and technological resources.

In this scenario, the development of digital games based on programming logic represents an innovative approach that can contribute to both the learning of specific content and the development of general competencies outlined in the National Common Curricular Base (BRASIL, 2018). The integration of the conceptual mastery of the classification of living beings with computational tools allows students to be protagonists in the learning process, constructing knowledge actively, critically, and meaningfully.

Therefore, this paper aims to present the creation and implementation of a digital educational game, developed in C++, focused on teaching the classification of living beings. The proposal seeks to combine computational resources and biological knowledge to make learning more dynamic, meaningful, and aligned with the challenges of contemporary education.

THEORETICAL FOUNDATION

Educational Games

According to Fragelli and Mendes (2012), traditional teaching focuses almost exclusively on exploring the logical aspects of knowledge: the teacher explains how a given piece of knowledge connects to other preexisting concepts or stereotypical everyday situations. The psychological aspect is rarely addressed explicitly in the classroom and is typically understood as a natural byproduct of the learning process, or its importance is not even recognized. However, only a portion of students, for family and personal reasons, feel naturally engaged in the classroom and are able to engage in meaningful learning. Most experience this as arbitrary and boring and fail to establish an emotional and idiosyncratic connection with the content presented.

A lack of engagement harms student performance in the classroom because it fails to promote meaningful learning. Often, the content discussed in class is simply memorized and quickly forgotten. To promote greater engagement and thus facilitate meaningful learning, Fragelli and Mendes (2011) propose the use of learning games. The central question in this debate is determining the characteristics of games and the learning situations that make their use more effective than traditional lectures.

Some argue that every game involves a learning process, since games involve problem-solving and have rules that must be learned. Government agencies, the military, hospitals, NGOs, businesses, and schools are using games as part of training and education—these are called *Serious* Games (SAVI, 2011).

The term *Serious Games* was created in the 1970s as “[...] games that have an explicit, carefully thought-out educational purpose and are not intended to be played primarily for fun” (MICHAEL; CHEN, 2006).

Contrary to popular belief, *Serious Games* are not games with adult themes; they are games focused on teaching, training, and informing. They can also be used as educational tools, utilizing information and communication technologies to contribute to the learning process while also entertaining learners. They can serve a variety of purposes and are applicable in many areas, for all ages. Educational proposals combined with design techniques make Serious *Games* a multimedia educational tool that not only enhances learning pleasure but also provides information and communication platforms through technology (MOUAHEB et al., p. 5505, 2012).

"...play is positive, seriousness is negative. The meaning of "seriousness" is exhaustively defined by the negation of "play"—seriousness meaning the absence of play or playfulness and nothing more. On the other hand, the meaning of "play" is in no way defined or exhausted if considered simply as the absence of seriousness. Play is an autonomous entity. The concept of play as such is of a higher order than that of seriousness. For seriousness seeks to exclude play, whereas play can very well include seriousness" (HUIZINGA, 2004).

Games can be effective instructional tools because they entertain while motivating, facilitate learning, and increase retention of what has been taught, exercising the player's mental and intellectual functions. Furthermore, they also allow for the recognition and understanding of rules, identification of the contexts in which they are being used, and the invention of new contexts for modifying them. Playing is participating in the world of make-believe, embracing uncertainty, and facing challenges in search of entertainment. Through play, autonomy, creativity, originality, and the possibility of simulating and experiencing dangerous and forbidden situations in our daily lives are revealed.

The immense seductive power of games and their ability to immerse players in the virtual universe have attracted education researchers and professors seeking to capture the attention of children and young people through interactive mechanisms that enable the construction of knowledge. Learning games can, therefore, stimulate players' intellectual abilities, as content is provided, structured, and constructed through thinking strategies. The playful activity of games allows players to place themselves in real and fictional situations and make new discoveries without the risk of suffering harm in the real world, renewing their energy (SANTOS, 2006).

As motivators of the learning process, they can be defined as educational games.

However, there is still much debate about what constitutes educational games. Dempsey, Rasmussen, and Lucassen (1996), cited by Botelho (2004), define educational games as "any instructional or learning activity that involves competition and is regulated by rules and constraints." There are different types of games, classified according to their objectives, such as action, adventure, casino, logic, strategy, sports, *role-playing games* (RPGs), and others. Some of these types can be used for educational purposes, as follows:

Action – Action games can aid children's psychomotor development, developing reflexes, hand-eye coordination, and aiding quick thinking in unexpected situations. From an instructional perspective, ideally, the game should alternate moments of intense cognitive activity with periods of motor skill development.

Adventure – Adventure games are characterized by the user's control over the environment to be explored. When well-designed pedagogically, they can help simulate activities impossible to experience in the classroom, such as an ecological disaster or a chemical experiment.

Logic – Logic games, by definition, challenge the mind much more than reflexes. However, many logic games are timed, offering a time limit within which the user must complete the task. These include classics like chess and checkers, as well as simple word searches, crossword puzzles, and games that require mathematical solutions.

Role-playing game (RPG) – An RPG is a game in which the user controls a character in a specific environment. In this environment, the character encounters and interacts with other characters. Depending on the user's actions and choices, the characters' attributes can change, dynamically building a story. This type of game is complex and difficult to develop. However, if developed and applied to instruction, it could offer a captivating and motivating environment.

Strategic – Strategy games focus on the user's business wisdom and skills, particularly when it comes to building or managing something. This type of game can provide a simulation in which the user applies knowledge acquired in the classroom, discovering practical ways to apply it. Regardless of the type of game, they can be used in a variety of ways, as Botelho (2004) points out.

Lara (2003, p. 24-27) presents some types of games, differentiating them from each other:

1. *Construction games* are those that introduce students to an unfamiliar topic, making them feel, through the manipulation of materials or through questions and answers, the need for a new tool, or, if you prefer, new knowledge to solve a given situation—a problem posed by the game. In seeking this new knowledge, students have the opportunity to independently find

a new alternative to solve the situation—a problem.

2. *Training games* are those created so that the student uses the same type of mathematical thinking and knowledge several times, not to memorize it, but rather to abstract, extend, or generalize it, as well as to increase their self-confidence and familiarity with it.

3. *Deepening games* are used after the student has constructed or worked on a specific topic. Problem-solving is a very useful activity for this deepening, and such problems can be presented in the form of games.

4. *Strategy games* are those in which the student must develop action strategies for better performance as a player. They must develop hypotheses and develop systematic thinking, allowing them to consider multiple alternatives to solve a given problem. Examples: Checkers, Chess, and Cards. Games with rules are important for developing logical thinking, as their systematic application leads to deductions.

They are more suited to developing thinking skills than to working with specific content. Rules and procedures should be presented to players before the game and pre-establish the limits and possibilities of action for each player. The responsibility to follow rules and ensure their enforcement encourages the development of initiative, alertness, and confidence in speaking one's mind honestly.

According to Leif (1978), play is an activity with intrinsic educational value. Leif states that "playing educates, just as living educates: there's always something left over." Leif also states that the use of educational games in schools brings many advantages to the teaching and learning process, including:

- Play is a natural impulse for children and works as a great motivator;
- Through play, the child obtains pleasure and makes a spontaneous and voluntary effort to achieve the objective of the game;
- The game mobilizes mental schemes: it stimulates thinking and perception of time and space;
- The game integrates several dimensions of personality: affective, social, motor and cognitive;
- The game promotes the acquisition of cognitive skills and the development of abilities such as coordination, dexterity, speed, strength, concentration, etc.

Based on professional experience as an educator, and on the content covered in the Financial Education course, this project is taking into consideration the learning process from the perspective of collaboration (LAAL & LAAL, 2012), a desire expressed by the researcher and which was predominantly for the construction of the game in a collaborative way.

The most common mechanic in some types of games is competition. There is a common link between competition and play. Huizinga (2004) points out that competition possesses all the formal characteristics and most of the functionalities of a game. He goes further and emphasizes that in all Germanic languages, and in several others, ludic terms are applied to armed combat. From this perspective, the author states that play is combat, and combat is a game (RITTERFELD & CODY, 2009).

Huizinga (2004) defines that in the mechanics of a collaborative game, conflict and competition can be inserted in favor of one of the players or opposing group. This collaboration would be embedded in the game, helping players devise strategies to overcome the game's mechanics. Schell (2008) advocates for the flexibility of competition between players and the management of existing conflicts between participants through a game that provides problem-solving from a playful perspective.

According to Gomes (2009), based on the definitions found and analyses made involving collaborative games, it was possible to draw a parallel between the game's theme and the chosen mechanics, after all, the game will take place in the universe of financial education for high school students, with teaching material that encourages family and work planning, environments that require intense collaboration.

Thus, collaboration and the culture these students are immersed in will be fundamental parts of the game's mechanics. Collaboration among players will create a team that can use financial education to achieve a common goal, while at the same time, individual players will use the experiences they learn to benefit the team, transforming them into actions that will be used within the context of the game, involving the players' external culture.

The game was designed to develop collaboration skills among players, using their experiences and sharing them with others to achieve the initial objectives.

A *game designer is the professional responsible for planning and creating games for computers, mobile phones, and websites,* as well as developing common games such as board games and RPGs. Various professionals may be involved in this creation process, such as artists, programmers, designers, composers, testers, *sound designers*, producers, or any other personnel required for the game's design. Some of these stakeholders are not necessary for the development of the project proposed in this report; the more important aspects are the game's mechanics, which will be used to transfer knowledge.

Given the appropriate definitions of games and their basic elements, we sought to understand other elements that will be necessary for the design of this project.

The following elements were raised: fun, balance, and flow. Shell defines fun in games as a pleasure in surprises (SCHELL, 2008). In other words, for the author, luck is part of the fun of a game, after all, luck generates uncertainties that are used in game mechanics. Thus, it is possible to define two levels of uncertainty in a game: the macro level, representing the overall outcome of the game, and the micro level, related to the random operations of the designed system (SALEN; ZIMMERMAN, 2004). Salen and Zimmerman also emphasize that a game that lacks any type or sense of randomness can, and generally is, more competitive than games with random mechanics. However, completely random games can become chaotic and unstructured. Therefore, the balance between certainty and uncertainty needs to be carefully balanced.

Balancing is one of the most complex, difficult, and important phases of a game. It is at this stage that the experience and engagement between players are built. What makes balancing complex and difficult are the specific needs of each game, creating different demands and factors to be balanced throughout its design. All four fundamental pillars (mechanics, aesthetics, technology, and story) need to be in sync to immerse players in the magic circle observed by Huizinga (2004) and, thus, ensure a state of flow for those involved.

The concept of flow is extremely important in game design (CHEN, 2007). Csikszentmihalyi (1991) reports that flow provides an understanding of the psychological states during the performance of an activity. Flow is like a state of pleasure in which the tasks to be performed are consistent with the skill level of the performer (CSIKSZENTMIHALYI, 1991). Chen (2007) relates the psychological state of flow to the state achieved by players when playing a digital game, and relates the level of difficulty of balancing a task within the game to the flow state in which the player finds themselves. If the task is too difficult or too easy, the experience will generate frustration for the players involved. Thus, once again, balancing becomes necessary to promote a flow state consistent with the players' skills.

Still in the flow state, the player is fully immersed in the space, time, and experiences created by the game. It is at this point that the content provided by the game is fully conveyed to its players. Achieving this state is one of the key goals for any *game designer.*

To ensure that the game is fun, balanced, and promotes flow in its players, multiple tests are necessary, such as self-tests and group testing sessions. All of these tests are conducted throughout the *design process* to gain *insights* and *feedback* on the game's ability to achieve its intended goals. Because the game's interaction with its players is initially unpredictable, constant review and reevaluation of its system is necessary. After defining the game's requirements, the development of ideas that aim to achieve all of these elements begins.

MATERIALS AND METHODS

This is an applied study with a qualitative, descriptive approach. The main objective was to develop and implement an educational digital game as a teaching strategy for the biological classification of living beings, aimed at second-year high school students aged 15 to 16.

Game development

The game was developed using the C++ programming language, using an integrated development environment (IDE) compatible with Windows systems. The game is based on a binary decision-making system, using conditional structures (such as if-else) to direct the player to the correct organism based on the answers provided.

The game's logical structure was designed based on a dichotomous classification key inspired by the concepts presented by Amabis and Martho (2006). The player begins the game by virtually drawing one of the 32 available organisms. They then answer a series of questions involving the organism's morphological, physiological, and taxonomic characteristics (e.g., presence of tissues, cell type, nutritional status, body structure, skeletal type, reproduction, among others). With each answer, the game directs the user to a new question until the drawn organism is correctly identified.

The algorithm was structured to simulate a decision-making flowchart, which is illustrated in Figure 1 (see Appendix I). The questions and alternatives were developed based on consolidated taxonomic criteria, seeking to ensure consistency between the hierarchical levels and the characteristics of the organisms involved.

The game works simply: a token containing the name of an organism is chosen at random. This name represents one of 32 possible final outcomes of the game. The goal is to achieve this outcome by answering questions based on the organism's characteristics indicated on the chosen token. The names of the organisms on the tokens are presented in Appendix I.

To answer the game's questions, students were allowed to use any study material, such as textbooks, notes from previous biology classes, or study websites, in addition to previously acquired knowledge on the subject.

The game works through a switching system, which uses the answers given by the user, following the flowchart shown in Figure 01 (Annex I).

The questions were written by the authors, using the dichotomous key classification system as defined by Amabis and Martho (2006). Great care was taken to ensure that the final keying system did not conflict, as they were designed based on characteristics of locomotion, reproduction, respiration, cell type, organization, and nutrition. These characteristics can be shared across different levels of classification, given the biological complexity of our planet.

The questions and their respective alternatives used in the game are found in Appendix II.

Semi-structured questionnaire

To assess the students' experience, a semi-structured questionnaire was developed specifically for this study. The instrument aimed to capture perceptions of engagement, question clarity, the game's contribution to learning, and suggestions for improvement. The questionnaire consisted of eight questions: five closed-ended on a five-point Likert scale (ranging from "strongly disagree" to "strongly agree") and three open-ended.

The closed questions addressed, for example:

- “Did the game facilitate understanding of biological classification?”
- “The time to complete the activity was adequate.”
- “The dynamics of the game kept my interest until the end.”

The open-ended questions sought to explore qualitative perceptions, such as:

- “What aspects of the game contributed most to your learning?”
- “What could be improved in the game to make it more engaging or educational?”

The questionnaire content was reviewed by two biology professors, who verified the relevance and clarity of the items. After making minor adjustments, the instrument was administered immediately after the students completed the activity, in printed format, with free time for students to respond.

Application with students

The game was administered to 28 students in their second year of high school at a state public school located in the city of Goiânia, in the second semester of 2023. Participation was voluntary and took place in a supervised school environment.

The study was conducted in the institution's computer lab, which had 30 computers with internet access and pre-installed software. The equipment was arranged individually, allowing each student to have their own space to complete the activity. The class consisted of male and female students with an average age of 15.8, who had basic computer skills and were familiar with using educational digital games.

Before the application, one of the researchers orally presented the study's objectives, the game's rules, and instructions on completing the questionnaire. This introductory stage lasted approximately 15 minutes and included a concise review of the fundamental concepts of biological classification, covering topics such as hierarchical levels, morphological criteria, and examples of groups of organisms.

Each participant then accessed the game on their computer and began the process of identifying the selected organism. During the activity, students worked individually, but were able to ask the researcher for clarification if they had operational questions about the software. They were encouraged to use previously selected support materials—textbooks, class notes, and recommended websites—to aid in decision-making when answering the game's questions.

Throughout the project, spontaneous comments about the experience, as well as any technical difficulties, were recorded. This qualitative observation allowed us to understand aspects of usability and engagement, complementing the data obtained from the questionnaire administered after the task was completed.

Measuring application time

The time taken to complete the challenge (from start to organism identification) was timed by one of the researchers using a digital stopwatch. Each participant's individual time was recorded to calculate the overall average.

Timekeeping was standardized: the moment each student clicked to start the game, the researcher started the timer. The timer was stopped when the participant confirmed the final answer corresponding to the organism drawn. This procedure allowed for an accurate record of the task's duration, excluding breaks for explanations or troubleshooting any technical issues.

To ensure consistency, a single researcher was responsible for monitoring all students, maintaining the same starting and ending timekeeping criteria. In addition to the total time, notes were taken on observed behaviors, such as long pauses to consult supporting materials or the need for clarification on specific questions, to contextualize significant differences between the records.

The data obtained were entered into a spreadsheet to calculate the mean, standard deviation, and time range. This analysis helped identify variations in the pace of resolution, allowing us to assess whether the game's length was compatible with lesson plans and whether it struck a balance between challenge and accessibility for different student profiles.

Data collection and analysis

After the activity, a semi-structured questionnaire with open- and closed-ended questions was administered regarding the game's experience, difficulty level, content understanding, and perception of the methodology used. Responses were analyzed using content analysis, as described in Bardin (2016), allowing for the identification of patterns of opinion, perception of learning, and student suggestions.

Data collection sought to understand the effectiveness of the proposal in terms of engagement, assimilation of content and the contribution of programming logic as a pedagogical tool.

The questionnaire was distributed immediately after the game ended, in a controlled environment, so that the students' perceptions would be fresh in their minds. The researcher monitored the completion of the questionnaire, clarifying doubts about the meaning of some items, but without interfering with the responses. All material was collected on the same day, ensuring uniformity in the collection process.

The responses to the closed-ended questions were coded and tabulated in a spreadsheet, enabling the calculation of absolute and relative frequencies, as well as means and standard deviations. This basic statistical analysis allowed us to summarize the group's general trends in engagement, game clarity, and perceived level of learning.

For open-ended questions, the categorization technique proposed by Bardin (2016) was applied. Initially, all responses were skimmed and grouped into thematic categories, such as "ease of use," "motivation," "difficulties encountered," and "suggestions for improvement." Each category was assigned codes that facilitated counting and qualitative analysis, highlighting the aspects most valued or criticized by participants.

In addition to the questionnaire, notes taken during game observation were incorporated into the analysis, enriching our understanding of student behavior. Spontaneous comments and reactions during question-solving were compared with written responses, providing a more comprehensive view of the pedagogical resource's impact and the adjustments needed to optimize future applications.

RESULTS

During the game, it was observed that 85% of students were able to correctly identify the organism drawn at the end of the sequence of questions. The average time to complete the activity was 15 minutes per student. In spontaneous reports and responses to the questionnaire administered after using the game, students demonstrated enthusiasm and interest, classifying the activity as "fun," "different," and "easy to understand."

Regarding content comprehension, 71% of participants said the game helped them review and consolidate concepts related to biological classification. Furthermore, 68% reported that the activity facilitated the visualization of the differences between kingdoms, groups, and characteristics of organisms, especially regarding cellular structure, locomotion, and reproduction.

Qualitative data, obtained through open-ended responses, indicated that students value interactive methodologies, especially those that involve cognitive challenges and rewards. Many suggested including images of the organisms, soundtracks, and difficulty levels as a way to enhance the experience.

Analysis of individual times revealed some variation among participants, with minimum times of 8 minutes and maximum times of 22 minutes. This variation may be associated with each student's level of familiarity with digital games, as well as the time spent consulting support materials. Despite this, most times were between 12 and 17 minutes, indicating that the proposal is adequate for short-term activities.

The categories extracted from the open-ended responses revealed four main axes: (1) usability, involving interface clarity and ease of navigation; (2) motivation, highlighting the playful nature and stimulating curiosity; (3) learning, with reports of greater retention of concepts; and (4) improvements, highlighting requests for visual and auditory improvements. This organization allowed for a structured view of the aspects most relevant to students.

Another important finding is the perception that the game fostered a more dynamic learning environment than traditional lectures. Several students mentioned that the format of successive questions, combined with the challenge of arriving at the final answer, made the content more engaging and facilitated memorization. This observation suggests that the strategy, in addition to promoting information retention, stimulates decision-making and logical reasoning skills.

DISCUSSION

The results demonstrate the game's potential as a pedagogical resource for teaching the classification of living beings. The high rate of correct identification of organisms and the students' engagement corroborate studies that highlight the importance of active methodologies in biology teaching (KISHIMOTO, 2011; SOUZA, 2021). This convergence highlights that proposals based on practical experimentation and interaction foster motivation and meaningful learning, especially in subjects traditionally associated with the memorization of concepts.

The use of programming logic as the game's structure proved effective not only for organizing the content but also as a tool for logical reasoning and problem-solving, as advocated by Papert (2008) and Delgado et al. (2019). The game's conditional structure, based on choices and consequences, brought the content closer to the dynamics of contemporary digital games, with which students are already familiar. This aspect may explain the enthusiasm reported by participants and the good performance shown in correctly identifying the organisms.

Another relevant point concerns the proposal's alignment with the guidelines of the National Common Curricular Base (BRASIL, 2018). The BNCC emphasizes the need for practices that incorporate digital technologies, encourage student leadership, and foster interdisciplinarity. The game analyzed aligns with these recommendations by combining biology concepts with basic notions of programming and decision-making, offering a contextualized and contemporary learning environment.

Student feedback suggests that the game not only contributed to learning specific biology content but also stimulated curiosity, decision-making, and independent work. The emphasis on elements such as images, soundtracks, and difficulty levels, observed in open-ended responses, highlights the importance of considering usability and motivational design principles in future improvements, as highlighted in studies on gamification in education (WERBACH; HUNTER, 2012).

The discussion should also consider that execution time varied among students, suggesting different processing speeds and learning styles. This finding is consistent with research that advocates adapting digital resources to meet diverse student profiles (PRENSKY, 2012). By offering gradual clues and allowing access to supporting materials, the game demonstrated sufficient flexibility to accommodate these differences without compromising the cognitive challenge.

Furthermore, the use of a digital dichotomous key demonstrates the possibility of integrating classic teaching tools, such as classification tables, with computational resources, resulting in an innovative educational product. Recent studies in science education (SILVA; PEREIRA, 2020) reinforce that the combination of traditional and digital resources broadens the methodological repertoire and fosters analytical skills.

Finally, it is worth highlighting that the experience reported demonstrates the value of interdisciplinarity between biology, Computer Science, and Education, paving the way for future research investigating how programming-based games can support the development of skills required for the New High School, such as critical thinking, problem-solving, and digital literacy. This perspective broadens the pedagogical scope of the proposal, positioning it as an example of integration between technological innovation and curricular content teaching.

CONCLUSION

The development and implementation of a digital educational game based on programming logic proved effective for teaching the classification of living beings in high school. Data obtained during the implementation of the proposal show that students not only better understood taxonomic concepts but also proved more motivated and engaged in the activity, contributing to more meaningful learning.

The use of C++ enabled the creation of a solid and interactive logical structure, fostering students' logical reasoning, autonomy, and decision-making. The combination of biological content and computer language resulted in a pedagogical tool that integrates technology and science in an innovative and accessible way. In addition to fulfilling its instructional function, the game demonstrated potential as an assessment, diagnostic, and review tool, and can be adapted to different educational contexts and age groups.

The results also indicate that the proposal meets the principles of the BNCC (Brazilian National Curricular Framework), by linking biology concepts with programming concepts, promoting student empowerment, and encouraging interdisciplinarity. The experience also demonstrated that the inclusion of motivational design elements, such as images, soundtracks, and gradual difficulty levels, contributes to students' positive perception of learning, reinforcing the importance of considering usability and engagement in digital educational tools.

As contributions, this study highlights that the integration of biology and computational thinking can broaden teachers' methodological repertoire, foster the development of diverse cognitive skills—such as critical analysis, problem-solving, and decision-making—and serve as a model for the creation of digital educational resources in other disciplines. Furthermore, it reinforces the relevance of active methodologies and gamification as strategies capable of aligning science teaching with the interests and abilities of contemporary students.

As future perspectives, we recommend expanding the game with new difficulty levels, integrating multimedia resources (images, videos, and sound), and adapting it for mobile devices to make the tool more accessible and engaging. We also suggest testing in larger classes and in different schools, enabling a more comprehensive analysis of the pedagogical impact. Another possibility is training teachers to use programming logic as an interdisciplinary teaching strategy, consolidating innovative practices in science teaching. Further research could explore the game's effect on different student profiles, as well as its application in hybrid teaching and project-based learning models.

Thus, this study contributes to the field of educational innovation by demonstrating that the integration of biology and digital technologies promotes more contextualized, stimulating, and meaningful teaching, strengthening essential skills for the student's comprehensive development. The evidence obtained suggests that digital pedagogical tools can be strategic not only for teaching specific content but also for fostering transversal skills, consolidating an educational approach aligned with the demands of the 21st century.

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APPENDIX I

CLASSIFICATION OF LIVING BEINGS

1) VIRUS
2) CYANOBACTERIA (blue-green algae)
3) BACILLI (bacteria of the Monera kingdom, rod type)
4) COCOS (bacteria of the kingdom Monera, cocci type)
5) SPIRILLI (bacteria of the kingdom Monera, spirillum type)
6) VIBRIONS (bacteria of the Monera kingdom, vibrio type)
7) ALGAE of the Protista kingdom
8) ANGIOSPERM of the kingdom Plantae (rice)
9) GYMNOSPERM of the kingdom Plantae (pine)
10) PTERIDOPHYTE of the kingdom Plantae (fern)
11) BRYOPHYTE of the kingdom Plantae (moss)
12) PROTOZOAN of the kingdom Protista (Trypanosoma cruz)
13) CNIDARIA of the Animalia kingdom (jellyfish)
14) PLATYHELMINTH of the Animalia kingdom (tapeworm)
15) NEMATHELMINTH (roundworm)
16) ANNELIDS (earthworms)
17) ARTHROPOD (insects)
18) MOLLUSK (octopus)
19) CHONDRICT (shark)
20) REPTILE (alligator)
21) AMPHIBIAN (frog)
22) MAMMAL (man)
23) AVE (chicken)
24) DIPNOIC (pyrambioa)
25) ACTINOPTERYGEA (latimeria)
26) AGNATHUS (lamprey)
27) CEPHALOCHORDA (amphioxus)
28) ECHINODERM (sea urchin)
29) FUNGUS (mushroom)
30) UROCORDATE (sea squirts)
31) CNIDARIANS (corals)
32) PORIFERA (sea sponge)

APPENDIX II

QUESTIONS USED IN IMPLEMENTING THE GAME

QUESTION 01: Does the organism have a cellular structure, that is, is it made up of cells?

1 – YES / 2 – NO

QUESTION 02: The chosen organism has which type of cell:

1 – PROKARYOTIC, cell that does not have a nucleus, the genetic material is dispersed in the cytoplasm

2 – EUKARYOTIC, cell that has a nucleus, the genetic material is found in the nucleus, surrounded by the nuclear envelope

QUESTION 03: Regarding food synthesis, the organism is:

1 – AUTOTROPHIC, synthesizes its own food

2 – HETEROTROPHIC, takes its food from the environment

QUESTION 04: According to the shape and arrangement, the organism can be classified as:

1 – Elongated

2 – Spherical

3 – Spiral

4 – Similar to a comma (,)

QUESTION 05: Does the organism carry out the process of photosynthesis to obtain its food, that is, is it photosynthetic?

1 – YES / 2 – NO

QUESTION 06: Does the organism have special cells organized into tissues or organs?

1 – YES / 2 – NO

QUESTION 07: According to the conductive tissues, such as xylem (conducts water and mineral salts) and phloem (conducts the processed sap)?

1 – YES / 2 – NO

QUESTION 08: Does the organism produce seeds (structure formed from the fertilized egg)?

1 – YES / 2 – NO

QUESTION 09: Regarding reproduction, does the organism produce fruit (structure formed from the development of the ovary)?

1 – YES / 2 – NO

QUESTION 10: Regarding the locomotion structure, the organism is:

1 – NON-SESSILE, has locomotion structures

2 – SESSILE, does not have locomotion structures

QUESTION 11: According to the number of cells, the organism is:

1 – UNICELLED (formed by only one cell)

2 – MULTICELLULAR (formed by several cells)

QUESTION 12: Does the organism have a cell wall made of chitin?

1 – YES / 2 – NO

QUESTION 13: Does the organism have special cells divided into tissues and/or organs?

1 – YES / 2 – NO

QUESTION 14: Does the organism have special cells divided into tissues and/or organs?

1 – YES / 2 – NO

QUESTION 15: Regarding the number of embryonic leaflets, the organism is:

1 – DIBLASTIC, when it presents only the endoderm and ectoderm

2 – TRIBLASTIC, when it presents endoderm, mesoderm and ectoderm

QUESTION 16: Regarding the presence and development of the coelom, the organism is:

1 – ACOELOMATE, that is, the mesoderm occupies all the internal space of the animal's body

2 – PSEUDOCOELOMATE or BLASTOCELOMATE, that is, there is a coelom between the endoderm and the mesoderm.

3 – COELOMATOUS, that is, it has a coelom, which is a cavity in the animal's body

where the organs develop. The coelom is completely covered by mesoderm

QUESTION 17: Regarding embryonic morphology, the organism is:

1 – PROTOSTOME and SCHIZOCOELOME, when the blastopore forms the mouth

2 – DEUTEROSTOME and ENTEROCELOMATE, when the blastopore forms the anus

QUESTION 18: The organism has a body formed by several segments that resemble rings fused together and the excretory system is formed by metanephridia, which are made up of the nephrostome?

1 – YES / 2 – NO

QUESTION 19: What organism is characterized by the presence of articulated appendages and chitin exoskeleton?

1 – YES / 2 – NO

QUESTION 20: Regarding morphology, does the organism present a dorsal nerve tube, notochord and pharyngeal slits during embryonic development?

1 – YES / 2 – NO

QUESTION 21: Does the organism, in terms of its morphology, have a differentiated head?

1 – YES / 2 – NO

QUESTION 22: Does the organism have a jaw, a bony or cartilaginous structure, articulated with the cranial box, which allows the animal to close and open its mouth?

1 – YES / 2 – NO

QUESTION 23: Regarding its supporting structure, the organism has a skeleton of the following type:

1 – CARTILAGINOUS, that is, the skeleton is made up entirely of cartilage

2 – BONE, that is, the skeleton is made up of bones

QUESTION 24: Regarding the morphology of the respiratory system, does the organism have lungs?

1 – YES / 2 – NO

QUESTION 25: Regarding its locomotion structure, does the organism have four limbs (tetrapod)?

1 – YES / 2 – NO

QUESTION 26: Regarding the body's ability to regulate temperature, the organism is:

1 – HETEROTHERMIC, that is, the body temperature would vary according to the ambient temperature

2 – HOMEOTHERMAL, that is, the body temperature remains constant, even with variations in the environment

QUESTION 27: Does the organism have a body covered by scales, carapaces, or plates?

1 – YES / 2 – NO

QUESTION 28: Does the chosen organism have mammary glands?

1 – YES / 2 – NO

FIGURE 01 - FLOWCHART

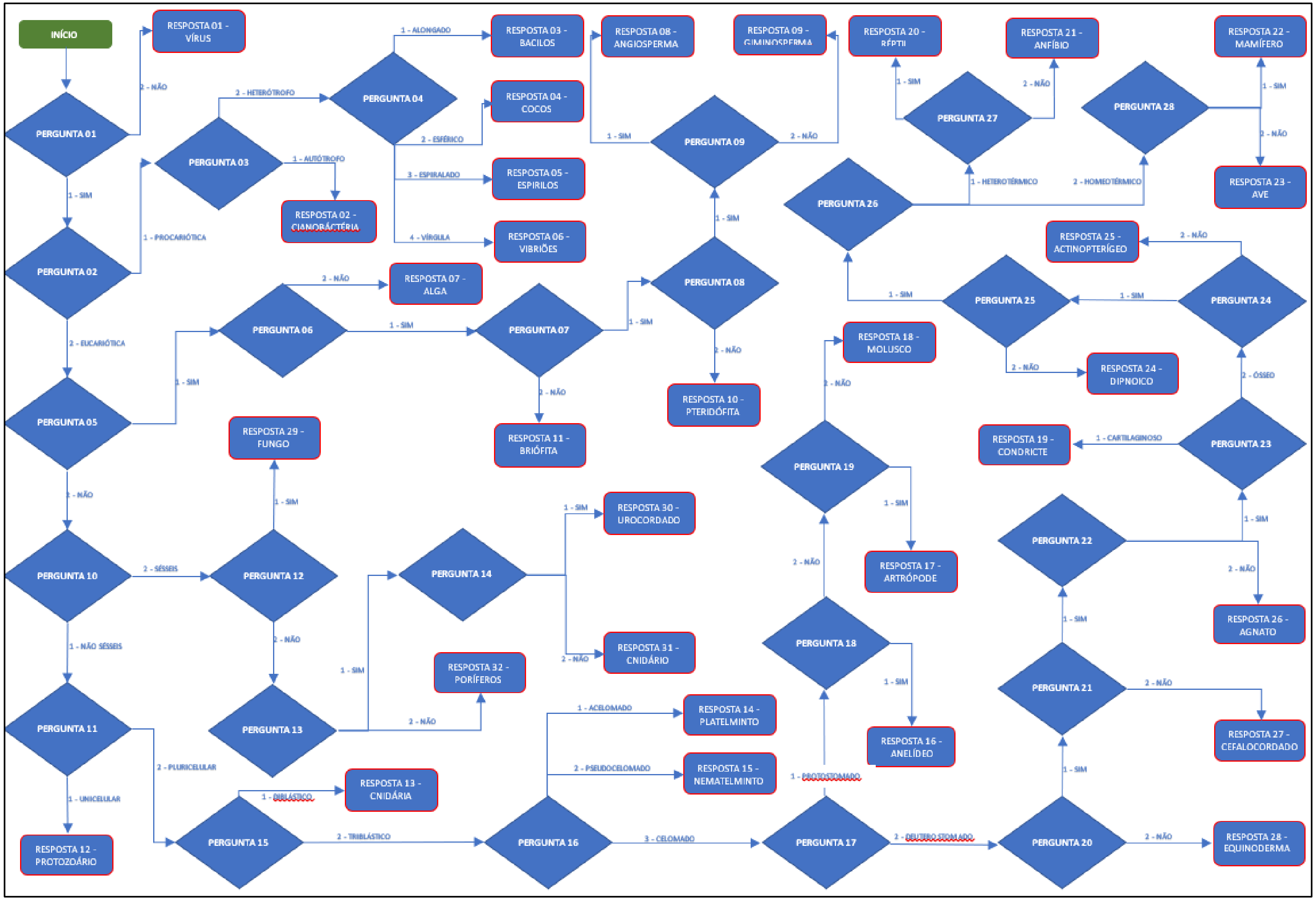

Figure 01 – Flowchart applied in the software for teaching biology for the content of classification of living beings.