IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 28 May 2024, accepted 1 July 2024, date of publication 8 July 2024, date of current version 19 July 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3425054

RESEARCH ARTICLE

Analysis Learning Model With Biometric Devices for Business Simulation Games: Brazilian Case Study

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This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Health Research Ethics Committee - CEPAS of the Federal University of Rio Grande (FURG), Brazil, under Application No. CAAE 45606915.8.0000.5324.

ABSTRACT Educational institutions have been adopting business simulation games as a resource for developing skills and competencies. However, the real-time study of aspects related to learning during their use still needs to further investigation. This work aims to present contributions of a new methodology that considers the analysis of the player's experience from the physiological, behavioural, and psychological perspectives, supported by biometric devices. Its validation was based on data collection conducted at a university in Brazil, with ten participants during a game monitored by Electroencephalogram and Eye Tracking technologies, relating the behaviour of the cerebral cortex with areas of greater interest and gaze fixation of the players. Additionally, pre-and post-test questionnaires highlighted personal behaviours and collective patterns influenced by aspects such as tutorial and game design elements, prior knowledge, ergonomic issues, cognitive strategy definition, organization of executive functions, and memory formation. The results show that the proposed model can be beneficial in assessing the potential of this type of organizational environment simulation, both for those who use it in the teaching process and for serious game developers.

INDEX TERMS Business simulation game, electroencephalogram, eye tracking, E-learning, HCI, player experience, serious game.

I. INTRODUCTION

The Business Simulation Games (BSG) have been gaining prominence as an E-learning resource widely used for simulating the different environments of a company, as it is recognized by the positive evaluation of its users as an excellent tool to support the development of skills such as critical thinking and decision-making and ability to deal with uncertainties and paradigms that involve the management of organizations [1], [2], [3]. By offering several possibilities for viewing scenarios inherent to corporations and with an interactive and exciting approach, the experience with the game itself contributes as a motivating factor for business learning [4], [5].

In addition, a BSG can present market trends and corporate behaviours that help fix concepts and establish important relationships in the contribution of knowledge in the management area [6], [7], [8]. Based on cognitive complexity theory, considering their potential to offer dynamic and complex problems, BSGs can significantly contribute to total brain stimulation, suggesting greater effectiveness compared to other traditional methods of learning and interaction.

Another relevant aspect is that using BSGs in the classroom can promote student inclusion through experiential and participatory learning motivated by gamification elements.

The associate editor coordinating the review of this manuscript and approving it for publication was Vincenzo Conti.

These elements offer the practice of self-control in the process of developing hard and soft skills [9], [10], [11], [12].

In terms of design, multitasking interaction is one of the main features of games. Specifically, with a BSG, this capacity is widely demanded from the player through the multiple decisions that directly influence the business's result, such as actions related to production, sales, workforce, and operating costs. These decisions instigate the player's attention, cognitive flexibility, and response capacity quickly in the face of new situations that constantly arise [13], [14].

As these games require the coordination of cognitive activities, the scenarios collaborate with elements that effectively "capture" the user's attention, under penalty of being labelled boring or, even worse, of not contributing to the expected learning process.

To ensure learning, serious games, including BSGs, are often enriched by features and elements that make analyzing and evaluating their effectiveness through traditional methods commonly used in interactive systems challenging. Thus, developing and improving mechanisms that evaluate the player's experience is crucial to ensure success in an increasingly competitive market with a wide range of products.

Several studies involving the monitoring of the cerebral cortex and visual stimulation of the player using human-computer devices, including the Electroencephalogram (HEG) and Eye Tracking (ET), in different moments and scenarios of other games, reveal cognitive and attentional strategies, contributing to the establishment of some particularities and patterns [15], [16], [17], [18], [19], [20]. However, although there are already studies that use methodologies to understand the Player eXperience (PX), there is little consensus among researchers about which specific techniques should be applied [21], [22] because of the complexity involved in the cognitive and emotional study of human beings during the use of learning technologies, such as games, it increasingly requires experimentation with different instruments for measuring learners' behaviour, including in combination, for more effective results.

The hypothesis considered in this study is that the analysis of behaviour from biometric devices with severe games for business simulation can be an excellent indicator of design aspects of the tool that contribute to the player's learning process when using an experimental model that combines monitoring techniques from physiological, psychological, and behavioural perspectives.

To obtain the expected results, this work employs multiple methodologies to observe players' performance in a business simulation game (BSG). The game McDonald's was chosen because it presents the basic concepts of management in a simple and even playful manner, considering that this is not a widely explored topic in engineering. Quantitatively, the experiment simultaneously monitored the physiological and behavioural signals of the participants, respectively, through the HEG devices, recording the behaviour of the cerebral cortex from the moments of most significant activation of the frontal region and the ET to the areas of most significant interest and fixation of the player look. Qualitatively, the study contemplates the player's perceptions about the game and personal experience. In the end, the results of all collection instruments are analyzed in an integrated way to identify possible elements that contributed to the player's learning process.

II. BACKGROUND

A. CONTRIBUTIONS OF NEUROSCIENCE TO LEARNING WITH SERIOUS GAMES

Whether by resistance to change or in the name of a tradition, it is not uncommon to find educational environments structured by a long-established teaching method, which reflects on the difficulty in adapting to the reality of the world of work and consequently creating an abyss for the student between what he learns in the classroom and what the professional reality will demand in terms of knowledge and skills. Because of situations like this, some research still shows that only a tiny part of the knowledge students acquire during their academic training is used and applied in practice after entering the labour market [23], [24]. However, this scenario is changing.

Recent studies show the recognition of games as an active methodology that allows student empowerment, enhancing educational opportunities by being more flexible and adaptable, highlighting that it is a way to develop digital and transversal skills in all contexts of life, whether personal, social or professionals [9], [25], [26]. In this sense, it is already a reality that institutions around the world, aware of the potential of this digital environment, are adopting severe games (SG), including business-themed ones, as a learning strategy [27], [28]. With these virtual tools, the learner can experience dynamic situations in the most diverse environments, approaching different realities of the organization and building new possibilities for organizational processes. The student interacts as a critical figure so that the exercise of planning, organization and decision-making is as or more important than the expected results [29].

From a neuroscientific point of view, SG promotes the development of skills such as analytical thinking, knowledge transfers and retention, motivation, adaptive learning, and change in the way of seeing and facing situations [30], [31], [32], [33], which can contribute to obtaining and recovering content, offering subsidies for a possible reconstruction of a moment or context. When dealing with something unusual and different, the brain tries to connect to an existing neural network, providing new information that potentially increases the retention of information, considering that a new situation makes sense or has real meaning when it fits a pre-existing neuronal pattern [34], [35], [36], [37].

Experimentation with the SG also influences the affective behaviour of players due to the close correlation between brain functions and aspects related to their feelings, precisely because limbic and paralimbic structures, the vegetative nervous system and reticular activation are closely related to processing and command of emotional behaviour [38], [39]. In this way, the SG elements and resources provide, through a virtuous flow, a feeling of well-being that motivates the user to challenge themselves and learn, promoting their individual and social skills according to the purpose and interaction possibilities of each game [40], [41], [42].

Other studies in the field of cognition have offered insights into simulation and SG by demonstrating that their use increases the volume of the cerebral cortex, develops neuronal plasticity, and improves visual acuity. It also increases motor coordination and memory, in addition to simple recognition of a situation or context [43], [44], [45], [46].

B. THE ANALYSIS OF THE PX IN BSG USING BIOMETRIC DEVICES

Some research games indicate that their analysis needs to go beyond the user experience (UX), which aims to establish how easy and well-suited the system is, in this case, the game, for the task that the person expects to perform in the requirement. Of usability [47], [48]. Players are primarily looking for stimulating games, so getting to know them better is necessary, using resources that allow you to point out how they behave and motivate them during the game. [49], [50]. Other investigations highlight the importance of investigating the cognitive, social, and emotional components of the experience that arise from the interaction between players and a game, including SG [43], [51], [52], [53]. These investigations show that knowing the uniqueness of the gaming experience is an essential reason for its remarkable success. This complexity of factors established the need to develop a new area of study that has been gaining strength recently: PX, which aims to investigate the cognitive, emotional, and social components that arise from the personal experience between the player and the game.

The PX research considers the user's state and their interactions at different times and levels of difficulty that are provided from the beginning to the end of the game [53], [54], [55].

Therefore, knowing how PX is structured is essential to systematically address the mechanisms that stimulate the game and enable it to fulfil its objectives. PX typically involves an experimental analysis of game system characteristics related to difficulty levels, control flow, and feedback related to their context. Through careful manipulation of these variables, it is possible to identify and quantify the specific effects of design or decision changes that occur during the game. For a better and more detailed understanding of PX, its components can be divided into physiological, behavioural, and psychological [42], [56].

The measurement of physiological activity allows monitoring of players' cognitive and emotional states through sensors in contact with the surface of human skin.

The monitoring of the behavioural component takes place through the measurement of elements of attention and interaction with the game through the recording of images or technologies such as ET.

The psychological assessment is based on the player's perception and uses tools such as pre-and post-game surveys or interviews. It is considered the most straightforward and least expensive approach. Still, information can be lost in the delay between the action (gameplay) and the recall (interview or questionnaire), unlike the other two that are obtained in real-time with the game [56].

The constant evolution of sensing technologies has provided new possibilities for monitoring people's interaction with e-learning tools, including games. Studies based on PX assisted by biometric devices such as electroencephalogram and eye tracking have provided a more accurate analysis of its characteristics, functionalities, restrictions and contributions to the design and optimization of SG, Simulators and BSG [17], [20], [57], [58], [59], [60], [61], [62].

A recent research field called Games User Research (GUR) combines research on Human-Computer Interaction (HCI) and game development [63], [64]. From the observation and understanding of the individual and personal experience maintained by the player before, during and immediately after the game, the methodology aims to provide subsidies and insights for the design of games that meet the expectations of its users.

Through devices and data collection tools, the user researcher applies psychology-inspired methods and user-centred design to monitor and evaluate the player. The communication channel is multidirectional, allowing interpretation of player reactions (and often questions) to determine which game features can be improved.

A proper GUR methodology considers player involvement crucial in game development, irrespective of its application as entertainment or education. Of gameplay and monitoring devices. Using an increasingly valuable mixed-methods approach, he leverages the benefits of each technique and complements their limitations. The great challenge of each research with serious games is, from the objective proposed in each experiment, to identify which instruments are best suited to provide the most efficient and effective result [63].

The EEG and ET biometric devices have already been widely used in UX analysis in the business context [65], [66], [67], [68], [69]. EEG research collaborates with data for the analysis of mental effort and emotion, characterized by high resolution, which means that changes in brain activity can be detected immediately after they occur.

Measurements from different EEG devices have also been considered in-game experimentation research [70], [71], and regarding its use in monitoring the PX of players, it is recognized as a reliable data source of cognitive processing [72] during your interaction.

The ET, a device that provides performance measurements and eye movement trajectory patterns during a pre-defined activity, has immense potential for monitoring PX. Currently available in different constructive technologies, using the emission of infrared rays or systems that take advantage of the webcam itself for eye recognition and tracking [73], its scope of application includes monitoring the experience of customers in the marketing area [67], [68], analysis of the usability of a system and games in general [57], [74], and more recently in studies of human behaviour and neurosciences [73], [75], [76]including the joint and complementary use with EEG [77].

It is important to highlight that the methodology proposal and the experiment for its validation, applied in this study, were designed based on previous work developed by these authors, including the analysis of existing theoretical and practical scientific contributions, aiming at the creation and implementation of an innovative and complete PX monitoring and evaluation structure with BSG [78], [79], [80], [81]. These same investigations complement the concepts and approaches presented in this chapter for a deeper understanding of this topic.

III. THE PBP METHODOLOGY FOR BSG ANALYSIS

The application of an experimental methodology presupposes the use of different instruments arranged in an orderly manner to solve a problem and obtain substantial contributions in the search for a solution. Its results must allow a closer understanding of reality and confirm or not assumptions, points of view, and convictions [82].

Given the potential contribution of biometric devices for the analysis of BSG, a model capable of covering the different methodological approaches in monitoring PX with serious games was created [56], [83], integrating different data collection instruments.

Thus, considering the physiological, behavioural, and psychological perspectives, the authors created the PBP methodology [79], an innovative proposal about other existing ones [80]. This theoretical study emphasizes the potential of utilizing various physiological and behavioural devices for data collection, provided they can measure variables corresponding to the respective monitoring perspective, allow for simultaneous data analysis, and deliver reliable results to address the questions outlined by the proposed study. Additionally, the Pre- and Post-Test questionnaires can be customized to align with the objectives of each game and correlated with data from biometric devices.

To illustrate the methodology's flexibility, the experiment presented in the following chapter used, at the authors' choice, Webcam Eye Tracking and EEG devices, in addition to pre-and post-test questionnaires previously prepared with open and closed questions. Another previously published study to validate the methodology [84] used a HEG device and ET glasses to, more specifically, analyze engagement as an element of PX, relating the variation in blood flow in the prefrontal cortex and pupil dilation, complemented by the players' perceptions. Along the way of methodological construction and improvement, other experiments were and have been carried out using devices such as ECG, facial expression, and body temperature monitoring.

Because it is an experimental methodology that uses more than one device, the choice of the most appropriate technologies must consider possible technical interference that they can provide when used together, as well as impacts on the player's behaviour, compromising the results. This concern arises from the fact that the interest in creating and executing an experiment lies in the effect that a method or tool has on one or more specific attributes to obtain significant results [85]. Thus, far from a purely conceptual proposal, the PBP model considers an operational and practical structure.

In this sense, using the signals from a device to collect physiological signals, simultaneously with the use of existing technology as a source of behavioural data, and complemented from a psychological perspective by the self-perception of the experiment participants through Pre and Post-questionnaires, the PBP model integrates the results obtained, to understand and explain how the player plans and reacts to the different situations provided by BSG.

IV. MATERIALS AND METHODS

The methodology adopted for its experimental validation considered the generation of quantitative and qualitative data since, using the mixed approach, it is possible to mix, invert and explore different types of data offered by different collection instruments better to understand the event under study [86].

Despite a more complex application, mixed research with its multiple approaches can offer excellent contributions [87] and is very much in line with the data collection structure of this study when considering the composition of biometric devices and questionnaires of self-perception for the prospection and analysis of information.

The experiment took place at the Federal Institute of Education, Science and Technology of Rio Grande do Sul (IFRS), Campus Rio Grande, Brazil, involving seven students and three professors from an engineering course. Of the 10 participants, nine were male, and one was female, aged between 21 and 41 (M=28.80; SD=8.64). All subjects participated voluntarily and declared they did not have a learning disability through a consent form.

It is essential to justify the criteria to define the sample size [88]. There has yet to be unanimity in the scientific community regarding the definition of the sample size involving the collection of physiological signals [89]. Research shows that in most EEG-based experiments, subjects typically range from 10 to 20 [90]. It is still possible to find studies collecting EEG signals using even smaller samples [91], [92]. During the experiment design process, some tests conducted with the devices in games indicated a smaller sample size, initially between 10 and 15 participants, mainly due to the magnitude of data generated, and two collections would be carried out to validate the methodology. Other vital occurrences during the process were predominant in the definitive choice of the number of individuals. The most critical thing was that the experiments took place during the COVID-19 pandemic, which brought a series of restrictions to their execution. An additional precaution was to select a sample that was as significant as possible regarding gender, age, and academic curriculum level to maintain a good representation of the population. The time stipulated for monitoring the game (20 minutes) was also a limiting factor, considering the amount of individual data generated by the 3 data collection instruments and their subsequent cross-analysis. For all these reasons, a sample size of 10 participants was used for the first validation [84], which was maintained for this second experiment with the chosen BSG.

The game used in the methodology validation experiment was The McDonald's, a BSG designed by Molleindustria, that provides company management knowledge in a more playful way, in which the player assumes the role of director of a well-known chain of fast-food stores in the search for the best result for its shareholders. The business sustainability in the game is achieved through multitasking decisions taken in four environments, representing different processes: Screen 1: Agricultural and Livestock Section, Screen 2: Cattle confinement and slaughter, Screen 3: Production and sale of Fast Food, Screen 4: Headquarters.

To monitor the behavioural variables, the online ET system developed by Realeye was adopted as a license to capture images through the user's webcam and store data in the cloud through the computer. The average spatial accuracy of this chosen tool (113 px) is consistent with moving stimuli and sufficient to replicate in eye fixation captures [62]. The technology uses the moving median algorithm to reduce the influence of noise on real results. Level 21 was applied, meaning a median was calculated for twenty-one consecutive measurement points. For the gaze speed limit, classified as fixation, the recommended level of 180 px/s was used with a sampling rate greater than 20 Hz. This technology is recognized as a reliable and low-cost alternative for online eye tracking [93], [94], [95]. Data recording and collection begins, with a time limit of 10 minutes of gamming after an eye calibration procedure at viewpoints positioned at different points. The features made available by the license on the developer's website include, in addition to recording and storing data in a virtual repository, visualization tools through heat maps and fixation graphs, obtained from the images recorded during the tests.

To obtain the physiological signals, the Emotiv EPOC device was chosen. This technology measures EEG signals adjustable to the head in a headset-type format. It contains 14 measurement electrodes distributed in the cortex according to the international system 10-20: AF3, F7, F3, FC5, FC6, F4, F8, FC4 (frontal lobe); T7, T8 (temporal lobe); P7, P8 (parietal lobe); and O1, O2 (occipital lobe). Two other sensors act as external electrical references: P3 is a reference point to which the amplitude of all other sensors is compared, and P4 is a feed-forward reference that reduces external electrical interference, bringing more quality and reliability to the generated signal [96]. The signals are submitted to Pre-amplification, high-pass filtering with a cutoff point of 0.16 Hz, and low-pass filtering with a cutoff point of 83 Hz, forming the adequate bandwidth. The Emotiv Pro Software license, provided by the device manufacturer, was used to record, store, and visualize the brain waves. This application features its pre-processing technique and an algorithm for removing artefacts applied to the collected EEG data with adequate reliability [97], [98]. Another feature that adds value to the device is wireless technology for signal transmission, being recognized as a lightweight and easy-to-use device, even for prolonged periods. A study analyzing ergonomic aspects using human-computer devices identified that, when using Emotiv Epoc, more than 75% of those surveyed feel comfortable when using it, even for times exceeding 60 minutes [99]. To capture the signals, the electrodes are moistened with saline solution (the same solution used to clean contact lenses) to reduce the impedance between the electrodes and the scalp, which is another advantage of this technology over other EEG devices.

Fig. 1 shows the sequence of steps for executing the experiment by applying the PBP model with each participant.

According to the sequence of operations established in Fig. 1, applying the pre-test (i) made it possible to obtain socio-demographic information and study variables, including reports of previous experiences and design perceptions about the GP. The correct preparation of the HEG and ET devices (ii) was essential to guarantee data fidelity and avoid any disturbances that could interfere with the PX. In the case of HEG, after inserting the cap on the user's scalp, it was necessary to adjust the position of the electrodes until they all obtained an adequate signal level. In the case of ET, the system required calibration through an eye fixation test at different points on the screen. Data collection while using BSG (iii), including the tutorial, has been structured to start and end simultaneously, keeping both devices synchronized. Throughout the experiment, the signals were monitored by another computer. All devices were turned off and disconnected (iv) immediately after the experiment's end, and all collected data were saved. In the case of HEG, due to being in physical contact with the player, the cap was removed so that he could complete the final stage of the test. At ET, the camera was turned off. The application of the post-test (v) addressed questions about the experiment and their perception of BSG, the constructive resources offered by the game, the time available for learning, and what helped or hindered the gameplay, including monitoring devices.

V. DATA ORGANIZATION AND RESULTS

The data organization, guided according to the model proposed for analysis, took place from three sources: EEG as a physiological analysis device, ET as a behavioural monitoring device, both used concomitantly and the Pre-Test

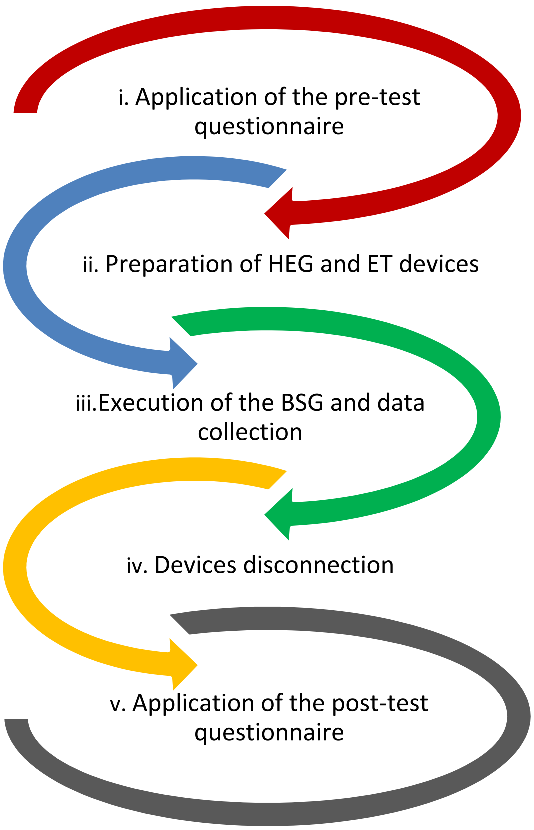

FIGURE 1. Visualization of the flow of activities of the experiment with each participant.

and Post-Test questionnaires as psychological measurement instruments, for subsequent cross-referencing of information. For processing and visualization of the data, the software of the EEG and ET devices was used, and it was available after the acquisition of the respective licenses. To monitor the EEG brain signals, with the Emotiv Pro Software, it was possible to monitor the activation of all 14 electrodes in each BSG moment or select them individually or even by groups of interest, such as, for example, all electrodes of the frontal cortex. The parameter analyzed from the EEG collection was the amplitude (A) of the electrical signal (in μV) of each electrode, individually for each participant, seeking to establish relationships between the possible areas of the brain activated at different times (frontal lobe, temporal lobe, parietal lobe, occipital lobe), together at certain times of the BSG. For the visualization of the signals coming from ET, with the Heat Maps Panel present on the Realeye platform, it was possible to follow the fixations of each participant throughout the experiment, represented in colour tones that made it possible to identify the regions of greater concentration of gaze of the player, in specific periods and areas of interest (AOI) in the different screens of the BSG. In this data structuring phase, the pre-and post-test questionnaire answers were organized and summarized in graphs. Faced with the high amount of information the devices and questionnaires generated, some criteria were established to select the most significant points in validating the proposed analysis model. Conceptually, a BSG seeks to learn an organization's environment from a virtual experience that requires decisions permeated by strategy [4] and, from a neuroscientific point of view, the area of the brain that regulates the central executive functions responsible for this mental process is the frontal cortex, by incorporating complex cognitive resources such as working memory, problem-solving and reasoning [100], [101]. Also, considering the frontal cortex as the area of the brain most covered by EEG (8 electrodes), it was then decided to analyze, individually from P1 to P10, the most significant Amplitudes (A) at these points and, in the sequence, cross them with other possible brain areas activated, considering the different electrodes. The idea of analyzing separately and then joining the data little by little was defined to facilitate the visualization of the graphs generated by the EmotivPRO application, according to Fig. 2.

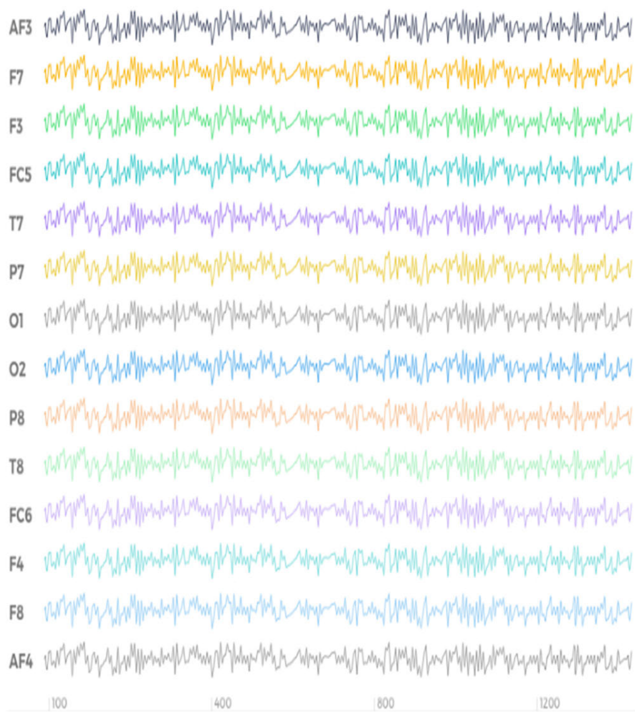

FIGURE 2. Raw EEG plot (14-channel data) displayed on Emotiv Pro application.

It is possible to configure the presentation of the display of the electrode signal in Fig. 2. Using Channel Spacing, the height of the display area of a channel is adjusted in multichannel display mode, changing the vertical resolution of the display when more than one channel is displayed. It is possible to set the minimum and maximum display amplitudes, select the scale to automatically align the upper and lower limit according to the current channel values (the lower limit is +/− 100 uV), and activate the high-pass filter that removes DC offset by applying a 0.16 Hz high-pass filter.

In the sequence, the same relevant periods identified in EEG were analyzed from the perspective of the heat maps generated by ET to observe the player's attentional strategy and, also, together with the perceptions of the players in the questionnaires, to bring, in the end, a consistent meaning for the information from all instruments used. The detailed sequence of steps for selecting and analyzing results is described in Fig. 3.

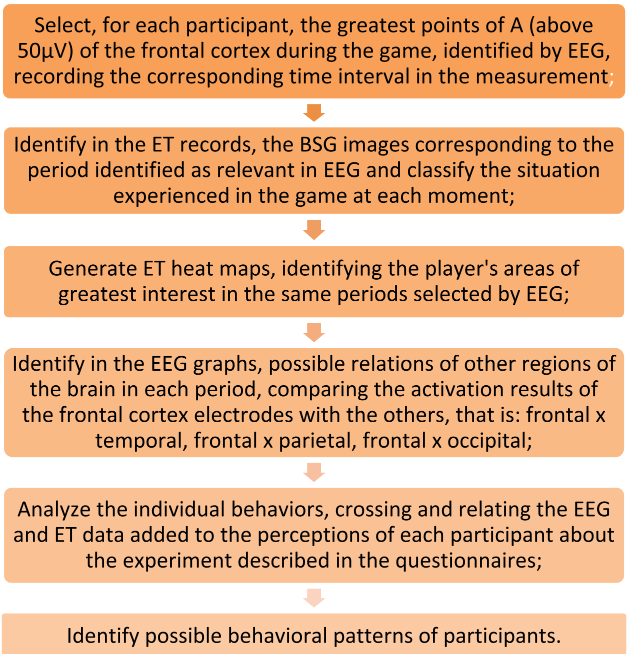

FIGURE 3. Sequence of steps for selection and analysis of results obtained.

As defined in the experiment's dynamics, the tutorial's visualization occurred before the BSG started. This time was also monitored by the EEG and ET devices to offer a complementary source of information in the analysis of the game, making it possible to subsidize possible behavioural changes, mainly in the phase start of the activity. For this purpose, for each participant, 3 to 5 periods were selected in which one or more electrodes of the frontal cortex presented greater signal amplitude during the tutorial reading, and the respective heat maps of the fixations were registered.

For the periods with heightened activation of the frontal cortex throughout the game, as indicated by the EEG, we meticulously classified the corresponding player experiences into one of the following 7 distinct categories: Game Start (GS), Operational Decision (OD), Strategic Thinking (ST), Insight (IS), Critical Situation (CS), Ethical Dilemma (ED), and Game Over (GO). This detailed categorization provides game developers with a nuanced understanding of player engagement and decision-making.

In the complete study, all these results of the ten players, available in the graphs of amplitude (A) of the electrical signal (in μV) of the 14 electrodes, were grouped in a table to facilitate the crossing and critical analysis of the information and, in the sequence, were selected 20 to 24 points. In the complete study, all these results of the ten players, available in the graphs of amplitude (A) of the electrical signal (in μV) of the 14 electrodes, were grouped in a table to facilitate the crossing and critical analysis of the information and, in the sequence, were selected 20 to 24 points.

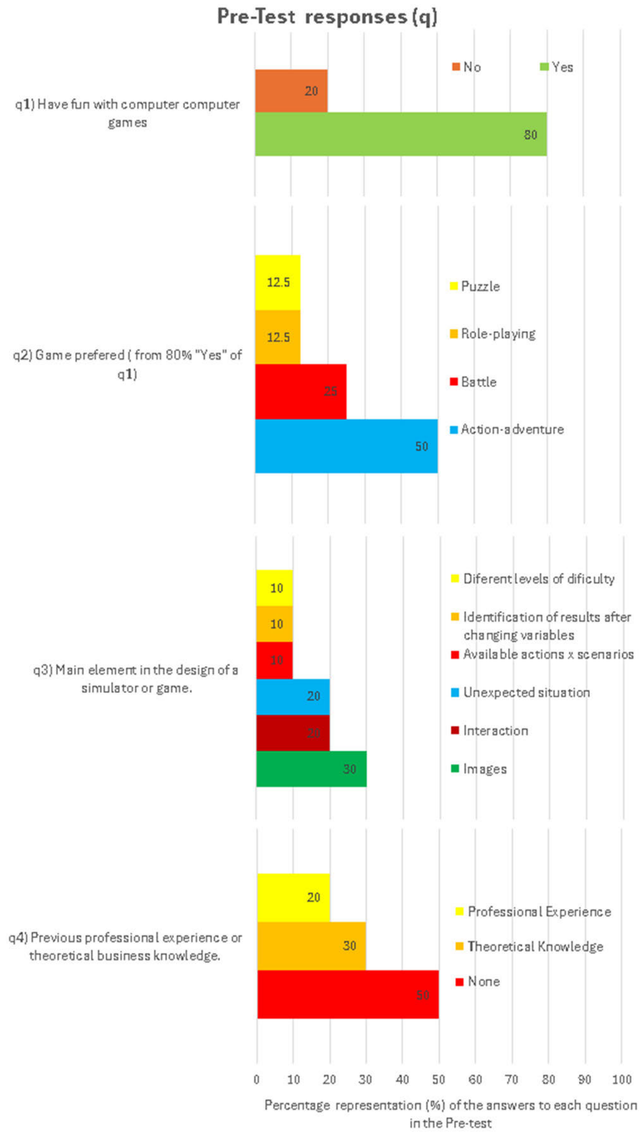

FIGURE 4. Answers obtained from participants to the questions applied in the Pre-Test.

Considering the complexity of the method, for the discussion of individual data in this article, a period was randomly selected for every two participants in moments of the seven categories created and during the tutorial reading so that all players were included in the analysis.

The EEG signals and TE heat maps resulting from the collections at the moments selected by the participants can be viewed in Table 1 and Figure 6, which also includes a description of the recorded game moment. The data was highlighted in different colours according to the established categories. The Pre-Test was designed to record participants' previous experiences and perceptions regarding the use of serious games and to identify possible influences of preconceptions and prior knowledge on game performance and their relationships with other results. The questions (q1 to q4) and the corresponding answers are represented in Fig.4.

Regarding the Post-Test, ten questions were directed to recording participants' perceptions about the experiment they were subjected to and their PX with the BSG. The answers, grouped by questions (Q1 to Q9), are presented in Figure 5.

The post-test also included an open-ended question (Q10) about what the participants would change in the game. The answers from each participant are presented below:

P1: "Greater clarification in the use of land";

P2: "Nothing, it was really fun";

P3: "As previously mentioned, the action of moving cattle for slaughter";

P4: "The game's interface and image quality";

P5: "Other types of monitoring charts";

P5: "A more dynamic way of playing";

P7: "Add variables such as the one mentioned previously: the option of off-season slaughter so as not to stop the industry";

P8: "It's a very fast game, maybe make it slower";

P9: "I believe that the Game is already in a very clear and objective way";

P10: "Receive warnings on any screen, without having to go to the specific screen to consult".

It is important to clarify important aspects of some Post-test answers. In Q1, the interference from the measuring devices that participants P1 and P7 reported is related to momentary losses of the ET signal because they moved their heads excessively during the experiment. In question Q2, participant P3, who registered some discomfort, reported that the table where he played the game had a small drawer that hindered his positioning.

VI. DISCUSSION

The interlocution between results obtained through the different data sources was structured according to the PBP methodology, allowing an individualized analysis in selected moments of the tutorial and the seven categories defined for PX monitoring with the BSG.

A. TUTORIAL

A study points out that, in addition to the areas associated with the frontal cortex, the joint activation of the temporal and parietal regions is related to the process of storage and processing of working memory [102], in line with what was identified in the period selected from P1-Tutorial, in Table 1, by intensely activating all 14 electrodes. At the same time, the HMTT-P1 heat map, Fig. 6, shows that P1 divides his attention into different points to establish relationships between the guidance board and the other visual elements on the screen, such as the position of the oxen and equipment. This behaviour seems to be associated with the multi-component model for the composition of working memory [103], which explains that the brain's executive centre creates a sense for the combination of visual semantics,

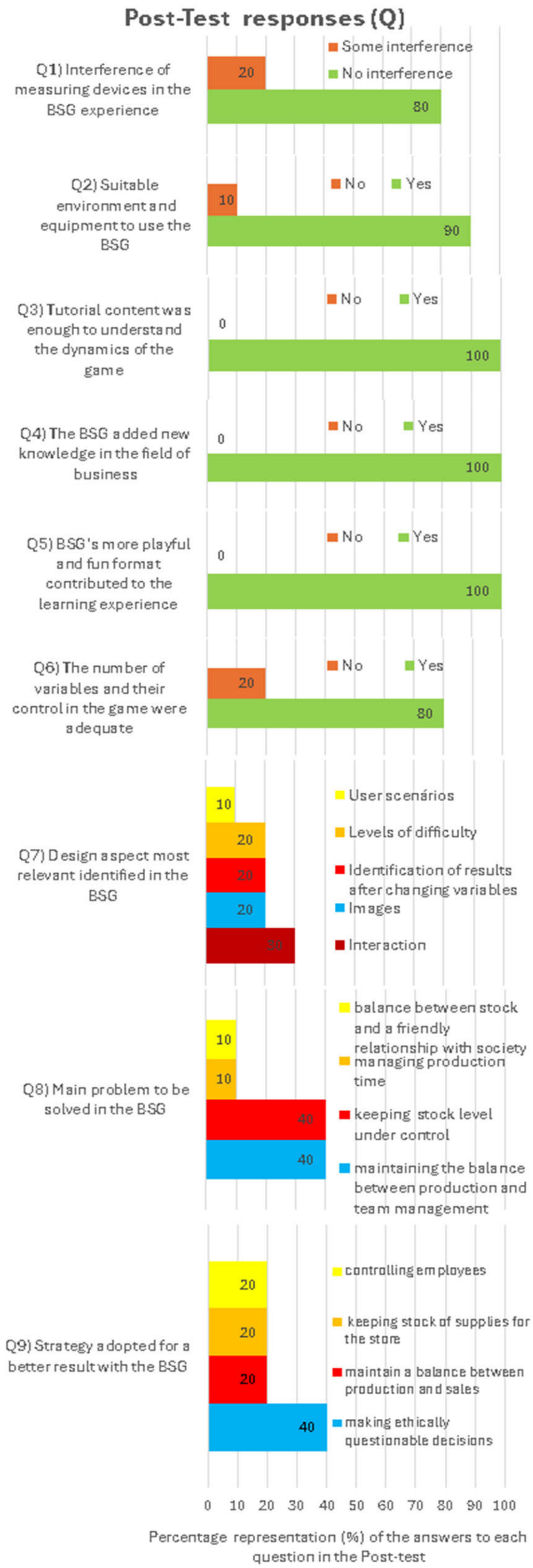

FIGURE 5. Answers obtained from participants to the questions applied in the Post-Test.

language, and episodic memory, justifying the activation of the occipital region. P1's Post-Test questionnaire also justifies this player's behaviour when he considers the visual elements presented to be the most important resource in the game.

In the selected period of P4 along the appropriation with the content of the tutorial, presented in Table 1, the entire frontal cortex is activated, demonstrating a recurrent activity of the executive function probably in the process of conception of the working memory as indicated by the scientific study [104], and also by the high level of attention identified in the HMTT-P4 heat map, as shown in Fig. 6, concentrated mainly in the guidance boxes and adjacencies of the respective tutorial pages. In addition, the greater complementary activation of the electrodes of the right hemisphere of the temporal (T8) and parietal (P8) region seems to be related to the study that shows that activation of the temporal and parietal lobes in the right hemisphere is associated with activities of perception and production of the general shape of an object and its proportions [105]. This behaviour also reflects his answer to a pre-test question, in which the participant chose the image resource as the most important element of a game. In another question, he describes a previous experience with other action games, highlighting his familiarity with that environment.

B. GAME START

The HMGS-P2 heat map, according to Fig. 6, shows that in addition to paying attention to the main elements on the screen, the player has a shift in gaze towards non-significant points. What may appear to be a lack of attention or focus on the game might have another explanation, especially considering that P2 had an excellent performance. P2 was one of the three players who maintained the company's results at reasonable levels and avoided a Game Over condition. The explanation may be related to the result of research that assumes that the gaze is briefly diverted from the leading fixation site when the subject needs to align what the author calls intersubjective attention [106], seeking to organize their thoughts about the task. Other research points out that looking away is a way of dwelling reflexively on an unexpected situation or threat as a form of adaptive behaviour, where more time is allocated for processing information and developing an adequate strategy to deal with a given situation [107]. As shown in Table 1, the fact that all 14 electrodes were significantly activated at that moment demonstrates that P2 starting the game is very involved in the cognitive and emotional management of the initial screen (frontal lobe), identifying movements (temporal lobe), spatial representation (lobe parietal) and visualization of the images of the BSG (occipital lobe), which is in line with the participant's report in the Pre-Test questionnaire, when describing his taste for games, and in the Post-Test when he states that it was ''…a lot of fun''.

The period during the beginning of P3's game, according to Table 1, shows the EEG signal with activation of all eight electrodes of the frontal cortex. The corresponding heat map, HMGS-P2 in Fig. 6, presents the player's attentional focus on a land space on Screen 1 immediately before the decision to elect this zone as a planting area. This combination of results suggests that the player was activating his executive functions and working memory when defining his first decisions in the game, corroborated by studies that support this behaviour [60], [104]. When we also consider the possibility of possible interaction with the player's previous memories in the construction of his action logic in the BSG, based on the influence of prior professional experience in the area of supply logistics reported in the Pre-Test, in addition to Screen 1 having been revisited more intensely than others throughout the game, it is possible to associate such conduct with research that points out that the elaboration of new associative memories that fit in previous knowledge involves areas of the prefrontal cortex, either in the recovery of remote or recently consolidated memories [108].

C. OPERATIONAL DECISION

The HMOD-P6 heat map, as shown in Fig. 6, shows P6 on Screen 1 of the game, orienting itself on where it will define the region for planting or raising cattle. At that moment, according to Table 1, the most activated brain regions are the frontal, temporal and parietal cortex, predominantly on the right side, which seems to be related to a study that indicates that although spatial attention can induce changes in connectivity in both hemispheres, there is good evidence that several areas of the right hemisphere, particularly the frontal, intraparietal, and temporoparietal junction, play a dominant role in the actual implementation of attention, regardless of where it is directed [109]. Regarding the operational decisions, the contribution of the Post-Test comes from the player's report that his strategy to solve the main problems of the game was: ''decreasing the number of employees helped to reduce the stock'', which in addition to being a decision mistaken does not follow the logic of the game. At the same time, P6 was the player who made the least progress in the BSG chronology and spent the most time on each screen. This can be explained by research on games that show that experience and performance do not always coevolve [110]. The study shows that some players cannot increase their performance as their experience increases, and it also shows that the difficulty affects the level of mental effort, which seems to justify why the game consumed the player's cognitive skills and did not reflect on a good result.

The HMOD-P8 heat map, as shown in Fig. 6, shows P8 on Screen 1 orienting itself, where it will define the region for planting or raising cattle. According to Table 1, the most activated brain regions are the frontal, temporal and parietal cortex, predominantly on the right side, with brain behaviour like that reported for P6 through a similar attentional attitude reflected in its cognitive activation [109]. The visual resource is also valued by the player himself, as can be seen in the player's report, both in response to the Pre-Test and the Post-Test, that Images are, respectively, the most crucial element in a game and the main resource of the game. BSG experienced. Despite P6's similar brain activation, his more exploratory strategy and spatial attention to images elicited a different meaning and better PX for P8, even though he reported disinterest in games.

D. STRATEGIC THINKING

The selected period of P1 portrays the moment of the first interaction with Screen 4 to act strategically in the BSG. As shown in Table 1, his cerebral activation of the frontal and right temporal cortex coordinate this more exploratory first contact, in this case, regarding the available tactical planning resources. This behaviour can also be observed in the HMST-P1 heat map, Fig. 6, when identifying a concentration of attention in each area that makes up the Head Office. In conjunction with the prefrontal and frontal cortex, activation of the temporal region acts as a filter between relevant and non-relevant), such as attentional processes that precede perception and action in more complex cognitive tasks [111], [112]. As reported in the analysis of the player's behaviour while reading the tutorial, the Post-Test questionnaire can also help to clarify this result by identifying his statement that the main problem to be solved and the strategy adopted in the game are not related to the variables strategies provided on screen 4, while keeping attention on form and movement.

The period selected from P10 portrays the moment the player has the most contact with Screen 4 in defining his strategic planning in the game. As shown in Table 1, their brain activation involves the frontal and right temporal cortex (T8) coordinating this first, more exploratory contact, in this case, regarding the available tactical planning resources. This behaviour can also be observed in the HMST-10 heat map, Appendix B when identifying an attentional concentration in each area that makes up the strategic decision screen. Repeating the cognitive behaviour identified with other participants, this result reinforces the findings that show that the more intense activation on one side of the temporal lobe seems to be related to studies that show that attention is the result of a network of cortical and subcortical connections of predominance law [113], [114], [115]. The importance of manipulating strategic variables in the game was identified by P10 when he reports in the Post-Test questionnaire that one of the main problems to be solved in the game is: "…complaints from society", a topic mainly addressed in Screen 4.

E. INSIGHT

The activation of the 14 EEG electrodes in the selected period of Insight indicates, according to Table 1, a high activation of all monitored brain regions. This behaviour seems to reflect the registers identified in the heat map HMIS-P3, according to Fig. 6, with the discovery of the resource for changing the speed/pause of the game on Screen 1 proving to be an exciting resource for the player and, subsequently, he continues to interact with other elements of the game to evaluate the result. This behaviour suggests an alignment with studies that point out that to solve problems from an insight, restructuring involves a perceptive reinterpretation of the situation, directing attention to the critical elements of the problem, recombining them to build a new meaning or a change on the goal [105], [106], and this new mental reorganization may require a brain connection involving the frontal, parietal, temporal, and occipital lobes. When also the psychological perspective of the player in this analysis, their perceptions in the Post-Test are closely related to the referred screen, justifying the involvement and attentional, cognitive and emotional effort, as observed in answer to a question, in which P3 reports that his strategy for the success of the game is related to Screen 1, and in another question, in which he describes what he would change in the BSG: "the action of moving the cattle to Screen 2".

The selected moment of P9 shows the significant activation of electrodes of the frontal, temporal, parietal, and occipital regions together, as shown in Table 1. By analyzing the HMIS-P9 heat map in Fig. 6, the player's quest to understand the process x speed relationship between production and sales on Screen 3 of the BSG is identified. As with other participants, this situation meets the concept of Insight, as an instant to take advantage of new tips received and experienced situations to reorganize their action strategy [105], [106] for success with BSG. This behaviour of Participant P9 also corroborates what he reports in the Post-Test: "The main problem was having to manage production time".

F. CRITICAL SITUATION

The heat map HMCS-P4, according to Fig. 6, shows that in addition to the attention on the main elements of Screen 3 of the game, analyzing the store's complaints, the player presents a deviation in the look to non-significant points below the screen. This behaviour may be related to reflective analysis [95], [96] as a strategy to deal with the situation. According to Table 1, the fact that all 14 electrodes are significantly activated at that moment is an indicator that P4 seeks to reorganize himself cognitively and emotionally from the screen, which is in line with the participant's report in the Post-Test questionnaire when he states that "The game brings excellent proposals for learning, and contributes to learning, as it shows the reality of managing a company.". This may be an essential indicator that even with his low performance in the game, P4 did not let himself down to the point of recognizing the learning with the BSG.

In the selected situation of P7, significant activation of all 14 EEG electrodes was also identified, as shown in Table 1. For this same period, the HMCS-P7 heat map, Fig. 6, shows the exact moment of viewing the image of a BSG warning on Screen 2. This feature of interrupting the game to present an impactful report has been an element of cognitive solid and attentional ap-peal for P7. This situation reveals a moment of reorganization of thoughts about the situation experienced, directing attention to the critical aspects of the problem for a re-signification of the goals to be achieved [116], [117], and which requires a mental effort that integrates areas of the frontal, parietal, temporal, and occipital lobes. The importance of the text messages offered by the game in the process of understanding and learning P7 was recognized by the player himself in the Post-Test response: "The game provides an overview of the business (agriculture, livestock, industry, commerce, environmental aspects, legal issues...) with direct texts and warnings in everyday language".

G. ETHICAL DILLEMA

Table 1 shows that the brain behaviour of player P2, in the selected period and in most decision-making moments involving an ethical posture, is concentrated in the frontal cortex. Supported by studies that point out that the entire frontal region of the brain is directly involved in the organization of working memory and the use of executive functions, the activation of the eight electrodes of the frontal set reflects the player's action in the search for a logic of decision and planning [60], [104], confirmed by the HMED-P2 heat map, Fig. 6, which shows a well-distributed attentional focus on the variables involved. What caused a certain strangeness was the similarity of brain behaviour in ethical and operational decisions, but, when identifying in the Pre-Test questionnaire P2's familiarity with games that address this theme and, when answering the Post-Test question about what the strategy adopted in the game, describing that: "first I bribed ...I increased marketing to children/parents", it is noticed that the player deals with the ethical and strategic issue very naturally and focused on results, without involving emotional and Preconceptions, once again justifying his excellent performance at BSG.

According to Table 1, relevant activation of the frontal cortex and T8 electrodes is noticed at the selected moment. As identified with other participants, more intense activation on one side of the temporal lobe seems related to a study that states that attention results from a network of cortical and subcortical connections of right predominance [114], [115]. However, it is essential also to analyze the respective ET heat map, Fig. 6, to seek a more accurate understanding of the situation. According to HMED-P4, the dilemma of incinerating sick oxen before the risk of contaminating the others also has emotionally influenced the player and has been responsible for this cerebral behaviour. The player effectively had the real possibility of managing the situation, even if against his principles. This allows us to infer that their brain behaviour may also have been affected by an emotional charge, in this case, a negative one and that activation is predominant on the right side of the brain, according to related studies [118], [119]. These moments of feeling incapable and deciding against the player's will must have influenced their responses in the Post-Test, when we verified their classification, in one of the questions, that the "Actions available in the interface" were the most important elements for success in BSG, and that later, in another answer, he suggests changes to this item to improve the game experience.

H. GAME OVER

The final moments and the exact end of the company's second life demonstrate that P5, on the verge of being unable to reverse the situation, maintains a significant cognitive activation in only one electrode of the frontal EEG region, Table 1. The respective HMGO-P5 heat map, Fig. 6, shows a closing warning, blaming the player for the result, using expressions such as "disgraceful" and "incompetent", which seems to have contributed to a lapse of motivation or engagement, for not finding in the BSG, the attributes that are part of its construction: attention, novelty, interest, control, feedback, and change [120]. Regarding the answers to the questionnaires, this situation does not reflect negatively on their perception of the BSG since P5 did not declare dissatisfaction with the game in any question, only suggestions for improving resources.

For P6, the HMGO-P6 heatmap, Fig. 6, demonstrates where the player loses control of the game despite attentional effort on-screen elements. According to Table 1, this situation appears to reflect significantly lower activation of the frontal cortex compared to other moments of the game, which appears to have contributed to a lapse in motivation or engagement, as BSG did not provide the necessary attributes that are part of game construction: attention, novelty, interest, control, feedback and change. [50], [113], [120]. It is possible that the simultaneous activation of an electrode in the parietal region is related to some visual/auditory stimulus received at these times. Regarding the answers to the questionnaires, the answer to the Post-Test question may be related to this less stimulating behaviour when P6 declares that what he would change in the BSG would be to create: "a more dynamic way of playing". Like P5, the feeling of incapacity caused the brain to "turn off". The activation of the temporal region electrode may be related to some movement stimulus perceived in these final moments.

The answers to the pre-and post-test questionnaires were also critical in identifying interesting analysis points about the results obtained with the EEG and ET. The heterogeneity of the group of participants demonstrates that liking (and playing) games or not is not directly related to BSG performance. Likewise, this also occurs due to prior knowledge of the learning concepts proposed by the game. A well-designed tutorial and easy game-player interaction, identified in the experienced game, facilitates its use with different groups of learners.

VII. CONCLUSION

The variables generated by the EEG and ET devices provided an analysis of the behaviour of the cerebral cortex from the moments of greater activation of the frontal region, relating it to the areas of most significant interest and fixation of the player's gaze. Completing the analysis by crossing Pre- and Post-game perceptions, it was possible to identify both very particular behaviours and collective patterns among players related to the influence of aspects such as tutorial/game design elements, prior knowledge, and even previous concepts in the definition of cognitive strategy, organization of executive functions and memory formation. This case study proved that the definition of the experimental methodological strategy is essential for successfully applying the model. Once this phase is over, the measurements with the different biometric devices and the joint analysis of the data with the player's perceptions effectively collaborate in identifying design aspects that have meaning for the user in the various moments of the BSG.

One issue this study presents is that, when using three collection instruments, the intertwined analysis of their results reveals a diversity of reactions from participants, many of which do not point to a collective standard. On the other hand, it makes it possible to infer how unique human beings are when considering this combination of physiological, behavioural, and psychological elements that make them up. This fact shows how versatile serious games must be to meet the most varied PX demands, maintain the player's attention, and provide learning at different levels.

The investigation had some limitations. Initially, despite a few reports, it is possible that there was some interference in the experiment due to the use of the chosen measuring devices, causing some discomfort to the participants, which increasingly requires concern in using technologies that provide the least possible limitation to the player. Another relevant aspect is the fact that, although the pre-and post-test responses give information on individual expectations and interpretations of the experience with the BSG, which were fundamental for understanding the different results obtained with the devices, this process requires a separate analysis from three perspectives for each participant and ends up being a limiting factor in the sample size. Furthermore, there is difficulty in establishing reliable interpretations for use in this context, suggesting that more research with a larger sample is needed. A contribution in this regard would be using devices to collect physiological and behavioural signals that are easier to integrate. Currently, the simultaneous monitoring of signals (such as EEG and ET) through a single device is already an available reality, which can facilitate the experimental process and subsequent analysis of the data obtained. Given the difficulties of interpreting the subjective and objective results presented, the other recommendation would be to carry out future tests with validated subjective emotional scales.

Finally, it is concluded that, based on a methodology that considers and integrates different perspectives, monitoring, and analysis instruments, the experimentally validated PBP model can provide a more effective dialogue between the results in the search for a real understanding of the PX in the different moments of the BSG.

The results show that BSG demands many attentional sources and may enhance visual and cognitive skills that influence motivational and emotional aspects. Thus, knowing how the player receives and processes information is the key to identifying the contributions, elements, and moments in which this tool can stand out as a learning resource. Thus, by replicating the proposed model for further investigation, serious business games can be placed more prominently.

In addition to the above, as a possibility of improving the limiting factors of this study, as a suggestion for future work, we propose the application of the validated model to other types of games and the combination of new biometric devices for monitoring other variables involving PX. Evaluating the evolution in SG design could also be an interesting application for new applications of the PBP model. Different lines of interest may include the analysis of educational games from the perspective of gender, education levels and age.

APPENDIX A

TABLE 1. Electrodes with the most significant EGG signal amplitude (A) during periods selected by the PX category.

		Electrodes with the greatest Amplitude (A)													
Part	Cat	AF 3	AF4	F3	F4	F7	F8	FC5	FC6	T7	T8	P7	P8	O1	O2
P1	TT	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Situation		Viewing the tutorial													
P4	TT	x	x	x	x	x	x	x	x		x		x		
Situation		Viewing the tutorial													
P2	GS	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Situation		First contact with the game (Screen 1)													
P3	GS	x	x	x	x	x	x	x	x						
Situation		Providing first decisions (Screen 1)													
P6	OD		x			x	x	x			x		x		
Situation		Buying mor land for livestock rearing (Screen 1)													
P8	OD	x	x	x	x	x	x	x	x		x		x		
Situation		Buying more cattle (Screen 1)													
P1	ST	x	x	x	x	x			x		x				
Situation		Observing the marketing strategies available (Screen 4)													
P10	ST	x	x			x	x		x		x				
Situation		Observing strategy options at the head office (Screen 4)													
P3	IS	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Situation		Discovering the game velocity resource (Screen 1)													
P9	IS	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Situation		Observing farm situation and process speed (Screen 2)													
P4	CS	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Situation		Analyzing store consumers complaints (Screen 3)													
P7	CS	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Situation		Reacting to on-screen warning (Screen 2)													
P2	ED	x	x	x	x	x	x	x	x						
Situation		Reacting to on-screen warning (Screen 4)													
P4	ED	x	x	x	x		x	x	x		x				
Situation		Slaughtering sick cattle (Screen 2)													
P5	GO							x							
Situation		Experiencing the moment of bankruptcies (Screen 1)													
P6	GO					x		x		x					
Situation		Experiencing the moment of bankruptcies (Screen 2)													

APPENDIX B

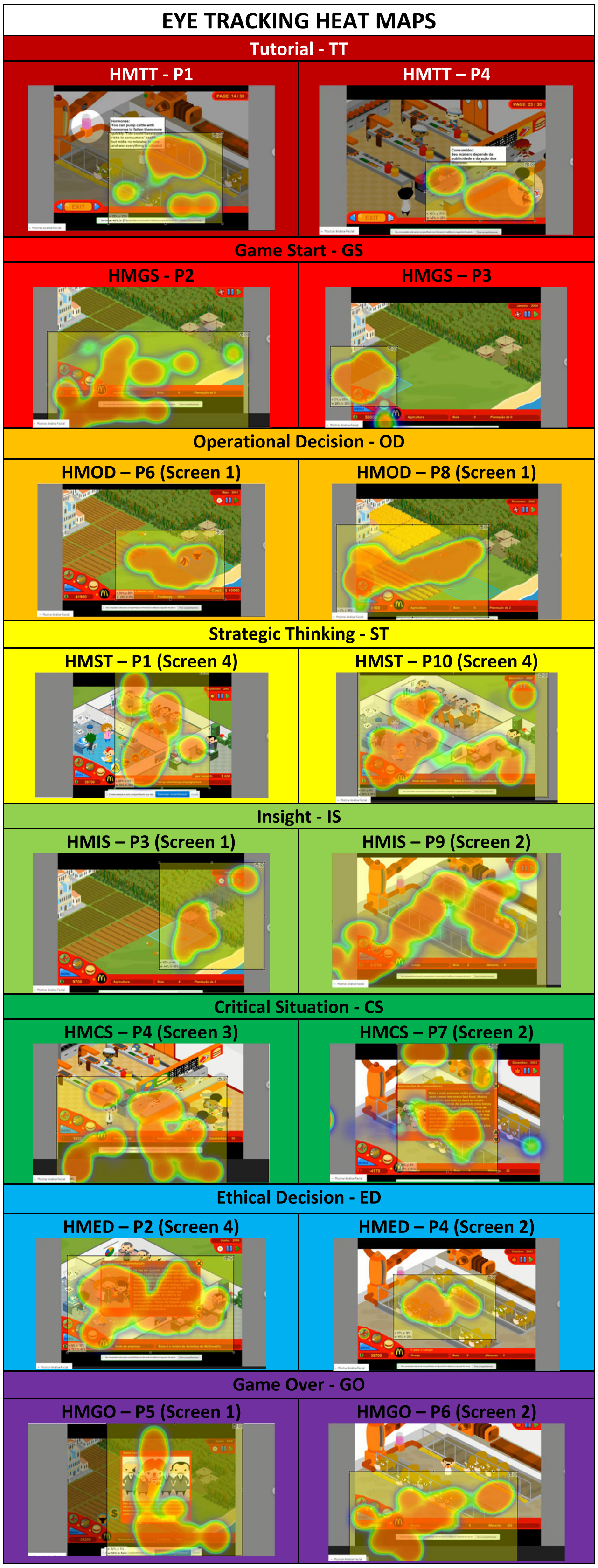

FIGURE 6. Eye fixation heatmaps during selected periods by PX category.

ACKNOWLEDGMENT

The authors would like to thank the Universidad de La Laguna (ULL) and the Universidade Federal do Rio Grande (FURG), which through a cooperation agreement between the two institutions has allowed them to advance research on the user experience with Serious Games through the support of biofeedback interfaces. They would also like to thank the Instituto Federal de Educação Ciência e Tecnologia do Rio Grande do Sul (IFRS), which has enabled the author Cleiton Pons Ferreira to integrate and contribute to this group of studies, and the collaboration of Universidade Portucalense.

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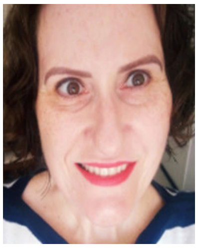

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